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Doctoral Dissertation
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Towards Nearly Zero-Energy Buildings

by

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Declaration

I hereby declare that, the contents and organization of this dissertation constitute my own original work and do not compromise in any way the rights of third parties, including those relating to the security of personal data.

Giovanni Murano
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Summary

In the last decades, the European Union has implemented several energy policies aimed to the decarbonisation of the building stock, the reduction of energy consumption, the reduction of energy poverty, and the restraint of global warming through the Paris Agreement. The role of architectural design, calculation models or building energy simulation for building behaviour prediction, and the availability of standard reliable data are central to the pursuit of these goals. According to the European Commission, the implementation of Nearly Zero-Energy Buildings (NZEBs) represents one of the biggest occasions to increase energy savings and reduce greenhouse gas emissions.

The design of NZEBs for different climatic and local conditions, requires a set of considerations including cost-optimal and high-performance technical solutions.

This thesis explores the theme of NZEBs focusing on those characteristics that have an influence on energy consumption.

The first section of the document analyzes the legislative development in Italy and Europe, highlighting the main differences and emphasizing how minimum design requirements and the related energy consumption can change from one country to another.

Attention is subsequently shifted to the Italian situation. The first definition of NZEB in Italy occurs in 2015, while the actual application (so far only in the public sector) was in 2019.

The national framework is therefore examined by proposing adjustments both to the technical regulations of the sector and to the legislative framework. Part of the work involves verifying the legislative requirements and updating the methodology of the notional reference building.

The energy performance of buildings can be estimated through various calculation methods. The most used approach by EU member states is the Quasi-Steady State Approach. This methodology is mainly used in the legal context of

energy certification. The academic world and the scientific community instead use more sophisticated simulation tools that perform an hourly calculation of energy needs and allow to estimate more realistic energy consumption. The energy performance of some case studies has been calculated using both the quasi-stationary calculation methodology and the dynamic calculation method. The objective was to highlight the main differences between the results when some building envelope parameters change. And so for which buildings and climates the semi-stationary method can provide acceptable results.

In this part of the research, the building is not considered only as a whole. In fact, the single building unit behaviour has been investigated proving how energy needs between building units can vary a lot in the same building.

Therefore, an index that expresses the homogeneity of energy needs behaviour between building units has been also introduced.

Then, following the path of dynamic simulation, parametric analysis was carried out with a building energy simulation program (*EnergyPlus*) to evaluate the energy behaviour by varying the thermal insulation, the presence of thermal bridges and the availability of transparent area (WWR) and its thermal properties.

This analysis was carried out for various locations in different climatic zones. The analysis has allowed to highlight how the design choices can modify the energy building performance. Although it is good practice to insulate buildings, not all buildings have the same behaviour: in fact, it varies according to the climatic characteristics of the locations. The research has investigated what conditions cause a significant imbalance of the energy needs and at which extent.

The last section concerns the realization of TMY for the verification and design of NZEB using the dynamic simulation program. A new methodology that considers the realization of TMYs has been proposed to determine the sensible and latent energy needs of buildings.

This methodology was applied to five locations and verified on twelve case studies with different characteristics of the building envelope. Therefore, sixty-seven TMYs have been tested. In fact, when designing NZEB buildings, considering the low or nearly-zero energy requirements, data about the most realistic boundary conditions are needed.

Acknowledgment

This research work was possible thanks to the contribution of various people. In 2008 I started getting closer to the energy sector, nearly 10 years have passed since then. A decade in which this sector was characterized by constant legislative and regulatory activity of considerable importance which I was able to take part in, bringing my contribution.

Undertaking this doctorate has meant sacrifice, investment of time and coming into contact with other people who have common goals, by studying to understand how other EU realities face the energy problem. Moreover, these days another problem is taking place, it is an environmental issue and a climatic change due to an increasingly intense human activity linked to energy use in buildings. All topics of interest that have been addressed in the course of this doctorate.

I want to thank various people: first of all, Prof. Riva who represented the first contact with the world of Energy, to him the most heartful thanks for trusting me. Together with him, all the CTI colleagues, from the current CEO, Dr. Panvini, to the other colleagues who deal with me in the energy field related to the management of the building, in particular Roberto Nidasio and Anna Martino. I couldn't wish for better colleagues.

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I would like to dedicate
this thesis to my loving
parents

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Nomenclature

Acronyms

AB	Apartment Block
BIO	Biomass
BPS	Building Performance Simulation
BS	Biomass boiler plus split system
DHW	Domestic Hot Water
EU	European Union
ED	Energy Demand
EEMs	Energy Efficiency Measures
EP	Energy Performance
EPBD	Energy Performance of Buildings Directive
HDD	Heating Degree Days
HP	Heat Pump
HVAC	Heating, Ventilation, Air Conditioning
MCA	Multi-Criteria Analysis
MD	Inter-Ministerial Decree
MI	Milan
MV	Mechanical Ventilation
MS	Member State
NV	Natural Ventilation
n	Total number
NZEB	Nearly Zero-Energy Building
OB	Office building
PA	Palermo
PV	Photovoltaic
SA	Sensitivity Analysis

SFH	Single-Family House
TMY	Typical Meteorological Year
TRY	Test Reference Year
TST	Total Solar Transmittance
TT	Thermal Transmittance (*U*-value)
UNC	Unconditioned space (facing)
UTC	Coordinated Universal Time
w	Weight
WWR	Window-to-Wall Ratio

Symbols

A	area [m^2]
Alt	altitude [m]
b	adjustment factor for heat transfer coefficient [-]
C	cost [€]
COP	coefficient of performance [-]
EER	energy efficiency ratio [-]
EP	yearly Energy Performance [$kWh \cdot m^{-2}$]
EPM	monthly Energy Performance [$kWh \cdot m^{-2}$]
F, f	factor [-]
g	total solar energy transmittance [-]
H	heat transfer coefficient [$W \cdot K^{-1}$]
H_{Tr}	overall heat transfer coefficient [$W \cdot K^{-1}$]
H'_T	mean overall heat transfer coefficient [$W \cdot m^{-2} K^{-1}$]
HDD	heating degree-days [°Cd]
I	global solar irradiance on a horizontal surface [$W \cdot m^{-2}$]
Ms, ms	areal mass [$kg \cdot m^{-2}$]
P	peak load per unit floor area [W·m-2]
RH	air relative humidity [-]
T	(dry-bulb) air temperature [°C]

U	Thermal transmittance [$W \cdot m^{-2} \cdot K^{-1}$]
U_{avg}	average U-value [$W \cdot m^{-2} \cdot K^{-1}$]
V	volume [m^3]
W	power [W]
W_p	peak power [kW]
Y_{ie}	periodic thermal transmittance [$W \cdot m^{-2} \cdot K^{-1}$]
WVP	water vapour pressure [Pa]
WS	wind speed [$m \cdot s^{-1}$]

Greek symbols

η	efficiency [-]
κ	areal heat capacity [$kJ \cdot m^{-2} \cdot K^{-1}$]
ρ	reflection coefficient [-]
τ	transmission coefficient [-]
Φ	cumulative distribution function regarding long-term data
σ	standard deviation

Subscripts

a, air	annual
A	adjacent
adj	adjusted
bio	biomass
C	space cooling
c	control (subsystem)
coll	collectors
D	direct (external)
d	distribution (subsystem)
del	delivered (energy)
DHU	dehumidification

E	energy
e	emission (subsystem)
el	electricity
env	building envelope
F	frame
F	cumulative distribution function for a specific year
f, fl	floor
FS	Finkelstein-Schafer statistic
g	ground, gross
gl	glazing, global
gn	generation (subsystem)
gr	ground
H	space heating
HU	humidification
ht	heat transfer
I	investment
i	internal
ι	index
J, K, L	rank order
ls	heat losses
lw	lower
m	month
Nm	number of months when the considered energy service is provided
N	number of days in a calendar month for long-term data
n	net, normal
n	number of days in an individual month
nd	need (energy)
nren	non-renewable

ob	obstacles
op	opaque (component)
P	primary (energy)
Pn	nominal power
p	projected
p	parameter
R	ranking
r	roof
ren	renewable
S	energy service
s	solar
sh	shading
sol	solar
sum	summer
sup	supply (air)
sh	shading
T, tr	thermal transmission
Tot	total
U, un	unconditioned (space)
u	utilisation (subsystem)
up	upper
V, ve	ventilation
W	domestic hot water
w	window
wl	wall (external)
y	year

Introduction

In 2010 the Energy Performance of Buildings Directive (EPBD Recast) was revised. In 2012 the Directive 2012/27/EU on energy efficiency (EED) was published. This legislative documents are the EU's main legislative instruments promoting the improvement of the energy performance of buildings. On 19 June 2018 new Directive (2018/844/EU) amending the EPBD and EED was issued. The framework is constantly updated with the ultimate purpose of reaching increasingly ambitious goals. Actions contained in EU directives represent some of the solutions identified at European level to fight climate change.

Strengthening the EPBD, with the aim to both reduce the greenhouse gasses emissions and save energy, draws attention to the fact that the main solutions could be improving the energy efficiency of new buildings and the renovation of existing buildings. Two important principles have been introduced in the EPBD Recast: (a) the nearly zero-energy buildings (NZEBs), and (b) the cost optimality. NZEBs are defined as buildings which have "*a very high energy performance, and the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*".

In Italy the detailed definition of NZEB has been associated with the decree of Ministry for the Economic Development (MD 26.06.2015 [143]). Requirements for the new buildings are the same with those for the refurbished buildings. According to the regulation, either new or refurbished buildings must comply with NZEB requirements by 2019 (public) and by 2021 (all buildings). The regulation for NZEB has been defined in order to harmonize new and existing laws and determine the requirements for applying the cost-optimal methodology to some nationally defied reference buildings.

The cost-optimal values are compulsory for both new and refurbished buildings, with the exemption of minor renovations. This regulation will continue to exist until 2018 or 2020, respectively for public or private buildings. Within the same period, ensuring the NZEB requirements is considered as a voluntary option which is promoted by relevant qualification (highlighted by a check mark on the energy certificate) if the above mentioned parameters are considered.

Several EU projects have focused on the topic of NZEB. ENTRANZE project (2012-2014) supported the policy makers by providing required data, analysis and guidelines to achieve the NZEB target with a focus on the refurbishment of existing buildings [8]. SOUTHZEB (2014-2015) has focused on NZEBs in areas with tight architecture regulations in Southern EU [9]. ZEBRA2020 is a project (2014-2016) that aims to create an observatory for NZEBs able to drive strategies and references for EU policy makers, energy agencies and stakeholders to boost the market uptake of NZEBs [10]. RePublic_ZEB project (2014-2016) [11] has concentrated on the refurbishment of the public building stock towards NZEB in the European countries of the South-East. The project was coordinated by Italian Thermotechnical Committee Energy & Environment and the Polytechnic University of Turin was one of the partners.

To achieve this goal, an assessment of the public building stock and a definition of reference buildings have been provided. The outcomes of the project have been a set of cost-optimal packages of measures for the promotion of building refurbishment addressed to operators at various levels involved in the construction market (national and regional authorities, construction industry, housing organizations, and owners of large building stocks). Some of the results of the applied methodology for identifying the cost-optimal levels of the EP requirements are shown in [61]. A definition of the NZEB target, that is in line with the EU Directive [1] has been established within the RePublic_ZEB consortium. According to RePublic_ZEB project "*a building is considered as NZEB when the following requirements are met the EP is lower than the cost optimal level (the NZEB is more energy efficient than the cost optimal building); the differential Global Cost (ΔGC) with reference to the building before the refurbishment is negative (NZEB is cost effective); the national minimum energy performance requirements for NZEBs are fulfilled. Thus, the NZEBs should have a primary energy consumption lower than the cost optimal range, and the global cost in between the cost optimal cases and the current reference building. As regards the renewable energy production, a minimum value of the Renewable Energy Ratio (RER) is specified at country level; for public buildings in Italy,* $RER_W > 55\%$, $RER_{H+C+W} > 55\%$ ([143],[160])".

However, some Italian regions have anticipated the entry into force of the mandatory adoption of NZEB requirements for all the buildings: Lombardy (2016) and Emilia Romagna (2017). Few cases of already built NZEBs are therefore available.

In parallel, following the issuance of the new EPBD Directive, in 2011 the European Commission assigned a new mandate to CEN - the M/480 mandate - with the explicit request that, subjected to the necessary flexibility, the new rules for energy performance calculation could be directly used by the Member States.

The package of standards was published by the national standardization bodies in 2018.

In spite of the measures related to energy saving in place, the opinion of the European Committee of the Regions n. 5810/2013 [142] is warning us that global warming and its effects are worsening. For this reason, the Committee of the Regions asked the EU to reach three important goals for 2030: (a) a 50 % reduction of greenhouse gas emissions (compared with the level of 1990); (b) a 40 % share of renewable energies; (c) a 40% reduction in primary energy consumption (compared to the level of 2005).

The last two have to be expressed as national targets. The pursuit of these goals will ensure EU a sustainable, safe and secure energy future.

Despite the implementation of the planned measures, ongoing researches on the construction of nearly zero-energy buildings denounce the growth of energy demands for electricity in summer due to a greater use of air conditioning systems. On the contrary, heating energy demands are increasingly reduced above all thanks to the adoption of adequate thicknesses of thermal insulation comply with the provisions of the national legislations (MD 26.06.2015 [143]).

The present work represents the development of a research aimed at deepening the theme of properties optimization of the envelopes in building design, with reference to different use scenarios and building types.

Furthermore, the other objective of this research is to improve and verify the existing legislative framework in order to articulate some critical issues and propose solutions. In this regard, a large part of the results has constituted a valid support for the activities of the advisory group within the Italian Thermotechnical Committee Energy & Environment (CTI – Standardization body), which provides technical support to the Ministry of Economic Development (MISE) on the issues related to Law 90 and related implementing MDs, certification energy efficiency and energy efficiency of buildings.

The survey methodology is developed by applying both quasi-steady method (UNI/TS 11300) and a detailed numerical simulation code (*EnergyPlus*) and, subsequently, identifying a specific way of representing the results.

In this framework, the exploration area of the present thesis is the **design of nearly zero-energy buildings** in an enlarged context. The following questions are examined and analyzed.

1) This section analyzes the European overview concerning the **differences in the application of NZEB** definition across the EU, especially regarding promotion measures, country regulation and policies;
2) This section deals with the **calculation of the energy performance** of buildings. The technical standards elaborated by CEN (EN ISO 13790, and UNI/TS 11300) and the other methods for calculating the energy needs assumed by the scientific community as a reference are analyzed. The aim is to outline the differences, the applicability field and to evaluate how the use of different codes influences the final results;
3) This section aims to investigate the **technical feasibility of design solutions** complying with the legislative requirements to validate the notional reference building approach. The calculations have been conducted by means of quasi-steady (UNI/TS 11300) and dynamic (*EnergyPlus*) methods;
4) Although there is a large scientific production, the NZEB design studies are rather general and similar, as the approach to the problem. Therefore, the need to expand the field of investigation emerges, with the scope of contemplating the **effect of the design choices on the building energy needs**. In this context the attention is shifted from an approach related to

the whole building to the single building unit. This section aims to investigate the conditions and extent to which the thermal insulation of building envelope is beneficial for reducing overall energy needs and maximise the overall *EP* of the building. A survey methodology is proposed for carrying out a parametric analysis on case studies in order to understand in which boundary conditions the importance of the building envelope design increases;

5) As evidenced by Pieter de Wilde and David Coley (2012) [6] most of the buildings are designed to meet national requirement on heating energy needs but large **change in weather conditions** is more probable during summer months. The United Nations has recognized the importance of climate change containment in various documents, among which the most important is the Paris Agreement (2015) [7].

   Climate change is an important global issue with repercussions for everyone. It cannot be underestimated to a supplementary impact on local climate conditions due to the effect of *urban heat island* which contributes to amplify above all summer overheating and therefore the energy behaviour of buildings. The improvement of energy performance of buildings is pursued and also widely supported by the EU. There are therefore two contemporary issues: a constant change in climate and new construction methods towards a NZEB perspective. Buildings with high energy performance must be designed using current and reliable data. The currently used data for building energy simulations are related to measurements dating back to the 70s. Therefore, it is strongly probable that they are not reliable in predicting energy needs. Starting from these considerations, the **calculation of the TMYs** using climatic data and updated calculation methodologies is further explored in this section.

Chapter 1

1 EP requirement of NZEBs

1.1 EU Framework

The Article 9.1 of 2010/31/UE Directive (2010) [1] regulates that "*Member States shall ensure that by 31 December 2020, all new buildings are nearly zero-energy buildings and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings*".

The concrete application of the NZEB definition is delegated to the EU Member States, taking into account local conditions, and measured by a numeric indicator corresponding to the primary energy consumption or global CO_2 emission.

In the national transposition of the EPBD Recast, several EU Member States have also incorporated in the requirements definition limitation of other parameters such as *U*-value of building envelope components and net and final energy for heating and cooling.

Afterwards the definition of NZEB was the subject of the EU Recommendation no 1318 (2016) [15], concerning guidelines for the promotion of nearly zero-energy buildings.

This recommendation bases its main indications also on the *Synthesis Report on the National Plans for Nearly Zero Energy Buildings (NZEBs)* (2016) [16] which reports the national implementation and the primary energy (expressed in $kWh \cdot m^{-2}$) that each Member State has indicated in the report. However, it should be noted that the indications are founded on non-harmonised calculation methods; therefore, the reported numerical references for primary energy can be widely vary. In fact, primary energy range comprises numerical values from $0 \div 160$ $kWh \cdot m^{-2}$, even if in most cases it varies indicatively from $20 \div 50$ $kWh \cdot m^{-2}$.

Several research show case studies about the EP of NZEB: in each case, the reference value strictly depends on the levels defined at national level. For example, the Polish Technical Conditions [13] require $EP_{H+W} = 70$ $kWh \cdot m^{-2}$, for single-family buildings from 2021. There aren't differentiated *U*-values like in Italy (where they are variable for climatic zones): they are the same for all the Regions, and for residential buildings.

The recent Directive 2018/844/EU [3], in addition to the reinforcement of EPBD's indications, has the purpose of decarbonizing the building stock for its conversion in energy efficient buildings. For this reason, EU member States should implement National Renovation Strategies for increasing deep renovations with projections of economic financing.

In order to pursue this objective, several studies are underway, concerning the knowledge of the existing building stock, an example is the EU project "*Robust Internal Thermal Insulation of Historic Buildings*" (RIBuild) [14], that provides technical information on historical building stock in several EU Countries.

The main focus of this project is to obtain a detailed description of the national historical building stock (with focus on thermo-physical properties of the building envelope) and to identify possible problems due to its conversion into NZEB.

The PANZEB (*Italian National Action Plan to increase almost zero-energy buildings*) reports some reference archetypes, which provide an average EP_{gl} for different typologies of residential buildings.

The Action Plan reports the *EP* index concerning two reference buildings, a single family-house and a large apartment-block only relative to two climate zones (climate zone B, HDD ≤ 900, and climate zone E, 2100 < HDD ≤ 3000). In accordance to EU ambitions, the existing building stock provides a great potential of energy savings.

Attia et al. (2017) [17] analyzed technical barriers and provided an overview of future prospects for NZEB in Southern Europe. In these areas, the countries are poorly prepared for NZEB implementation and in retrofitting of existing buildings. The definition of the minimum energy performance of nearly zero-energy building is very different among EU Member States. The variation is mainly due to the economic, climatic, social and technological differences among EU countries.

Aldossary et al. (2017) [33] investigated the variation of the energy performance of NZEBs in Saudi Arabia (calculated by using building modelling and simulation packages). They demonstrated that is possible to achieve residential NZEBs in Saudi Arabia with primary energy needs between $77 \div 90$ kWh m^{-2}.

Testi et al. (2017) [34] focalized the attention on the retrofit of school buildings. The authors concentrated on this category of buildings because in next future a significant amount of these construction will have undergone refurbishment. They performed the analysis using two energy models: the former based on a tailored method and the latter based on an asset rating method; both methods was performed by quasi-steady state calculation method based on EN ISO 13790 (UNI/TS 11300). The authors have suggested to modify the current definition of NZEB, introducing correction factors for buildings with intermittent uses in order to reach appropriate measures in terms of cost-benefits.

Santos-Herrero et al. (2018) [35], through a careful literature review, have defined that the Model Predictive Control (MPC) can be considered as an useful tool to optimize energy needs in order to achieve NZEB target. In fact, MPC take in account occupancy information, and weather conditions for defining optimal energy management. During the design phase, association of MPC, active and passive strategies ensure the reduction of energy consumption.

Moving from the EU IEE ZEBRA 2020 project, Paoletti et al. (2017) [36] analyzed the main technical characteristics of NZEBs collected in 17 EU countries keeping in account the influence of the boundary conditions. Among the common features there is a general high thermal insulation level of the building envelope and, for the technical building systems are recurrent HVAC technologies (i.e., heat pumps and mechanical ventilation). According to the authors, the most critical index is the EP_{gl}, since it is calculated through methods with different boundary conditions, primarly *EP* factors, CO_2 equivalent emissions and with different contributions of active and passive technical building systems (i.e., H, C, L, V). The analysis confirms that the *U*-value of the NZEB's envelope is similar across the climatic zones. The most used materials for the thermal insulation of the building envelope are: EPS and stone wool (for the vertical wall), stone wool and wood fibers (for the roof). As for the glazing envelope, the most frequently used technology, for buildings both in warm and cold climates, is the triple glazing system. About 85% of buildings are equipped with mechanical ventilation with heat recovery. About 60% of the analyzed NZEBs used the same technical building system for both energy needs (H, DHW). The most common technologies are the heat pump (32%) and condensing boiler (23%) while the district heating is common in cold climates (i.e. North and East Europe).

The most used cooling systems are heat pumps that use outside air as heat source. Among the passive technologies normally used to reduce energy needs there are (a) natural ventilation, (b) green roofs, (c) sunshade, (d) night cooling and (e) thermal mass. As concerned to the use of RES, the most used technologies are solar thermal systems (28%), photovoltaic systems (29%) and both (24%). The authors' downstream of analysis concluded that the climate conditions (not taking into account renewable solar sources) do not represent the main parameter affecting the definition of the package to achieve the NZEB target.

The 16th of May 2019 was also published the Commission Recommendation (EU) 2019/786 on building renovation [38]. In accordance with the Directive 2018/844/EU this document supports strategies and financial mechanisms for the mobilisation of investment in building renovation with the aim of achieving considerable energy savings.

Papamanolis et al (2015) [37] have estimated the impact of the EPBD Recast implementation on the progress of RES in buildings in Greece. As in other EU countries, the implementation of the new framework coincided with the economic recession, which had a big impact on the building construction sector. Nevertheless, the statistics have shown a positive trend in RES uses in building. A large part of this growth stemmed from the use of biomass boilers, while solar energy applications are still to stabilise. Finally, geothermal applications remained at low levels.

Rodríguez-Soria et al. (2014) [39] compared the energy performance requirements of residential buildings in various EU countries (Germany, France, the UK, and Spain), USA, the *Passivhaus* standard and discussed the main reasons of deviations.

Szalay et al. (2014) [40] set up a method for the generation of combinations of building sample for the definition of threshold values, certification schemes, and requirements to use for building energy regulation of residential buildings in

Hungary. This methodology has been applied by the Ministry for setting the building energy requirements. Nevertheless, the results have not been officially approved ([40][41][42]).

The examples found in scientific literature show that the realization of NZEB can lead to very different EP indices that vary depending on several factors, including climatic conditions [88], calculation methodology used, and threshold requirement values locally permitted.

Political decisions can also affect the overall energy and environmental performance of NZEBs, for instance through the decision of primary energy factors [243] (renewable primary energy factor, non-renewable primary energy factor, and total primary energy factor). This constitutes a critical aspect in the overall calculation of energy saving measures. According to the EPBD Recast [1] the global EP of buildings may be expressed as primary energy, based either on non-renewable or total primary energy factors. This concept is also taken up by Directive (EU) 2018/844, which provides several possibilities for the calculation of primary energy [3]. *The primary energy can be based on primary energy factors or weighting factors per energy carrier, which may be based on national, regional or local annual, and possibly also seasonal or monthly, weighted averages or on more specific information made available for individual district system.* This indication gives an idea of the variability that may exist among EU Member States.

The Recommendation (EU) 2016/1318 [15] also raises problems on the comparison of EP indicators across EU Member States because of the adopted calculation methodologies. As specified in EN ISO 52016-1[245] the adopted calculation method at national level, to assess the EP and demonstrate the conformity of buildings with the minimum requirements, may change as well as the results. In general, hourly or monthly calculation method can be adopted. In some cases, they can refer to even more accurate hourly models like *EnergyPlus* or *TRNSYS*. The EU Recommendation [3] identifies for the different climate zones of the EU (continental, northern and Mediterranean) reference values for the EP of NZEB.

Table 1 Benchmarks for the energy performance of NZEBs for geographic area and typology of building

Area	Typology of building	Net primary energy $kWh\cdot m^{-2}$	Primary energy $kWh\cdot m^{-2}$	Renewable primary energy $kWh\cdot m^{-2}$
Mediterranean	OB	20÷30	80÷90	60
	SFH	0÷15	50÷65	50
Oceanic	OB	40÷55	85÷100	45
	SFH	0÷15	50÷65	35
Continental	OB	40÷55	85÷100	45
	SFH	20÷40	50÷70	30
Nordic	OB	55÷70	85÷100	30
	SFH	40÷65	65÷90	25

OB=Office, SFH=New single family house

1.2 Differences between EU States

The definition and features of NZEBs change from Country to Country. According to Garcia and Kranzl (2018) [37], the most critical issues across EU Countries are (a) a different calculation approach for *EP* indicators, (b) primary energy factors and (c) ambition requirement levels. This section reports a review of the regulatory framework.

As reported by the *Synthesis Report on the National Plans for Nearly Zero Energy Buildings (NZEBs)* [43] Member States (MS) set intermediate targets in line with the provisions of the EPBD Recast: (a) some Countries chose minimum *EP* requirements (e.g. EP_{gl}=50 kWh·m^{-2}) (b) other required *EP* certificate level (e.g. class A), (c) other defined qualitative targets. Some examples and a comparative summary table are listed below.

In **France**, the "*Réglementation Thermique - RT2012*" [44], requires: (a) for new residential buildings, $EP_{gl}\leq 50$ kWh·m^{-2} (including H, DHW, C, V, L and auxiliary systems); (b) for office buildings, $EP_{gl}\leq 70$ kWh·m^{-2} in the case of buildings without air conditioning and $EP_{gl}\leq 110$ kWh·m^{-2} if they have air conditioning (including H, DHW, C, V, L and auxiliary systems); (c) for residential buildings undergoing renovation, $EP_{gl}\leq 80$ kWh·m^{-2} (including H, DHW, C, V, L and auxiliary systems); (d) For buildings with S≥1000 m^2 built in 1948 or later and for which the renovation costs amount to at least 25% of the building value, the average target is $EP_{gl}\leq 120$ kWh·m^{-2}.

The limits reported before depend on geographical areas and altitudes, characteristics and uses of buildings.

The Th-B-C-E 2012 Method (*Méthode de calcul Th-BCE 2012* [45]), in order to apply the Thermal Regulations, describes the following coefficients: Bbio (energy requirement of the building); Cep (primary energy consumption); Tic (indoor temperature). The Thermal Regulations 2012 (TR 2012) pursues three outcome requirements: (1) residual energy need that is not offset by design, Bbio max being the maximum permissible residual energy need; this standard entails simultaneous limitation of the energy needed for each purpose – heating, cooling and lighting; (2) a maximum permissible conventional energy need of EP_{gl}, Cep_{max}; the Cep coefficient relates only to conventional consumption of energy for H, C, L, DHW and auxiliary devices (pumps and ventilators); (3) $Tic<Tic_{ref}$, for those buildings in which it is possible to provide comfort in summer without active cooling systems;

The use of RES is one of the objectives of the TR 2012. RES must be used for residential buildings and it has to be chosen from a precise list of options: (a) solar heating panels for DHW; (b) connecting to a heating network with an energy input comprising at least 50% RES or recovered heat; (c) demonstrating that the contribution of RES to the $EP_{gl}\geq 5$ kWh·m^{-2}.

In **Austria**, the "*OIB-Guideline 6 – Energy economy and heat retention"* [46] establishes that: (i) for new residential buildings, $EP_{\text{gl}} \leq 160$ kWh·m^{-2} (including H, DHW, C, V and electric appliances); (ii) for new non-residential buildings, $EP_{\text{gl}} \leq 170$ kWh·m^{-2} (including H, DHW, C, V, electric appliances and L).

Four main *EP* indicators are settled in the *OIB-Guideline 6* [46]: (a) Energy performance for space heating "*Heizwärmebedarf*" in kWh·m^{-2}, (b) Primary energy need in kWh·m^{-2}, (c) Carbon dioxide emission in kg/m^{2}, and (d) Total energy efficiency factor fGEE (comparative value) [–]. It is possible to realize a NZEB following two alternative paths:

- Either the heating energy need requirement and a minimum efficiency of the building technical installations are fulfilled.
- Either the heating energy need requirement and the fGEE requirement are fulfilled.

Austria is the only EU Country that already had by January 2016 a formal NZEB definition. The energy performance includes the household overall electricity demand (i.e., including appliances etc.).

In **Germany**, the reference is the Energy Conservation Regulation (EnEV 2016)[47]. The Regulation requires, for new buildings a label of KfW 40 and for refurbishments a label of KfW 55 and 70. These numbers represent the ambition level of annual primary energy need (%) in relation to a notional reference building. The Energy Saving Ordinance (EnEV) includes additional requirements regarding the building envelope (average specific heat transmission losses, thermal bridges, air tightness) and, in order to avoid overheating, the summer heat protection.

Germany does not have a formal NZEB definition for non-public buildings. For new residential buildings the definition is expected within 2021 [48].

In **Spain**, the regulation reference is the "*Documento Basico de Ahorro de Energia - DBHE - Royal Decree 235/201*" ([49],[50]). The NZEB definition for new public, residential, and non-residential buildings has been released in the building code DBHE according to the order FOM/588/2017 of 15 June 2017.

The requirements to be verified are: (a) the total and non-renewable primary energy need in kWh·m^{-2}, (b) Energy needs for heating and cooling in kWh·m^{-2}, and (c) Building CO_2 Emissions.

Detailed requirements in the use of RES are also planned (i.e., Minimum RES, water heating of indoor swimming pools and conditioning of open spaces permanently) and the consideration of additional requirements, such as the global thermal transmittance (*Calidad de la envolvente*) and the summer heat protection. The new Basic Document DB-HE 2018 (*Propuesta de valores de indicadores para el DBHE 2018 NZEB*) is however a preliminary work and has no regulatory character [50].

The NZEB definition is presented in Basic Document DB-HE 2018 under the order FOM/588/2017 of June 2017 and refers to new residential and non-residential buildings [49].

In **England** the reference is the Approved Document L "*Conservation of Fuel and Power*" [51]. The UK Government applied the target "*zero carbon*" from 2016 for all new domestic buildings and from 2019 for all new non-domestic buildings, while for existing buildings there is not a formal definition. The requirements for new residential buildings are: (a) Target CO_2 Emission rate TER in kg $CO_2 \cdot m^{-2}$;(b) Target fabric energy efficiency TFEE rate in $kWh \cdot m^{-2}$. For new non-residential and public buildings, the unique requirement is the Target CO_2 Emission rate TER in kg $CO_2 \cdot m^{-2}$. TER and TFEE are indicators calculated as limits from the notional reference building.

The NZEB definition is in line with the initiative called "*zero carbon hub*" for new residential buildings since 2016.

In **Greece**, the definition of NZEB features are suggested by the Regulation on the Energy Performance of Buildings' (KENAK) [146]. The Regulation sets minimum requirements for the building elements, as well as for the whole building envelope. The building elements requirements consist of maximum U-values for the building envelope and a maximum shading factor for windows. For the technical building systems are set the minimum requirements for the efficiency systems (heating, cooling, hot water production) plus lighting for buildings of the tertiary sector. The EP is based on the monthly methodology of EN 13790 plus set of national parameters defined where necessary. The Directive EPBD is transposed into legislation by Law 412/2013 ([147], [148]) and includes numerous provisions on reducing energy needs in the buildings sector and improving the EP_{gl} of buildings. The limits for NZEBs are: (a) for new residential buildings, $EP_{\mathrm{gl}} \leq 80$ $kWh \cdot m^{-2}$, and RES≥60 %; (b) for new tertiary sector buildings, $EP_{\mathrm{gl}} \leq 85$ $kWh \cdot m^{-2}$, and RES≥20%; (c) for existing residential buildings, $EP_{\mathrm{gl}} \leq 95$ $kWh \cdot m^{-2}$, and RES≥50%; (d) for existing tertiary sector buildings, $EP_{\mathrm{gl}} \leq 90$ $kWh \cdot m^{-2}$, and RES≥15%;

In **Cyprus**, the definition of NZEB for residential and non-residential buildings is prescribed by the Requirements and the Technical Characteristics of the NZEB ministerial order of 2014 (Κ.Δ.Π.366/2014) [149]. The Decree sets more stringent requirements for maximum energy consumption and thermal insulation levels in relation to the minimum energy efficiency requirements currently in place for new buildings. In addition, a minimum contribution rate of renewable energy sources is set for energy consumption, while for office buildings there is a maximum allowable installed electrical power to meet the lighting needs.

In **Malta**, the minimum requirements introduced limits for the size and positioning of glazing to reduce overheating. Requirements to limit thermal losses through the building fabric included maximum *U*-values for all building elements. The requirements for walls reflected the local practice of constructing external cavity walls with two 150 mm thick stone leafs. The *EP* of NZEBs will be such that the primary energy balance will not exceed 220 kWh·m^{-2}, except for dwellings which shall have a primary energy balance lower than 75 kWh·m^{-2}. Requirements for residential NZEB are differentiated according to building category to take into account the different capabilities to achieve high EP. The Law reports the maximum percentage of WWR for orientation.

Table 2 Maximum window-to-wall ratio for orientation in Malta

	N	S	NE	E	SE	SW	NW	W	H
%	25	20	17	12	12	12	12	9	7

The calculation of the cost-optimal levels of minimum requirements has indicated that NZEBs are not cost-optimal level. However, in all cases, including major renovations, NZEBs are cost-effective for the investor compared to the 'taking no efficiency measures' scenario.

A NZEB is more economically feasible if more emphasis is given on increasing roof and wall insulation, while PV systems seem to be an attractive investment for the building's renewable energy provider [19].

In **Slovenia** the reference are the Rules on Efficient Use of Energy in Buildings (PURES 2010) [150], which introduces (a) the methodology for calculating indicators of the EP of buildings, (b) the minimum EP requirements for new buildings and major renovations of existing buildings, (c) the minimum requirements relating to maintenance and technical improvements. Requirements for all public buildings are 10 % more stringent. According to the Action Plan for Nearly Zero-Energy Buildings, the maximum energy need for heating of a building have to be smaller or equal to 25 kWh·m^{-2} (this value is adjusted taking in account the climatic condition of building location and its shape factor) [151].

In **Table 3** are reported the maximum permitted primary energy values of NZEBs according to Slovenian Nearly Zero-Energy Buildings Action Plan 2015 [154].

Table 3 Maximum EP values of NZEBs and Minimum share of energy from renewable sources (RER) according to Slovenian Nearly Zero-Energy Buildings Action Plan 2015 [154]

Typology of building	New building kWh·m^{-2}a	Major renovation kWh·m^{-2}a	Min RER %
SFH	75	95	50
MFH	80	90	50
NRB	55	65	50

Single Family House (SFH), Multi-Family House (MFH), Non-residential buildings (NRB)

An open question is connected to the target expressed as *numeric indicator of primary energy use based on primary energy factors per energy carrier* as required by Annex 1 of the EPBD Recast. The EPBD does not impose a specific way to express the EP; furthermore, the application of EN ISO 52000 [232] allow flexibility in defining the total primary energy factors, for instance, the relation to the energy carrier specification used in energy performance calculations. It also allows a choice in the definition of the total yearly output data. The weighted energy performance, in fact, can be expressed in kWh, $kgCO_2$, $kgCO_{2eq}$, €, and $kWh{\cdot}m^{-2}$. CO_2 emissions associated with the energy consumed are the most closely related to environmental impact.

For example, the Total Primary Energy Factor (PEF) per energy carrier definite at national level are reported in Table 4. The choice of PEF is at the discretion of MSs. As shown by the research by Hitchin et al (2018) [152], the procedures for the determination of PEFs adopted by each MS are far from transparent.

Table 4 Total Primary Energy Factor for energy carriers for some Member States ([153], [143]).

	AT	ES	IT	RO	FR	DE	FI
Electricity	1.91	1.89	2.42	2.53	2.72	2.45	2.69
Gas	1.13	1.00	1.05	1.00	1.00	1.00	1.00
District heating	1.00	1.00	1.50	1.00	1.00	1.00	0.70
Biomass	1.08	1.25	1.00	1.50	1.50	1.50	1.50

AT=Austria, ES=Spain, IT=Italy, RO=Romania, FR=France, DE=Germany, FI=Finland

Generally, the MS have selected as energy performance indicator the primary energy, but energy need, delivered/site energy, and energy use have also been adopted. Primary energy includes, in addition to the delivered energy, the energy expended in producing and delivering to the final user.

To sum up, the NZEB range of EP_{gl} values goes from positive energy buildings up to 270 $kWh{\cdot}m^{-2}$. In residential buildings EP_{gl} indicator can be in the range 20÷180 $kWh{\cdot}m^{-2}$ but typically targets aim at 45÷50 $kWh{\cdot}m^{-2}$. For non-residential buildings the range is 25÷270 $kWh{\cdot}m^{-2}$ with higher values for hospital buildings.

Table 5 Comparison between the characteristics of NZEBs for some EU Countries

MS	Residential buildings		Non- Residential buildings		
	New	Existing	New	Existing	
	$kWh{\cdot}m^{-2}a$	$kWh{\cdot}m^{-2}a$	$kWh{\cdot}m^{-2}a$	$kWh{\cdot}m^{-2}a$	Note
AT	160	200	170	250	From 2021
BE	45	90	54	108	Belgium – Brussels. Depending on the notional reference building
BE	30%·PE	40%·PE			Belgium Flanders. Maximum PEC defined as a percentage of the primary energy consumption (PE) of a reference building
BG	30÷50	40÷60	30÷50	40÷60	Buildings need to comply with class A.
CY	100	100	125	125	Included energy use: H, C, DHW, L, V, AUX
CZ	75÷80%·PE	75÷80%·PE	90%·PE	90%·PE	Maximum PEC defined as a percentage of the primary energy consumption (PE) of a

MS	Residential buildings New kWh·m^{-2}a	 Existing kWh·m^{-2}a	Non- Residential buildings New kWh·m^{-2}a	 Existing kWh·m^{-2}a	Note
					reference building. Reference *U*-values have also been defined.
DE	40%·PE	55%·PE			Maximum PEC defined as a percentage of the primary energy consumption (PE) of a reference building
DK	20	20	25	25	Included energy use: H, C, DHW,V, L
EE	50 (detached houses) 100 (apartment buildings)		100 (office buildings) 130 (hotels, restaurants) 120 (public buildings) 130 (Shopping malls) 90 (Schools) 100 (day care centres) 270 (hospitals)		Included energy use: H, C, V, DHW, L, HVAC AUX
FR	40÷65	80	70 (office buildings without air conditioning) 110 (office buildings with air conditioning)	60% PE	Included energy use: H, C, V, DHW, L, AUX. Residential values depending on building type and climate
HU	50÷72	60÷115			Requirements proposed, depending on the reference building
IE	45 - defined as Energy load	75÷150	~ 60%·PE		Included energy use: H, V, DHW, L.
LV	95	95	95	95	Included energy use: H, C, V, DHW, L. The energy demand for heating does not exceed 30 kWh·m^{-2}
MT	55 (semi-detached and fully detached houses) 75 (terraced houses) 115 (flatted dwellings)	< 220	220÷255		Included energy use: H,C, DHW, V, L.
PL		60÷75			Depending on building type.
RO	93÷117	120÷230	50÷102	120÷400	Depending on building type and climate
SE	30÷75		30÷105		Depending on building type and climate
SI	75 (single family) 80 (multi-family)	95 (single family) 90 (multifamily)	55	65	Depending on building type and climate

MS	Residential buildings		Non- Residential buildings		
	New kWh·m^{-2}a	Existing kWh·m^{-2}a	New kWh·m^{-2}a	Existing kWh·m^{-2}a	Note
SK	32 (apartment buildings) 54 (family houses)		60÷96 (office buildings) 34 (schools)		Included energy use: H, DHW (for residential buildings). H, C, V, DHW, L (for non-residential buildings)

BE = Belgium, AT = Austria, BG = Bulgaria, CY = Cipro, CZ = Czech Republic, DE = Germany, DK = Denmark, EE = Estonia, FR = France, HU = Hungary, IE = Ireland, LV = Latvia, MT = Malta, PL = Poland, RO = Romania, SE = Sweden, SI = Slovenia, SK = Slovakia, PEC = Primary Energy Consumption, H=Heating, C=Cooling, DHW= Domestic Hot Water, L=Lighting, V=Ventilation, AUX=Electrical auxiliaries

1.3 Framework in Italy

In Italy, the Inter-Ministerial Decree 26/06/2015 [143] specifies the requirements of NZEBs. It establishes that the EP limits of NZEBs through the calculation on a notional reference building (a building which has the same location, function, size, but reference thermal insulation level and technical systems efficiencies) and introduces a minimum renewables share (including H, DHW, C, V in residential buildings and also L and mobility of people in non-residential ones). It implements the law no. 90/2013 which, by modifying and integrating the legislative Decree no. 192/2005 [144], transposes the EPBD Recast. The MD sets the methodology for assessing the EP of buildings and establishes the minimum EP requirements of buildings and building units.

The requirements of NZEBs will be applied to new buildings and major renovations from 1st January 2019 for the public buildings and from 1st January 2021 for all the other buildings. In compliance with the MD, during the building design several parameters must be verified, from the features of single components to EP indicators regarding the energy services and the EP of the whole building.

The MD requires for new buildings to verify the following parameters concerning the building envelope:

a) the mean overall heat transfer coefficient by thermal transmission (H'_T), calculated as:

$$H'_{\mathrm{T}} = \frac{H_{\mathrm{tr,adj}}}{\sum_{k} A_k} \tag{1}$$

where, $H_{\mathrm{tr,adj}}$ is the overall heat transfer coefficient by thermal transmission of the building envelope determinate according to EN ISO 13789 [233], and A_k is the thermal envelope area of component *k*.

The H'_T limit is fixed by the MD 26/06/2015 [143] in function of the compactness ratio of the building (A_{env}/V_g) and the climatic zone, as shown in

Table 6.

Table 6 Max allowable value of the mean overall heat transfer coefficient by thermal transmission H'_T [$W \cdot m^{-2}K^{-1}$].

Compactness ratio [m^{-1}]	Italian climatic zone				
	A and B	C	D	E	F
	(≤900 HDD)	(900< HDD ≤1400)	(1400< HDD ≤2100)	(2100< HDD ≤3000)	(HDD >3000)
	$W \cdot m^{-2}K^{-1}$	$W \cdot m^{-2}K^{-1}$	$W \cdot m^{-2}K^{-1}$	$W \cdot m^{-2}K^{-1}$	$W \cdot m^{-2}K^{-1}$
$A_{env}/V_g < 0.4$	0.80	0.80	0.80	0.75	0.70
$0.4 \leq A_{env}/V_g < 0.7$	0.63	0.60	0.58	0.55	0.53
$A_{env}/V_g \geq 0.7$	0.58	0.55	0.53	0.50	0.48

b) the summer solar effective collecting area ($A_{sol,sum}$), calculated as:

$$A_{sol,sum} = \sum_k F_{sh,ob,k} \cdot g_{gl,sh,k} \cdot \left(1 - F_F\right)_k \cdot A_{w,p,k} \cdot F_{sol,sum,k} \tag{2}$$

where, for each transparent envelope component k:

- $F_{sh,ob,k}$ is the shading reduction factor for external obstacles;
- $g_{gl+sh,k}$ is the total solar energy transmittance of the transparent part of the element in presence of a shading device;
- $F_{F,k}$ is the frame area fraction;
- $A_{w,p,k}$ is the overall projected area of the glazed element;
- $F_{sol,sum,k}$ is the correction factor for the incident solar radiation: ratio between the global solar irradiation of July, in the same site and orientation, and the mean annual global solar irradiation in Rome on a horizontal plane.

According to the MD 26/06/2015 [143], the limit of the summer solar effective collecting area, normalized on the building conditioned net floor area ($A_{sol,sum}/A_f$), is 0.03 for the residential use and 0.04 for all the other uses.

The MD requires that:

- the vertical opaque building envelope has surface mass $M_S \geq 230$ $kg \cdot m^{-2}$ *or* periodic thermal transmittance $Y_{ie} \leq 0.10$ $W \cdot m^{-2}K^{-1}$;
- the horizontal or tilted opaque building envelope have $Y_{ie} \leq 0.18$ $W \cdot m^{-2}K^{-1}$.

The verification parameters concerning the whole building and its technical building systems are the following:

- $EP_{H,nd}$ is the annual heating energy need divided by the building conditioned net floor area;
- $EP_{C,nd}$ is the annual cooling energy need divided by the building conditioned net floor area;
- $EP_{gl,tot}$ is the global total annual primary energy of the building divided the conditioned net floor area, include all the building services and both renewable and non-renewable energy sources.
- η_H, η_C, η_W are the mean global seasonal efficiencies respectively of the heating system, of the cooling system and of the domestic hot water system.

According to the Decree No. 28 of March 3rd [160], concerning the transposition into the Italian legislation of the Directive 2009/28/EC, on the use of energy from renewable sources (RES), the following requirements must be met:

- from 1st January 2017, 50% of energy need for DHW and 50% of the sum of energy needs for DHW, space heating and space cooling must be covered by RES;
- the minimum electrical power of a technical building system fed by RES (like a photovoltaic system) is designed in function of the building footprint area.

1.4 The Energy Performance Assessment

As specified in EN ISO 52000-1 [232], the EP is expressed as global primary energy need, associated with a typical use of building, and normalized on its useful floor area. The global primary energy refers to all the EPBD energy use (heating, cooling, ventilation, domestic hot water and lighting) and it is calculated according to the relevant EPB standards. The energy performance can either include only non-renewable energy (EP_{nren}), or include both non-renewable and renewable energy (EP_{tot}):

$$EP_{\mathrm{tot}} = EP_{\mathrm{nren}} + EP_{\mathrm{ren}} \tag{3}$$

The energy performance is fully described by a couple of indicators: EP_{tot} and EP_{nren}, or alternatively, EP_{tot} and Renewable Energy Ratio (RER). The RER is the ratio of the renewable primary energy to the total primary energy:

$$RER = \frac{EP_{\mathrm{ren}}}{EP_{\mathrm{tot}}} \tag{4}$$

According to current legislation, the first step is the calculation of the energy need for heating and cooling by means of the quasi-steady state numerical model of the Italian technical specification UNI/TS 11300-1 [235], which implements the international standard EN ISO 13790 [234]. In addition, the delivered energy is calculated by means of UNI/TS 11300, which implements the European standards EN 15316 series [237] and EN 15243 [238]. The energy need for lighting is calculated by means of the EN 15193 standard [239]. The overall energy performance (EP_{gl}), expressed as the ratio of the annual non-renewable primary energy for space heating and space cooling to the net useful floor area, was determined as the weighted sum of the thermal energy needs for heating and for cooling:

$$EP_{\mathrm{gl}} = \frac{EP_{\mathrm{H,nd}} \cdot f_{\mathrm{p,nren,gas}}}{\eta_{\mathrm{H,u}} \cdot \eta_{\mathrm{H,g}}} + \frac{EP_{\mathrm{C,nd}} \cdot f_{\mathrm{p,nren,el}}}{\eta_{\mathrm{C,u}} \cdot \eta_{\mathrm{C,g}}} \tag{5}$$

Where:

- $EP_{\mathrm{H/C,nd}}$ is the annual energy need for space heating/cooling;

- $f_{p,nren,gas/el}$ is the non-renewable primary energy conversion factor for natural gas (1.05) and electricity (1.95) respectively according to Table 7;
- $\eta_{H/C,u}$ is the mean seasonal efficiency of the heating/cooling utilisation subsystems (i.e. heat emission, control and distribution, equal to 0.81) and $\eta_{H/C,g}$ is the mean seasonal efficiency of the heating (0.95) and the cooling (2.50) generation subsystem, respectively.

Table 7 Conversion factors in primary energy of energy carriers. Source MD 26/06/2015 [143]

Energy carrier	$f_{P,nren}$	$f_{P,ren}$	$f_{P,tot}$
Natural gas	1.05	0	1.05
LPG	1.05	0	1.05
Fuel Oil	1.07	0	1.07
Coal	1.10	0	1.10
Solid biomass	0.20	0.80	1.00
Liquid and gaseous biomass	0.40	0.60	1.00
Electrical energy from grid	1.95	0.47	2.42
District heating	1.50	0.00	1.50
Urban Solid Waste	0.20	0.20	0.40
District cooling	0.50	0.00	0.50
Thermal energy from solar collectors	0	1.00	1.00
Electricity produced by photovoltaic, mini-wind e small-scale	0	1.00	1.00
Thermal energy from the external environment – free cooling	0	1.00	1.00
Thermal energy from the external environment – heat pump	0	1.00	1.00

Weighting factors based on the resources used to produce the exported energy.
f_P=Weighting factors (based on gross or net calorific value), nren= non-renewable, r=renewable.

1.5 Application

This part of research aims to examine the applicability of the MD for the verification of NZEB's EP requirements, highlighting its limits and strengths. This is a common research topic in the scientific community: several studies deal with examination of legislative documents with numerous objectives, e.g. (a) to verify influences of requirements on technology development, (b) to investigate questions of harmonization, (c) to classify practices and methodologies for requirements definition, and (d) verify the applicability of new procedural methodologies.

In the present section, the following features related to the MD are studied in deep: (a) technical feasibility of the design solutions that comply with the legislative requirements set up for NZEBs, (b) issues concerning the notional reference building approach, (c) robustness of calculation methods in assessing NZEBs.

There are three case studies examined: (a) a single family house, (b) a building for school use (c) an office building. For the analyses, three Italian locations were chosen: Palermo, Rome and Turin. The energy performance of the building is assessed by means of the simplified method prescribed by the MD (UNI/TS 11300 [235]). The analysis takes into account all the energy services installed in the building. Some high efficiency technical building system variants are simulated. The reference mean seasonal efficiency values of the subsystems were assumed in compliance with MD, and the most used energy carriers in Italy were adopted (Table 7).

One of the objectives of the study is to check whether the limits and legislative requirements imposed for these parameters are verifiable or not through the use of different technological solutions. In addition to this, it must also be considered that, in the case of new buildings or buildings undergoing major renovations to get the NZEB level, it is necessary to comply with the obligations of RES according the Annex 3 of the Legislative Decree 3rd March 2011, n. 28 [160].

The requirements concerning the mean global seasonal efficiencies are independent of the fabric configuration, while the overall energy performance of the building requirement depends on both the characteristics of the whole building and the performance of the technical building systems.

While for the fabric the MD foresees two temporal "steps" (2015 and 2019/21), for the technical building systems the parameters of the notional reference building are not differentiated. This means that a technical building systems configuration that observes the efficiencies limits to 2015 will also meet the 2019 requirements. Therefore, the verification of the global total primary energy requirement for 2019/21 will only depend from the building envelope. For these reasons, at the methodological level, for the analysis of the technical building systems (verification of the legal limits), it was decided to start, for all the case studies, from building envelope configurations that respected the limits to 2015; this choice, given the above considerations, does not reduce in any way the significance of the results.

For each case study, certain technical building systems configuration are then evaluated with the aim of providing an analysis that includes the most widespread technologies on the Italian market. Table 8 summarizes technical building systems combinations implemented for each case study. A more detailed description is subsequently shown in the relative paragraphs.

Table 8 Case studies. Examined combinations of technical building systems

Case study	no	**Technical building systems combination**
Single Family house SFH	A	**H+DHW:** Gas boiler
	B	**H:** Gas boiler + pellets stove **DHW:** Gas boiler
School building SB	A	**H:** Gas boiler **DHW:** Electric water heater **L:** Lighting **T:** Lift
	B	**H:** Cogenerator + gas boiler **DHW:** Electric water heater **L:** Lighting **T:** Lift
Office building OB	A	**HC:** gas boiler + electric air / water heat pump **V:** Mechanical ventilation (mixed fan coils + primary air) **DHW:** Electric water heater **L:** Lighting **T:** Lift

All the system configurations shown in Table 8Table 9, for the three climate zones, are evaluated considering the different levels of performance of each technology. The variability of the parameters of the energy performance was analyzed.

As concerned to the input data related to the dimensioning (for example nominal powers of the installed heat generators), in the simulations have been made according to the type of building and the climatic zone. This in order to adapt the technical building systems configuration to the different thermal load required.

For lighting and People transport (e.g., elevators, escalators) services, the MD does not currently set benchmarks.

In particular, for these energy services, the notional reference building has the same parameters (occupancy, exploitation of natural light) of the actual building (automatic regulation systems (class B) of the EN 15232 standard [240]). The class B can be achieved using the daylight regulation with automatic presence detection and automatic regulation based on daylight.

The presence control was determined according to the Table D.1 of the EN 15193 standard [239]. The notional reference building adopts the same value of the actual building (value depending on the presence or absence of dimmer and on the type of regulation of the actual building).

For daylight control, the used reference was the Table C.9; in this case the notional reference building adopt a value depending by the penetration of natural light. As regards people transport (e.g., elevators, escalators), the reference feature of the notional reference building was the same of the actual building. This point was not included in the MD.

1.5.1 Methodology

For each verification option relating to the case studies reported in the following paragraphs, there are matrixes of values that describe all the characteristics of the building: (1) there are fixed geometric characteristics of the building (geometry, shape, volume, useful surfaces, dispersing envelope surfaces, orientation, location, building categories and building boundaries...), (b) and matrices of variable values relating to the thermos-physical characteristics of building elements and building envelope components (vertical opaque structures, opaque horizontal or inclined roof structures, glazing and opaque technical closures, etc. ...).

For each case study, as the thermos-physical characteristics of the building vary, the search for the field of existence is foreseen, which satisfies all the legislative requirements referred to in MD [143]. The limits of the field of existence for the building are represented by the verification of the indexes of the design building in reference to those of the notional reference building (indexes $EP_{\mathrm{H,nd}}$, $EP_{\mathrm{C,nd}}$ and $EP_{\mathrm{gl,tot}}$) together with other parameters of quality verification of the building envelope (H'_{T} and $A_{\mathrm{sol,sum}}/A_{\mathrm{f}}$). Limits vary according to: climate zone of location, geometry of the building (design choices), building categories, etc. Formula 5 represents the set of conditions that must be satisfied in the design of NZEB.

$$\begin{cases} EP_{\mathrm{H,nd(des)}} \leq EP_{\mathrm{H,nd(ref)}} \\ EP_{\mathrm{C,nd(des)}} \leq EP_{\mathrm{C,nd(ref)}} \\ EP_{\mathrm{gl\ (des)}} \leq EP_{\mathrm{gl\ (ref)}} \\ H'_{\mathrm{T(des)}} \leq H'_{\mathrm{T(ref)}} \\ \mathrm{A}_{\mathrm{sol,sum(des)}} / \mathrm{A}_{\mathrm{f}} \leq \left(\mathrm{A}_{\mathrm{sol,sum}} / \mathrm{A}_{\mathrm{f}}\right)_{(\mathrm{ref})} \\ \eta_{\mathrm{H,(des)}} \geq \eta_{\mathrm{H,(ref)}} \\ \eta_{\mathrm{C,(des)}} \geq \eta_{\mathrm{C,(ref)}} \\ \eta_{\mathrm{W,(des)}} \geq \eta_{\mathrm{W,(ref)}} \end{cases} \tag{6}$$

Regarding the presence of solar protection devices, a reduction factor was considered, equal to the ratio between the total solar energy transmittance of the glazing of window with a movable or switchable solar protection devices ($g_{\mathrm{gl+sh}} / g_{\mathrm{gl}}$), according to the combination examined. Regarding the presence of thermal bridges, the choice of the typology was made on the basis of the characteristics of the various structural elements constituting the building envelope. The thermal transmittance of each thermal bridge was determined according to EN ISO 10211 [247] with IRIS software. For all the opaque components adjacent with external space, a colour of the external average surfaces was assumed, corresponding to a solar absorption coefficient of external opaque surfaces (α_{sol}) equal to 0.6. For all opaque components, a thermal emissivity of 0.9 was considered.

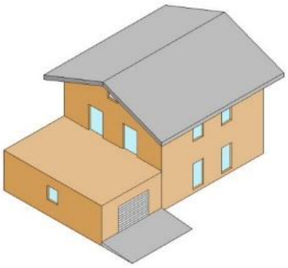
Concerning fenestration, the relative thermal transmittance is variable for case study, with a thermal emissivity of 0.837. For all transparent components, with variable thermal transmittance, based on the type of glass described, it was considered a total solar transmittance factor for normal incidence ($g_{\mathrm{gl,n}}$) equal to 0.67.

1.5.2 Single Family House

The case study is a residential building of a single-family house type. The building category, with reference to the classes of Italian Presidential Decree 412/93 is E.1.1 [159]. The building consists of a single building unit arranged on three levels (the ground floor, the first floor and the attic). The conditioned rooms are located on the ground floor and on the first floor.

Even the whole stairwell is considered heated. There are also two unconditioned zone: a garage and a technical room, bordering the conditioned rooms on the ground floor, and an attic that is not habitable on the third level of the building. Internal heat gains are calculated according to UNI/TS 11300-1 with a constant value of 5.04 $\mathrm{W \cdot m^{-2}}$. The ventilation flow rate is equal to an average value of 0.036 $\mathrm{m^3 \cdot s^{-1}}$ (determined according to UNI/TS 11300-1). The main geometrical information are reported in Table 9.

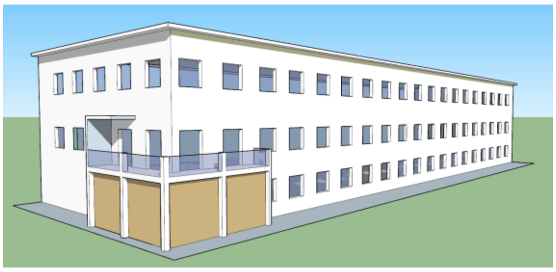
Table 9 Picture and main data of single family-house.

	Geometric data	
	A_{f} [m^2]	161
	V_g [m^3]	673
	V [m^3]	429
	A_{env}/V_g [m^{-1}]	0.56
	A_w [m^2]	26.6
	A_w/A_f [-]	0.17

1.5.3 School Building

The building consists in a single building unit organized on three levels (ground floor, first floor and second floor). All locals are conditioned. The energy performance was calculated taking into account the following energy services: heating, cooling, domestic hot water, lighting, and transportation of people. The total useful floor area of the building is 2 565 m^2 while the conditioned net volume is 8551 m^3. The internal heat gains are calculated according to UNI/TS 11300-1 with a constant value of 4.00 W·m^{-2}. The same approach was followed for the ventilation flow rate, equal to an overall value of 2.57 m^3·s^{-1} (determined according to UNI 10339). The main geometrical information are reported in Table 9.

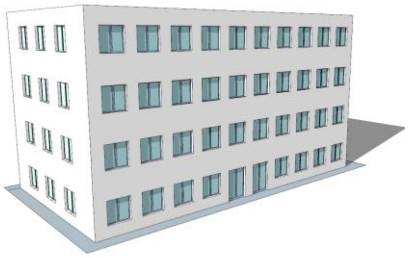
Table 10 Picture and main data of school building.

	Geometric data	
	A_{f} [m^2]	2561
	V_g [m^3]	10817
	V [m^3]	8536
	A_{env}/V_g [m^{-1}]	0.33
	A_w [m^2]	304.6
	A_w/A_f [-]	0.12

1.5.4 Office Building

The present case study consists in a building used as office. The building category, with reference to the classes of Italian Presidential Decree 412/93 [159] is the E.2. The building is composed by a single unit organized on five floor levels all conditioned. The calculation of energy performance, as required by current legislation, takes into account the following services: heating, cooling, domestic hot water, lighting, and transportation of people. The main geometrical information are reported in Table 11. In the case study, with regard to the calculation of the minimum design air flow rate, the equation no 33 of the UNI/TS 11300-1 [235] with the specific flows for people and for the surface of the UNI 10339 [236] was applied. The flow $q_{ve,0}$ has been calculated, according to the current technical standard. The following types of locals have been identified: (a) locals where there are stationing of people (single offices, meeting rooms), (b) locals where are not planned the stationing of people (corridors, atrium, stairwells, anti-bathrooms), and (c) toilets (bathrooms).

Table 11 Picture and main data of office building.

	Geometric data	
	A_f [m^2]	2203
	V_g [m^3]	9308
	V [m^3]	7271
	A_{env}/V_g [m^{-1}]	0.30
	A_w [m^2]	508.0
	A_w/A_f [-]	0.23

For locals where there are stationing of people was considered a crowding index of (a) 0.06 people/m^2 for single office, and (b) 0.60 people /m^2 for meeting rooms. An external air flow rate equal to 11 m^3·s^{-1} per person and to 10 m^3·s^{-1} per person was considered for single offices and the meeting rooms, respectively.

1.5.5 Results related to the Building Envelope

Some design solutions that allow to verify the parameters of the notional reference building as defined by the MD are reported below. The design of new buildings provides solutions and technological combinations that have energy performances similar to those of the notional reference building and that comply with all the design parameters imposed by current legislation.

The various case studies have shown that there is not only a combination of the NZEB project, but generally there is a field of existence that meets the set of legislative requirements referred to in MD. The limits of the field of existence for the building are represented by the verification of the indexes of the actual building in relation to those of the notional reference building together with other parameters for checking the quality of the building envelope.

Considered that the thermal transmittance values of the building imposed by MD already take into account the effect of thermal bridges, a good design practices will minimize its presence limiting firstly the heterogeneity of form (design choices of the technician) and avoiding, to follow, the heterogeneity of structure (technological choices such as the combination of materials with different thermal conductivity, e.g. presence of structural elements in reinforced concrete, joints, etc.).

As regard the design of a building made up of several building units with different geometric characteristics, such as the case of an apartment block, it is necessary to define a common building envelope solution that is also suitable for uniqueness, both for individual actual building units (which have different dispersing areas, different S/V ratio, different orientation, and different energy limits to be respected), and those of the whole building, this aspect is a further design constraint, this research has also examined this appearance.

For the locations for which the calculation simulations were performed (climate zones B, D and E), and in relation to the case studies presented in the research, the parameters of the notional reference building appear to be correctly calibrated, however only for the area Climate B the ‘Max allowable value of the mean overall heat transfer coefficient by thermal transmission’ (H'_T) appears to be incorrectly matched to the values of the notional reference building.

To carry out this study a special tool built in Excel + VBA has been created. This tool automatically changes the thermal characteristics of the building envelope depending on the calculation of energy performance. In a first step the characteristics of each individual element of the building envelope are changed (ex. external wall, roof slab, window properties, solar protection devices properties, etc.) and in a second step several properties are changed simultaneously. The purpose of the calculation is to select multiple design solutions of NZEB that satisfy the requirements of the MD and then evaluate how the properties of each element influence those of the other elements. In **Fig. 1** is reported the process implemented in the tool for verifying NZEB building envelope solutions.

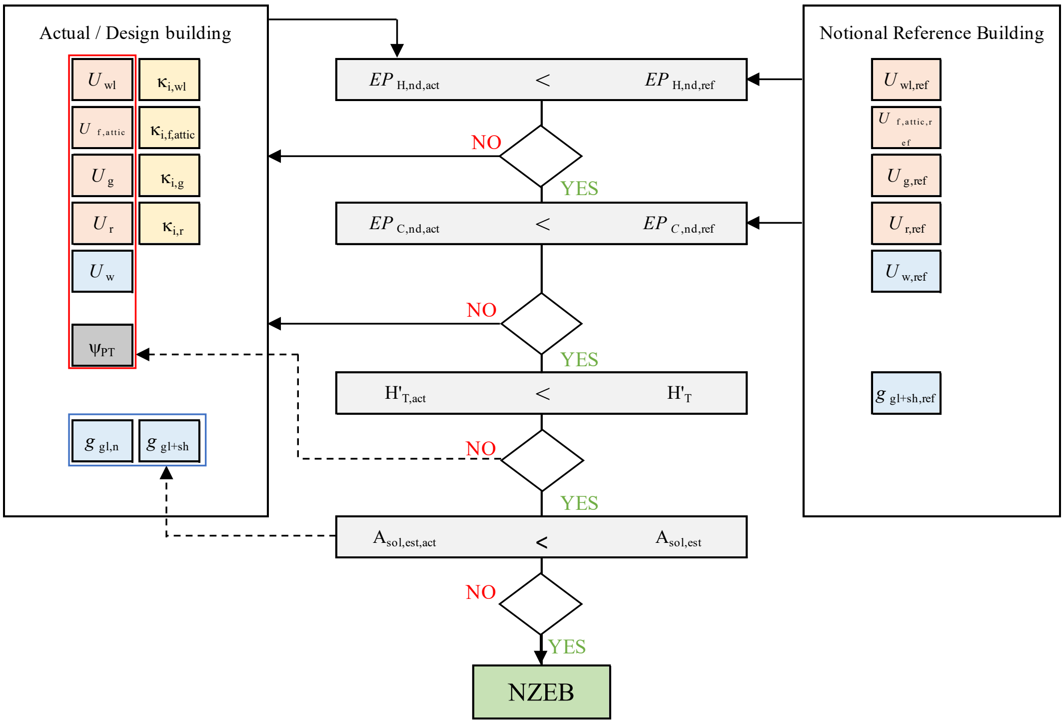


Fig. 1 Process for verifying NZEB combinations for the building envelope in the created VBA software

Table 12 Single-family house - NZEB building envelope solutions for Palermo, Rome, and Turin and their energy performance.

Parameter		Technical solutions																	
		2015									2019/2021								
		Palermo			Roma			Torino			Palermo			Roma			Torino		
		sol.1	sol.2	sol.3	sol.1	sol.2	sol.3	sol.1	sol.2	sol.3	sol.1	sol.2	sol.3	sol.1	sol.2	sol.3	sol.1	sol.2	sol.3
U_{wl}	$\mathrm{W\ m^{-2}K^{-1}}$	0.41	0.36	0.34	0.26	0.25	0.25	0.23	0.24	0.26	0.41	0.34	0.34	0.22	0.18	0.20	0.18	0.17	0.20
U_{g}	$\mathrm{W\ m^{-2}K^{-1}}$	0.41	0.36	0.34	0.26	0.25	0.25	0.23	0.24	0.26	0.41	0.34	0.34	0.22	0.18	0.20	0.18	0.17	0.20
U_{r}	$\mathrm{W\ m^{-2}K^{-1}}$	0.34	0.30	0.29	0.22	0.21	0.21	0.19	0.20	0.22	0.34	0.29	0.29	0.18	0.15	0.17	0.15	0.14	0.17
U_{w}	$\mathrm{W\ m^{-2}K^{-1}}$	2.23	3.00	3.20	1.60	1.80	2.00	1.48	1.40	1.40	2.23	3.00	3.20	1.42	1.80	2.00	1.27	1.40	1.40
$g_{\mathrm{gl+sh}}/g_{\mathrm{gl}}$	-	0.37	0.32	0.55	0.22	0.21	0.45	0.19	0.20	0.55	0.37	0.30	0.55	0.18	0.14	0.45	0.14	0.13	0.55
$\mathrm{H'_T}$	$\mathrm{W\ m^{-2}K^{-1}}$	0.57	0.58	0.58	0.40	0.40	0.41	0.36	0.36	0.38	0.57	0.56	0.58	0.35	0.34	0.37	0.31	0.30	0.33
$A_{\mathrm{sol,sum}}/A_{\mathrm{f}}$	-	0.02	0.02	0.03	0.01	0.01	0.02	0.01	0.01	0.03	0.02	0.01	0.03	0.01	0.01	0.02	0.01	0.01	0.03
$EP_{\mathrm{H,nd}}$	$\mathrm{kWh\ m^{-2}}$	13.48	14.33	13.26	17.25	17.45	17.08	41.73	41.45	41.51	13.48	13.67	13.26	13.56	13.55	13.49	33.42	32.95	33.22
$EP_{\mathrm{H,nd\ (lim)}}$	$\mathrm{kWh\ m^{-2}}$		14.93			17.46			41.81			13.82			13.72			33.47	
$EP_{\mathrm{C,nd}}$	$\mathrm{kWh\ m^{-2}}$	33.23	31.13	34.65	27.23	26.61	30.57	16.66	16.87	21.59	33.23	30.83	34.65	27.40	26.13	31.31	17.56	17.25	23.08
$EP_{\mathrm{C,nd\ (lim)}}$	$\mathrm{kWh\ m^{-2}}$		35.83			33.51			21.93			36.20			34.82			24.13	

Table 13 Building for school use - NZEB building envelope solutions for Palermo, and their energy performance

a)

ref. 2015		Technical solutions																	
	U.M.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
U_{wl}	W m^{-2}K^{-1}	0.44	0.37	0.39	0.40	0.41	0.42	0.44	0.45	0.54	0.51	0.51	0.49	0.47	0.45	0.43	0.40	0.38	0.37
U_{g}	W m^{-2}K^{-1}	0.45	0.38	0.40	0.41	0.42	0.43	0.44	0.46	0.55	0.53	0.52	0.50	0.48	0.46	0.44	0.41	0.39	0.38
U_{r}	W m^{-2}K^{-1}	0.37	0.31	0.33	0.34	0.35	0.36	0.37	0.38	0.45	0.43	0.43	0.41	0.40	0.38	0.36	0.34	0.32	0.31
U_{w}	W m^{-2}K^{-1}	2.61	2.19	2.30	2.36	2.42	2.49	2.57	2.63	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.20
$g_{\mathrm{gl+sh}}/g_{\mathrm{gl}}$	-	0.75	0.10	0.25	0.35	0.45	0.55	0.65	0.75	0.45	0.45	0.55	0.55	0.60	0.65	0.65	0.65	0.65	0.75
$\mathrm{H'_T}$	W m^{-2}K^{-1}	0.71	0.61	0.63	0.65	0.67	0.68	0.70	0.72	0.69	0.68	0.69	0.70	0.70	0.70	0.70	0.70	0.69	0.71
$A_{\mathrm{sol,sum}}/A_{\mathrm{f}}$	-	0.02	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$EP_{\mathrm{H,nd}}$	kWh m^{-2}	25.43	25.49	25.50	25.46	25.49	25.46	25.58	25.56	25.51	25.57	25.47	25.59	25.56	25.54	25.59	25.50	25.53	25.53
$EP_{\mathrm{H,nd\,(lim)}}$	kWh m^{-2}	25.59																	
$EP_{\mathrm{C,nd}}$	kWh m^{-2}	25.11	20.42	21.48	22.21	22.94	23.66	24.38	25.11	23.99	23.77	24.38	24.18	24.36	24.55	24.35	24.14	23.92	24.52
$EP_{\mathrm{C,nd\,(lim)}}$	kWh m^{-2}	25.13																	

b)

ref. 2019		Technical solutions																	
	U.M.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
U_{wl}	W m^{-2}K^{-1}	0.41	0.35	0.36	0.37	0.39	0.40	0.41	0.42	0.49	0.47	0.46	0.44	0.42	0.41	0.38	0.36	0.34	0.33
U_{g}	W m^{-2}K^{-1}	0.42	0.35	0.37	0.38	0.39	0.40	0.42	0.43	0.50	0.48	0.47	0.45	0.43	0.42	0.39	0.37	0.34	0.33
U_{r}	W m^{-2}K^{-1}	0.34	0.29	0.31	0.31	0.33	0.34	0.34	0.35	0.42	0.40	0.39	0.37	0.36	0.34	0.32	0.30	0.28	0.28
U_{w}	W m^{-2}K^{-1}	2.40	2.05	2.13	2.19	2.28	2.34	2.40	2.47	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00	3.20
$g_{\mathrm{gl+sh}}/g_{\mathrm{gl}}$	-	0.66	0.10	0.25	0.35	0.45	0.55	0.65	0.75	0.45	0.45	0.55	0.55	0.60	0.65	0.65	0.65	0.65	0.75
$\mathrm{H'_T}$	W m^{-2}K^{-1}	0.66	0.57	0.59	0.61	0.63	0.64	0.66	0.68	0.64	0.64	0.65	0.65	0.65	0.66	0.66	0.65	0.65	0.66
$A_{\mathrm{sol,sum}}/A_{\mathrm{f}}$	-	0.02	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$EP_{\mathrm{H,nd}}$	kWh m^{-2}	24.44	24.47	24.35	24.36	24.47	24.45	24.48	24.46	24.42	24.43	24.46	24.44	24.42	24.47	24.46	24.45	24.46	24.46
$EP_{\mathrm{H,nd\,(lim)}}$	kWh m^{-2}	24.48																	
$EP_{\mathrm{C,nd}}$	kWh m^{-2}	24.53	20.46	21.55	22.28	22.98	23.72	24.46	25.20	23.90	23.69	24.29	24.08	24.27	24.46	24.25	24.04	23.84	24.43
$EP_{\mathrm{C,nd\,(lim)}}$	kWh m^{-2}	25.22																	

Table 14 Building for school use - NZEB building envelope solutions for Rome, and their energy performance

	ref. 2015		Technical solutions									
		U.M.	1	2	3	4	5	6	7	8	9	10
	U_{wl}	W m^{-2}K^{-1}	0.19	0.29	0.33	0.33	0.31	0.28	0.27	0.24	0.23	0.21
	U_{g}	W m^{-2}K^{-1}	0.19	0.30	0.34	0.34	0.31	0.28	0.27	0.24	0.23	0.21
	U_{r}	W m^{-2}K^{-1}	0.16	0.25	0.28	0.28	0.26	0.23	0.23	0.20	0.19	0.18
	U_{w}	W m^{-2}K^{-1}	1.10	1.71	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80
a)	$g_{\mathrm{gl+sh}}/g_{\mathrm{gl}}$	-	0.10	0.65	0.65	0.75	0.75	0.75	0.80	0.80	0.85	0.90
	H'_{T}	W m^{-2}K^{-1}	0.34	0.49	0.49	0.51	0.51	0.51	0.52	0.51	0.52	0.53
	$A_{\mathrm{sol,sum}}/A_{\mathrm{f}}$	-	0.00	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	$EP_{\mathrm{H,nd}}$	kWh m^{-2}	38.57	40.30	40.29	40.18	40.20	40.11	40.26	40.05	40.31	40.18
	$EP_{\mathrm{H,nd\,(lim)}}$	kWh m^{-2}	40.31									
	$EP_{\mathrm{C,nd}}$	kWh m^{-2}	15.79	19.24	19.56	20.09	19.90	19.71	19.88	19.66	19.84	20.01
	$EP_{\mathrm{C,nd\,(lim)}}$	kWh m^{-2}	20.39									

	ref. 2019		Technical solutions									
		U.M.	1	2	3	4	5	6	7	8	9	10
	U_{wl}	W m^{-2}K^{-1}		0.25	0.26	0.26	0.24	0.21	0.20			
	U_{g}	W m^{-2}K^{-1}		0.25	0.26	0.26	0.24	0.21	0.20			
	U_{r}	W m^{-2}K^{-1}		0.21	0.22	0.22	0.20	0.18	0.16			
	U_{w}	W m^{-2}K^{-1}		1.46	1.40	1.60	1.80	2.00	2.20			
b)	$g_{\mathrm{gl+sh}}/g_{\mathrm{gl}}$	-		0.65	0.65	0.75	0.75	0.75	0.80			
	H'_{T}	W m^{-2}K^{-1}		0.43	0.43	0.45	0.45	0.45	0.45			
	$A_{\mathrm{sol,sum}}/A_{\mathrm{f}}$	-		0.02	0.02	0.03	0.03	0.03	0.03			
	$EP_{\mathrm{H,nd}}$	kWh m^{-2}		37.35	37.45	37.48	37.54	37.51	37.46			
	$EP_{\mathrm{H,nd\,(lim)}}$	kWh m^{-2}		37.56								
	$EP_{\mathrm{C,nd}}$	kWh m^{-2}		19.45	19.51	20.05	19.85	19.65	19.82			
	$EP_{\mathrm{C,nd\,(lim)}}$	kWh m^{-2}		20.52								

In the design of a NZEB, for the Italian climate zone B, considered that the notional reference building is characterized by high thermal transmittance values of the building envelope, the legislative verification that has greater impact on the design of buildings is the H'_T limit.

To satisfy this energy requirement, the designer can opt to reduce the thermal transmittance of transparent technical closures or of the opaque building envelope. This choice, combined with the use of mobile solar shading, can allow compliance with legislative requirements.

However, under specific conditions such as for some actual building units with exclusive exposure to the North, it is not possible to intervene on the containment of the thermal energy needed for summer conditioning through the use of mobile shading device (the use of which don't have effect in north side), the alternative is to intervene on the building envelope by increasing the thermal transmittance, trying to stay within the limits imposed by the parameter H'_T. In some special circumstances there may not be acceptable design building envelope solutions.

Table 15 Building for school use - NZEB building envelope solutions for Turin, and their energy performance

	ref. 2015		Technical solutions							
		U.M.	1	2	3	4	5	6	7	8
	U_{wl}	$\mathrm{W\,m^{-2}K^{-1}}$	0.22	0.25	0.26	0.32	0.26	0.26	0.23	0.21
	U_{g}	$\mathrm{W\,m^{-2}K^{-1}}$	0.22	0.25	0.26	0.32	0.26	0.26	0.24	0.21
	U_{r}	$\mathrm{W\,m^{-2}K^{-1}}$	0.18	0.21	0.22	0.27	0.21	0.22	0.20	0.18
	U_{w}	$\mathrm{W\,m^{-2}K^{-1}}$	1.25	1.44	1.52	1.10	1.40	1.60	1.80	2.00
a)	$g_{\mathrm{gl+sh}}/g_{\mathrm{gl}}$	-	0.16	0.60	0.75	0.80	0.60	0.80	0.80	0.80
	$\mathrm{H'_T}$	$\mathrm{W\,m^{-2}K^{-1}}$	0.38	0.43	0.44	0.45	0.43	0.45	0.45	0.45
	$A_{\mathrm{sol,sum}}/A_{\mathrm{f}}$	-	0.01	0.02	0.03	0.03	0.02	0.03	0.03	0.03
	$EP_{\mathrm{H,nd}}$	$\mathrm{kWh\,m^{-2}}$	81.76	81.47	81.73	81.67	81.61	81.70	81.71	81.70
	$EP_{\mathrm{H,nd\,(lim)}}$	$\mathrm{kWh\,m^{-2}}$	81.77							
	$EP_{\mathrm{C,nd}}$	$\mathrm{kWh\,m^{-2}}$	5.34	7.47	8.09	8.62	7.49	8.28	8.15	8.01
	$EP_{\mathrm{C,nd\,(lim)}}$	$\mathrm{kWh\,m^{-2}}$	8.84							

	ref. 2019		Technical solutions							
		U.M.	sol.1	sol.2	sol.3	sol.4	sol.5	sol.6	sol.7	sol.8
	U_{wl}	$\mathrm{W\,m^{-2}K^{-1}}$		0.20	0.21	0.23				
	U_{g}	$\mathrm{W\,m^{-2}K^{-1}}$		0.20	0.21	0.23				
	U_{r}	$\mathrm{W\,m^{-2}K^{-1}}$		0.17	0.18	0.19				
	U_{w}	$\mathrm{W\,m^{-2}K^{-1}}$		1.14	1.21	1.10				
b)	$g_{\mathrm{gl+sh}}/g_{\mathrm{gl}}$	-		0.60	0.75	0.80				
	$\mathrm{H'_T}$	$\mathrm{W\,m^{-2}K^{-1}}$		0.35	0.37	0.38				
	$A_{\mathrm{sol,sum}}/A_{\mathrm{f}}$	-		0.02	0.03	0.03				
	$EP_{\mathrm{H,nd}}$	$\mathrm{kWh\,m^{-2}}$		75.89	75.79	75.89				
	$EP_{\mathrm{H,nd\,(lim)}}$	$\mathrm{kWh\,m^{-2}}$			76.02					
	$EP_{\mathrm{C,nd}}$	$\mathrm{kWh\,m^{-2}}$		7.98	8.97	9.30				
	$EP_{\mathrm{C,nd\,(lim)}}$	$\mathrm{kWh\,m^{-2}}$			9.50					

With the purpose to limit the cooling energy need and the internal temperature of the locals, with the increasing of WWR, it is necessary to use shading devices, with interception characteristics of solar radiation more and more effective.

This option contributes to improving the building summer performance, however it implies a worsening of the heating performance due to the double contribution (greater thermal dispersion proportionate to lower solar heat gain contributions).

The major dispersions are due to the increase in the dispersing surface with greater *U*-value (compared to the opaque envelope) associated with an increase in the amount of thermal bridges.

The direct consequence to be within the limits of the MD is a hyper thermal insulation of the opaque building envelope.

Table 16 Office Building - NZEB building envelope solutions for a) Palermo and b) Rome and their energy performance

a)

		2015							**2019**						
		Incidence of thermal bridges							Incidence of thermal bridges						
	U.M.	15%	20%	25%	30%	35%	40%	45%	15%	20%	25%	30%	35%	40%	45%
U_{wl}	W m^{-2}K^{-1}	0.31	0.27	0.23	0.19	0.12	0.13	0.11	0.30	0.26	0.22	0.18	0.12	0.13	0.10
U_{g}	W m^{-2}K^{-1}	0.54	0.44	0.35	0.35	0.20	0.21	0.17	0.52	0.41	0.32	0.32	0.20	0.21	0.15
U_{r}	W m^{-2}K^{-1}	0.25	0.22	0.19	0.16	0.10	0.11	0.09	0.25	0.21	0.18	0.15	0.10	0.11	0.08
U_{w}	W m^{-2}K^{-1}	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
$g_{\mathrm{gl+sh}}/g_{\mathrm{gl}}$	-	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
$\mathrm{H'_T}$	W m^{-2}K^{-1}	0.80	0.80	0.80	0.80	0.79	0.79	0.80	0.79	0.79	0.79	0.79	0.79	0.79	0.79
$A_{\mathrm{sol,sum}}/A_{\mathrm{f}}$	-	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$EP_{\mathrm{H,nd}}$	kWh m^{-2}	21.62	21.66	21.64	21.62	21.50	21.47	21.53	21.49	21.44	21.48	21.34	21.50	21.47	21.40
$EP_{\mathrm{H,nd\,(lim)}}$	kWh m^{-2}				22.43							21.51			
$EP_{\mathrm{C,nd}}$	kWh m^{-2}	30.42	30.39	30.41	30.40	30.52	30.58	30.61	30.51	30.53	30.52	30.57	30.52	30.58	30.72
$EP_{\mathrm{C,nd\,(lim)}}$	kWh m^{-2}				32.13							32.76			

b)

		2015							**2019**						
		Incidence of thermal bridges							Incidence of thermal bridges						
	U.M.	15%	20%	25%	30%	35%	40%	45%	15%	20%	25%	30%	35%	40%	45%
U_{wl}	W m^{-2}K^{-1}	0.28	0.25	0.22	0.19	0.17	0.16	0.13	0.19	0.16	0.14	0.13	0.10	0.09	0.07
U_{g}	W m^{-2}K^{-1}	0.50	0.45	0.41	0.36	0.32	0.29	0.25	0.36	0.30	0.27	0.24	0.20	0.17	0.15
U_{r}	W m^{-2}K^{-1}	0.23	0.20	0.18	0.16	0.14	0.12	0.10	0.16	0.13	0.11	0.10	0.08	0.07	0.05
U_{w}	W m^{-2}K^{-1}	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
$g_{\mathrm{gl+sh}}/g_{\mathrm{gl}}$	-	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
$\mathrm{H'_T}$	W m^{-2}K^{-1}	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.49	0.49	0.49	0.49	0.49	0.49	0.49
$A_{\mathrm{sol,sum}}/A_{\mathrm{f}}$	-	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$EP_{\mathrm{H,nd}}$	kWh m^{-2}	35.27	35.25	35.34	35.19	35.18	35.33	35.24	33.44	33.32	33.35	33.49	33.39	33.45	33.47
$EP_{\mathrm{H,nd\,(lim)}}$	kWh m^{-2}				35.37							33.49			
$EP_{\mathrm{C,nd}}$	kWh m^{-2}	30.21	30.21	30.13	30.22	30.24	30.15	30.24	31.45	31.57	31.60	31.52	31.66	31.67	31.69
$EP_{\mathrm{C,nd\,(lim)}}$	kWh m^{-2}				32.45							33.77			

Table 17 Office Building - NZEB building envelope solutions for Turin and their energy performance

		2015							**2019**						
		Incidence of thermal bridges							Incidence of thermal bridges						
	U.M.	15%	20%	25%	30%	35%	40%	45%	15%	20%	25%	30%	35%	40%	45%
U_{wl}	W m^{-2}K^{-1}	0.29	0.27	0.25	0.22	0.20	0.19	0.16	0.18	0.15	0.13	0.12	0.10	0.09	0.07
U_g	W m^{-2}K^{-1}	0.54	0.50	0.46	0.42	0.38	0.36	0.32	0.34	0.30	0.27	0.24	0.21	0.19	0.16
U_r	W m^{-2}K^{-1}	0.25	0.23	0.21	0.19	0.17	0.16	0.14	0.15	0.13	0.11	0.10	0.09	0.07	0.06
U_w	W m^{-2}K^{-1}	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
g_{gl+sh}/g_{gl}	-	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
H'_T	W m^{-2}K^{-1}	0.50	0.51	0.51	0.51	0.50	0.51	0.50	0.41	0.41	0.41	0.41	0.41	0.41	0.41
$A_{sol,sum}/A_f$	-	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$EP_{H,nd}$	kWh m^{-2}	70.59	70.76	70.81	70.76	70.62	70.83	70.50	65.35	65.25	65.06	65.16	65.20	65.16	65.05
$EP_{H,nd\ (lim)}$	kWh m^{-2}				70.93							65.42			
$EP_{C,nd}$	kWh m^{-2}	21.86	21.77	21.71	21.69	21.71	21.62	21.70	23.74	23.78	23.88	23.86	23.88	23.95	24.07
$EP_{C,nd\ (lim)}$	kWh m^{-2}				23.48							25.69			

Even the building units that have exclusive main orientation to the North side, to comply with the MD limits, must provide for the use of mobile shading device that shield from solar radiation. From the comparison of the building of reference for the two application phases 2015 and 2019/2021, it is clear that a tightening of the requirements (decrease of thermal transmittance of the notional reference building) corresponds on the one hand a containment of the thermal energy needs useful in the season of heating and, on the other, higher thermal energy needs in the cooling season. In any case, however, the sum of the two energy needs (cooling + heating) goes down.

As for major refurbishment (first-level,) they must observe the same requirements as those of new buildings. However, the designer who works on existing buildings can only partially intervene on the building envelope by replacing the windows, improving the thermal insulation and correcting the thermal bridges as much as possible, while, in general, the opaque building envelope is not replaced but improved with addition of a thermal insulating layer.

While in the design of new buildings it is possible to apply standardized technological and design measures, for major refurbishment (first-level) the discourse is configured as more delicate because the transparent building envelope area is already defined a priori as well as the presence of thermal bridges (due to the shape heterogeneity and the presence of balconies). In the simulations, the incidence percentage of thermal bridges with increasing variable incidence (from 15% to 50% on the overall heat transfer coefficient by thermal transmission) was taken into account, thus quantifying the main project relapses.

1.5.6 Technical building systems configurations

1.5.6.1 Single Family house

In **the first** considered **configuration**, both the heating and the DHW service are guaranteed by a single combined system consisting of a gas boiler with a heating distribution circuit serving radiators and the distribution network of the DHW. The following tables show the main input parameters for different performance levels.

Table 18 Single Family house. Configuration A of technical building system. Actual building efficiency for a) Heating energy service (H) and b) domestic hot water system (DHW)

	a)			**b)**		
	Performance levels			Performance levels		
	1	2	3	1	2	3
Emission efficiency	0.970	0.970	0.970	1.000	1.000	1.000
Control efficiency	0.980	0.980	0.980	-	-	-
Distribution efficiency	0.972	0.972	0.926	0.926	0.926	0.893
Nominal generation efficiency (100% of the	0.930	0.880	0.880	0.930	0.880	0.880
Nominal generation efficiency (30% of the load)	0.900	0.850	0.850	0.900	0.850	0.850

In the case study are also considered electrical distribution auxiliaries (circulating pump of the heating circuit of 50W functioning intermittently) and electrical auxiliaries of generation (powers varying according to the power of the generator and given by the UNI/TS 11300-2 [235]. Below are tested two different configurations for three locations.

Table 19 Single Family house. Configuration A of technical building system. Verification of compliance with MD requirements and indicators

		Torino				Roma				Palermo			
		Level			Limit	Level			Limit	Level			Limit
		1	2	3		1	2	3		1	2	3	
η_H	-	0.78	0.73	0.70	0.73	0.79	0.74	0.71	0.73	0.81	0.76	0.73	0.73
η_W	-	0.63	0.60	0.58	0.57	0.65	0.62	0.6	0.57	0.63	0.61	0.58	0.57
η_C	-	-	-	-	-								
$EP_{gl,\,tot}$	$kWh{\cdot}m^{-2}$	77.9	82.1	85.90	83.7	41.9	44.2	46.2	46.5	36.6	38.6	40.3	40.7
$EP_{gl,\,nren}$	$kWh{\cdot}m^{-2}$	77.7	81.9	85.7	-	41.8	44.1	46.1					
QR	%	0.30	0.30	0.30	-	0.20	0.20	0.20		0.20	0.20	0.20	
QR_{H+W+C}	%	0.30	0.30	0.30	-	0.20	0.20	0.20		0.20	0.20	0.20	
QR_W	%	0.00	0.00	0.00	-	0.00	0.00	0.00		0.00	0.00	0.00	

With a Nominal generation efficiency of 0.93 (to 100%) and 0.90 (to 30%), attributable to a standard gas boiler, all the legal requirements can be met with a certain margin. In this case, the mean global seasonal efficiency of the technical system of the actual building is 0.84. In fact, the efficiency is higher during the heating season; in the case of production of DHW only, the generator works instead at lower loads with a consequent decrease in efficiency.

It should therefore be noted that even with a mean global seasonal efficiency lower than the reference value of the MD (0.95), also considering the presence of electrical auxiliaries for distribution and generation, it is possible to meet the legal limits. The reason for this is attributable to the utilization subsystems, which in the actual building are more performing in relation to the reference efficiency (0.81 for H and 0.70 for DHW).

With nominal lower generation efficiency (of 0.88 to 100% and of 0.85 to 30%) and with a mean global seasonal efficiency of 0.79, the limit is reached on meeting the requirements; in particular, only the heating efficiency requirement for a few decimal points is not satisfied; this on condition that utilization returns remain high; If, on the other hand, with nominal efficiency of 0.88% at 100% and 0.85% at 30%, for example, pipe insulation is neglected, or there is a very extensive distribution network and / or current for some stretches outside the heated building envelope, neither the average heating efficiency requirement nor the total global primary energy requirement would be verified.

The analysis carried out in the previous points is valid for all three locations, with slight differences mainly due to the different sizing of the generator according to the climatic zone and the consequent thermal load of the building.

In the **second configuration** examined, the heating service is guaranteed by two technical building systems. The first consists of a pellet boiler placed in a heated environment. This system then directly heats the ambient air through the generator, without the distribution circuit. The second building system consists of a gas boiler with its own distribution circuit serving thermal radiators. The DHW production system is combined with the hydronic heating system; the generator for DHW is therefore the same boiler that provides for heating.

The pellet boiler is located on the ground floor of the house (living area) and it is assumed that it can meet a maximum of 50% of the heat requirement of the area actually served by the biomass generator (UNI/TS 11300-4, Table 23). The hydronic system (gas boiler) is instead used by both areas (day and night). The system with the pellet generator is managed in priority with respect to the boiler. It is also possible to close and / or adjust and control the terminals of the area where the pellet stove is present to prevent overheating of the rooms when it is operating. In the following tables the main input parameters for different energy performance levels.

Table 20 Single Family house. Configuration B of technical building system. Actual building efficiency for a) Heating energy service (H) and b) domestic hot water system (DHW)

	a)			b)		
	Performance levels			Performance levels		
	1	2	3	1	2	3
Emission efficiency	0.970	0.970	0.970	1.000	1.000	1.000
Control efficiency	0.980	0.980	0.980			
Distribution efficiency	0.972	0.972	0.926	0.926	0.926	0.893
PB. Nominal generation efficiency (Pellet generator)	0.750	0.700	0.650			
GB. Nominal generation efficiency (100% of the load)	0.930	0.880	0.880	0.930	0.880	0.880
GB. Nominal generation efficiency (30% of the load)	0.900	0.850	0.850	0.900	0.850	0.850

* PB Pellet Boiler, GG Gas Boiler

The calculation results related to the technical building systems configurations are presented below. The tables show both the results of the actual building and the reference limit values. The values shown in red indicate that the requirement is not satisfied. Subsequent to the quantitative analysis are reported comments that constitute a qualitative analysis and summarize the main conclusions related to the specific case.

Table 21 Single Family house. Configuration B of technical building system. Verification of compliance with MD requirements and indicators

		Torino				Roma				Palermo			
		Level			Limit	Level			Limit	Level			Limit
		1	2	3		1	2	3		1	2	3	
η_H	-	0.73	0.69	0.65	0.67	0.73	0.68	0.64	0.67	0.75	0.71	0.67	0.67
η_W	-	0.66	0.63	0.61	0.57	0.69	0.65	0.63	0.57	0.67	0.64	0.62	0.57
η_C	-												
$EP_{gl.tot}$	$kWh \cdot m^{-2}$	80.3	84.9	89.44	88.6	42.7	45.2	47.5	48.7	37.1	39.2	41.2	42.5
$EP_{gl.nren}$	$kWh \cdot m^{-2}$	63.4	66.9	70.1	-	35	36.9	38.6		31.1	32.8	34.2	
QR	%	21.00	21.10	21.70	-	18.00	18.20	18.70		16.30	16.50	16.90	
QR_{H+W+C}	%	21.00	21.10	21.70	-	18.00	18.20	18.70		16.30	16.50	16.90	
QR_W	%	0.00	0.00	0.00	-	0.00	0.00	0.00		0.00	0.00	0.00	

In general, even with the introduction of the pellet boiler as a heating system, situations similar to those of the of thermal system configuration A occur. In particular, also considering the electrical auxiliaries (in addition to those of the hydronic circuit there are, in in this case, even those of the pellet generator) the limits can be reached even with a nominal efficiency lower than the reference one (for generators fed with solid biomass equal to 0.72 for the heating service). This is mainly thanks to the yields of the utilization subsystems.

As for example 1, attention must be paid to the sizing of the thermal system, since low real load factors lead to monthly mean values lower than the reference one.

1.5.6.2 School Building

In the present system configuration, the whole building is equipped with a hydronic heating system, from a gas boiler located in a thermal system not adjacent to the building. The production of DHW is carried out separately from the heating system, through electric water heaters located in the service rooms of each floor. There is no summer cooling or air conditioning system and / or mechanical air ventilation. The air exchange in the rooms is guaranteed by natural ventilation. The lighting of the building is considered only as regards the interior lighting of the rooms. For the transport of persons, the presence of a lift serving the two raised floors of the building is considered.

In the building in question there is a hydronic heating system (water heat transfer fluid) composed of the following subsystems: (a) Emission, radiators on external walls; (b) Control by zone (floor) and by single room; (c) Distribution, horizontal two-pipe distribution per floor; (d) Accumulation, thermal storage in the boiler room to service the boiler, (e) Generation, gas boiler in thermal power station. In the following tables the main input parameters for different performance levels.

Table 22 School Building. Configuration A of technical building system. Verification of compliance with MD requirements and indicators

	a)			**b)**		
	Performance levels			Performance levels		
	1	2	3	1	2	3
Emission efficiency	0.980	0.980	0.980	1.000	1.000	1.000
Control efficiency	0.940	0.940	0.940			
Distribution efficiency	0.980	0.980	0.980	0.926	0.926	0.926
Nominal generation efficiency (100% of the load)	0.880	0.940	0.940	0.650	0.650	0.650
Nominal generation efficiency (30% of the load)	0.850	1.000	1.000			

Notes:

- The distribution efficiency indicated in the table includes the accumulation storage losses and net of thermal recoveries of the distribution subsystem;
- The nominal thermal power of the boiler has been considered variable according to the thermal load (dependent on the climatic zone);
- The distribution efficiency was determined according to the analytical method of Appendix A of the UNI/TS 11300-2:2014;
- The generation losses are determined according to the analytical method of Appendix B.1 ("Directive method") of the UNI/TS 11300-2:2014.

In the case study they are also considered electrical distribution auxiliaries (circulation pump of the heating circuit running intermittently), electrical auxiliaries of generation (powers varying according to the power of the generator and given by the UNI/TS 11300-2:2014) and circulation pumps on the primary circuit of the generator. In the notional reference building, on the other hand, electrical auxiliaries are already included in the reference efficiencies for winter air conditioning services, summer air conditioning and DHW. Therefore, only the electricity requirements for the generation of DHW, lighting and transport are considered.

Table 23 School Building. Configuration A of technical building system. Illumination energy service

		Level		
		1	2	3
Luminous efficacy of the lamps	$lm \cdot W^{-1}$	65 (*) 85 (**)	65 (*) 85 (**)	75 (*) 90 (**)
Occupancy control systems	[-]	absent	absent	present
Lighting control systems	[-]	absent Manual	absent Manual	present Automatic

(*) Lights installed in transit areas
(**) Lights installed in normally occupied areas

Table 24 School Building. Configuration A of technical building system. Transport energy service

		Level		
		1	2	3
Type of system	-	Gearless with inverter		
Speed	m/s	1.00	1.00	1.00
Capacity	kg	480	480	480
Type of framework	-	Relè	Relè	Relè
Type of lamps	-	halogen	halogen	halogen
Switch off in the parking phases	-	yes	yes	yes

The calculation results related to the configurations of the technical building systems are exposed in the following tables.

Table 25 School Building. Configuration A of technical building system. Verification of compliance with MD requirements and indicators

		Torino				Roma				Palermo			
		Level			Limit	Level			Limit	Level			Limit
		1	2	3		1	2	3		1	2	3	
η_H	-	0.75	0.84	0.84	0.73	0.75	0.85	0.85	0.73	0.75	0.85	0.85	0.73
η_W	-	0.25	0.25	0.25	0.19	0.25	0.25	0.25	0.19	0.25	0.25	0.25	0.19
η_C	-												
$EP_{gl.tot}$	$kWh \cdot m^{-2}$	164.19	153.11	143.77	156.28	108.73	102.58	92.71	98.73	88.86	84.76	74.26	77.64
$EP_{gl.nren}$	$kWh \cdot m^{-2}$	153.22	142.14	134.62	-	97.93	91.78	83.83		78.17	74.08	65.61	
QR	%	6.70	7.20	6.40	-	9.90	10.70	9.60		12.00	12.60	11.60	
QR_{H+W+C}	%	0.40	0.50	0.50	-	0.60	0.70	0.70		0.80	0.90	0.90	
QR_W	%	19.40	19.40	19.40	-	19.40	19.40	19.40		19.40	19.40	19.40	

Analysing the results related to the first level of performance, it emerges that, although the case study is equipped with generators with efficiency lower than reference value, and despite in the case study are considered electrical auxiliaries while in the reference efficiency it is included the verifications are still respected. This, as already underlined, is again due to utilization efficiency, which in the case study are higher than the reference ones. Always in relation to the first level, the verification of the $EP_{gl,tot}$ is not satisfied mainly for the lighting service and in particular for the absence of automatic regulation systems.

In the second level we tried to compensate the deficit in terms of $EP_{gl,tot}$ of the lighting service with another service. A more efficient (condensing) generator was therefore installed for the heating service. It should be noted that it was decided to act only on the heating service because, with regard to the remaining two, the DHW has a minimum relative weight in the present case study and the transport service is invariant with respect to the limits.

The best efficiency of the heating system leads to the achievement of all the requirements in Turin, where the relative weight of the heating compared to the lighting is higher. In the hottest locations (Rome and Palermo) the generator with the best performance is not sufficient to satisfy the $EP_{\mathrm{gl,tot}}$ requirement.

By introducing, in the third level, automatic lighting control systems, all the requirements can be met in all locations. In addition, with regard to the lighting service, note that the current configuration of the notional reference building make the limit independent of the type of lamps installed: vary the lighting fixtures, that is, varying the efficiency in terms of $\mathrm{lm \cdot W^{-1}}$ and therefore consequently, the installed power in $\mathrm{W \cdot m^{-2}}$ does not in fact produce any effect on the limits of the MD.

In configuration B, the whole building is equipped with a hydronic type heating system, served by a gas cogenerator and a gas boiler both located in a thermal system not adjacent to the building. The production of DHW is carried out separately from the heating system, through electric water heaters located in the service rooms of each floor.

There is no summer cooling or conditioning system and / or mechanical air ventilation. The air exchange in the rooms is guaranteed by natural ventilation.

The lighting of the building is considered only as regards the interior lighting of the rooms. For the transport of persons, the presence of a lift serving the two raised floors of the building is considered.

In the case study there is a hydronic heating system (water heat transfer fluid) composed of the following subsystems: (a) Emission: radiators on external walls; (b) control by zone (floor) and by single room; (c) Distribution: horizontal two-pipe distribution per floor; (d) Storage: thermal storage in a heating system for the cogenerator and the boiler; (e) Generation: gas cogenerator and gas boiler in Generation, gas boiler in thermal power station. The cogenerator is regulated to work exclusively according to the energy need (thermal mode segue). Therefore, all the thermal energy produced in cogeneration is used, i.e. the dissipation of the heat produced during the normal operation of the thermal system is not foreseen. The electricity produced by the cogenerator during its operation to satisfy the thermal loads is used to cover the building's electricity energy needs (requirements of all the services). The energy input to the cogenerator is allocated to the thermal and electrical energy produced according to the allocation factors calculated according to what is defined by national legislation. The electricity produced by the cogenerator and not used to meet the building's electricity needs (exported energy) is converted into primary energy through a conversion factor calculated according to UNI/TS 11300-5 according to the weight factors of the national legislation. The cogeneration section in the building consists of a single cogeneration unit with storage, sized to operate at nominal load for most of the heating period. For the calculations the method of the "*fractional contribution*" was used as described in the UNI/TS 11300-4. In the following tables are reported the main input parameters for the different investigated performance levels.

Table 26 School Building. Configuration B of technical building system. Verification of compliance with MD requirements and indicators

	a)			**b)**		
	Performance levels			Performance levels		
	1	2	3	1	2	3
Emission efficiency	0.980	0.980	0.980	1.000	1.000	1.000
Control efficiency	0.94	0.94	0.94			
Distribution efficiency	0.98	0.98	0.98	0.926	0.926	0.893
CG. Nominal electrical efficiency of the cogenerator	0.3	0.3	0.27			
CG.Nominal thermal efficiency of the cogenerator	0.55	0.55	0.5			
GB Nominal generation efficiency (100% of the load)	0.88	0.88	0.88			
GB. Nominal generation efficiency (30% of the load)	0.85	0.85	0.85			
E.B.Nominal generation efficiency of Electric Boiler				0.750	0.750	0.750

CG: Cogenerator Generator, GB: Gas Boiler, E.B: Electric Boiler

Notes:

- The distribution efficiency indicated in the table includes the accumulation storage losses and net of thermal recoveries of the distribution subsystem;
- The thermal and electrical nominal powers of the cogenerator and the nominal thermal power of the boiler have been considered variable according to the thermal load (dependent on the climatic zone);
- The distribution efficiency was determined according to the analytical method of Appendix A of the UNI/TS 11300-2;
- The generation losses are determined according to the analytical method of Appendix B.1 ("directive" method) of the UNI/TS 11300-2.

In the case study they are also considered electrical distribution auxiliaries (circulation pump of the heating circuit running intermittently), electrical auxiliaries of generation (powers varying according to the power of the generator and given by the UNI/TS 11300-2) and circulation pumps on the primary circuit of the generator. In the notional reference building, on the other hand, electrical auxiliaries are already included in the reference efficiencies for winter air conditioning services, summer conditioning and DHW. Therefore, only the electricity requirements for the generation of DHW, lighting and transport are considered.

Table 27 School Building. Configuration B of technical building system. Illumination energy service

		Level		
		1	2	3
Luminous efficacy of the lamps	$lm \cdot W^{-1}$	65 (*) 85 (**)	65 (*) 85 (**)	65 (*) 85 (**)
Occupancy control systems	[-]	absent	present	present
Lighting control systems	[-]	absent Manual control	absent Automatic control	present Automatic control

(*) Lights installed in transit areas

(**) Lights installed in normally occupied areas

Table 28 School Building. Configuration B of technical building system. Transport energy service

		Level		
		1	2	3
Type of system	-	Gearless with inverter		
Speed	m/s	1.00	1.00	1.00
Capacity	kg	480	480	480
Type of framework	-	Relè	Relè	Relè
Type of lamps	-	halogen	halogen	halogen
Switch off in the parking phases	-	yes	yes	yes

The calculation results related to the technical building systems configurations are presented below.

Table 29 School Building. Configuration B of technical building system. Verification of compliance with MD requirements and indicators.

		Torino				Roma				Palermo			
		Level			Limit	Level			Limit	Level			Limit
		1	2	3		1	2	3		1	2	3	
η_H	-	0.90	0.90	0.84	0.85	0.92	0.92	0.86	0.86	0.92	0.92	0.86	0.86
η_W	-	0.36	0.37	0.35	0.22	0.32	0.32	0.31	0.22	0.31	0.31	0.30	0.22
η_C	-												
$EP_{gl.tot}$	$kWh \cdot m^{-2}$	134.76	125.44	133.05	139.69	92.32	81.67	86.48	89.13	78.41	66.92	70.20	71.40
$EP_{gl.nren}$	$kWh \cdot m^{-2}$	130.29	122.15	129.76	-	86.38	77.27	82.08		71.39	61.62	64.90	
QR	%	3.30	2.60	2.50	-	6.40	5.40	5.10		9.00	7.90	7.60	
QR_{H+W+C}	%	0.10	0.10	0.10	-	0.30	0.30	0.20		0.40	0.40	0.40	
QR_W	%	10.40	10.50	10.00	-	12.40	12.20	11.80		14.00	14.00	13.60	

In relation to the performance level 1 it is interesting to carry out a comparative analysis of the results for the three climatic zones. In Turin all the verification are respected, while in Rome and Palermo, with the same configuration and performance of the thermal system, although the mean global seasonal efficiencies of the heating and DHW systems are verified, the $EP_{gl,tot}$ is not verified. The reason for this is due to the incidence of the lighting service. In fact, in the situation in Turin, as heating requirements are higher, the relative incidence of lighting on the $EP_{gl,tot}$ is more contained. As a result, even if the real lighting system does not have control systems and therefore, even if the lighting energy need for the actual building is greater than the notional reference building one, the good performance of the heating and DHW systems compensate this situation and they allow to satisfy the $EP_{gl,tot}$ limit.

On the contrary, by reducing the relative weight of the heating service in relation to lighting, by virtue of the warmer climate of Rome and Palermo, the verification of the global limit is more influenced by the lighting service.

All other conditions being equal, by introducing in the lighting system a device for controlling presence and automatic devices for adjusting artificial light (compare performance levels 1 and 2 in this regard), the requirement on $EP_{\mathrm{gl,tot}}$ is satisfied. In the present case study, the introduction of the above systems leads to a reduction of the $EP_{\mathrm{gl,tot}}$ of about 9 ÷11 $\mathrm{kWh \cdot m^{-2}}$ depending on the climatic zones (the percentage benefit is higher in Palermo than Turin since in the first case there is a greater and better exploitation of natural light through automatic control systems).

Regarding the QR, considering the DHW service only, it is higher than the average of all services. This is motivated by the fact that DHW is obtained via electricity from the grid and this energy carrier has a share of renewable energy (around 19%). In this case study, however, the presence of the gas cogenerator (non-renewable fuel) reduces the QR because part of the electricity from the network is replaced by that self-produced by the cogenerator (non-renewable).

Nevertheless, the use of a cogenerator is highly deterred by Italian regulation. But from an energy conservation point of view the heating produced while producing electricity serves a utility, while the heat produced by the not renewable part of electricity from the network is wasted, so in a global balance the gas cogenerator system could result less pollutant.

Between the performance level 2 and 3 there is a decrease in the performance of the cogenerator, in particular as regards the nominal thermal efficiency, although the limit on $EP_{\mathrm{gl,tot}}$ has not been verified the satisfaction of the requirement for the mean global seasonal efficiencies of the heating system does not occur.

It should therefore be noted that, in general, for the purposes of verification, the thermal efficiency with respect to the electrical efficiency is more relevant, especially as regards seasonal mean global average efficiencies.

Regarding the mean global seasonal efficiency of the DHW system, note that rather low values are due to the fact that the denominator is the total primary energy and that in this case the energy vector used is the electric energy from the network ($f_{\mathrm{p,tot}} = 2.42$) in addition to the electric energy self-produced by the cogenerator, which however flows mainly on the lighting service, as the electricity energy needs are considerably higher than those for DHW.

1.5.6.3 Office Building

In this configuration, the whole office building is equipped with a heating and cooling conditioning system. To guarantee these services there is a mixed technical building system (fan coils and primary air). The primary air also assumes the function of ventilation, both in the periods of activation of the conditioning, and in periods of non-activation. The air-water heat pump refrigeration unit, the heat generator consisting of a back-up gas boiler and the air handling unit are situated on the roof of the building (flat roof).

The hydronic circuit that supplies the fan coils is a two-pipe system. The rings of the pipes run along the perimeters of the two floors of the building.

The primary air is distributed at constant flow through vents located in all the rooms where there is continuous presence of people. No air-recirculation is performed.

The extraction of air takes place through a special network, from the disengagements and from the toilets in the buildings, placed in depression. There is a heat recovery unit from the extract air. The production of DHW is carried out separately from the AC system, through electric water heaters located in the toilets of each floor. The lighting of the building is considered only as regards the interior lighting of the locals. For the transport of persons, the presence of a lift serving the four raised floors of the building is considered.

In the following tables the main input parameters for different performance levels.

Table 30 Office Building. Configuration A of technical building system. Verification of compliance with MD requirements and indicators

	a)			**b)**		
	Performance levels			Performance levels		
	1	2	3	1	2	3
Emission efficiency	0.960	0.960	0.960	1.000	1.000	1.000
Control efficiency	0.97	0.97	0.97	-	-	-
Distribution efficiency	0.95	0.95	0.95	0.926	0.926	0.893
H.P. COP nominal heat pump +7 °C / +35 °C	4.18	3.3	3.3			
GB. Nominal generation efficiency (100% of the load)	0.92	0.92	0.92			
GB. Nominal generation efficiency (30% of the load)	0.98	0.98	0.98			
Nominal efficiency of the heat recovery unit	0.50	0.50	0.00			
E.B.Nominal generation efficiency of Electric Boiler				0.750	0.750	0.750

GB: Gas Boiler, E.B: Electric Boiler, H.P. Heat Pump

Notes:

- The nominal powers of the generators (boiler and heat pump) have been considered variable according to the thermal load (dependent on the climatic zone).
- The distribution efficiency was determined according to the analytical method of Appendix A of the UNI/TS 11300-2:2014.
- The nominal COP of the heat pump is variable depending on the different temperatures of the cold source and the hot well. In the table above, for the sake of brevity, the only COP reported is referred at temperatures -7 / + 35 ° C. However, the calculation was carried out according to analytical methodology (UNI/TS 11300-4) using as the temperature bins and sixteen COP points (pairs of cold source temperature / hot well).
- The generation losses were determined according to the analytical method of Appendix A of the UNI/TS 11300-2.

In the case study they are also considered electrical distribution auxiliaries (circulation pump of the heating circuit running intermittently), electrical auxiliaries of generation (powers varying according to the power of the generator and given by the UNI/TS 11300-2) and circulation pumps on the primary circuit of the generator. In the notional reference building, on the other hand, electrical auxiliaries are already included in the reference efficiencies for heating service, cooling service, and domestic hot water service. Therefore, only the electricity requirements for the generation of DHW, lighting and transport are considered.

Table 31 Office Building. Configuration A of technical building system. Verification of compliance with MD requirements and indicators. Cooling system

	a)		
	Performance levels		
	1	2	3
Emission efficiency	0,98	0,98	0,98
Control efficiency	0,97	0,97	0,97
Distribution efficiency (hydronic circuit)	0,94	0,94	0,94
Nominal ERR heat pump (100% of the load)	2.56	2.2	2.2
Nominal ERR heat pump (50% of the load)	3.2	2.88	2.88

Notes:

- The distribution efficiency shown in the table above refers to the hydronic circuit. The losses were considered to be recovered at 95%, as the pipes were current inside the air-conditioned housing.
- As far as the thermal and mass losses of the aeraulic circuit are concerned, as current pipelines are present entirely inside the air-conditioned rooms (inspectable false ceilings), they have been considered entirely recovered.

Table 32 Office Building. Configuration A of technical building system. Illumination energy service

		Level		
		1	2	3
Luminous efficacy of the lamps	$lm \cdot W^{-1}$	60 (*) 90 (**)	60 (*) 90 (**)	60 (*) 90 (**)
Occupancy control systems	[-]	absent	absent	absent
Lighting control systems	[-]	present Automatic	present Automatic	present Automatic

(*) Lights installed in transit areas

(**) Lights installed in normally occupied areas

Table 33 Office Building. Configuration A of technical building system. Transport energy service

		Level		
		1	2	3
Type of system	-	Gearless with inverter		
Speed	$m \cdot s^{-1}$	0.63	0.63	0.63
Capacity	kg	480	480	480
Type of framework	-	Relè	Relè	Relè
Type of lamps	-	Led	Led	Led
Switch off in the parking phases	-	yes	yes	yes

The calculation results related to the technical building systems configurations are presented below.

Table 34 Office Building. Configuration A of technical building system. Verification of compliance with MD requirements and indicators.

		Torino				Roma				Palermo			
		Level			Limit	Level			Limit	Level			Limit
		1	2	3		1	2	3		1	2	3	
η_H	-	1,35	1,25	0,82	0,57	1,58	1,47	0,92	0,57	1,36	1,27	0,84	0,58
η_W	-	0,29	0,29	0,29	0,22	0,29	0,29	0,29	0,22	0,29	0,29	0,29	0,22
η_C	-	0,52	0,47	0,47	0,52	0,54	0,49	0,49	0,51	0,45	0,41	0,41	0,40
$EP_{gl,tot}$	$kWh \cdot m^{-2}$	178,57	187,29	216,16	275,43	161,88	169,59	183,88	227,55	167,44	175,94	184,59	216,76
$EP_{gl,nren}$	$kWh \cdot m^{-2}$	127,20	136,60	152,24	-	122,39	129,55	136,74		129,59	136,82	141,59	
QR	%	28,8%	27,1%	29,6%	-	24,4%	23,6%	25,6%		22,6%	22,1%	23,3%	
QR_{H+W+C}	%	35,2%	31,9%	34,7%	-	28,5%	26,8%	29,7%		25,1%	24,0%	25,8%	
QR_W	%	19,4%	19,4%	19,4%	-	19,4%	19,4%	19,4%		19,4%	19,4%	19,4%	

With regard to the performance level 1, it can be seen that in all three locations selected, system configurations meet the requirements in terms of $EP_{gl,tot}$. Clearly, the energy services considered have a different relative weight depending on the location, so, moving from Turin to Palermo, the cooling service compared to heating service has an increasing weight.

The satisfaction of the heating requirements is also due to the good performance of the heat pump (in Turin COP average seasonal average = 2.94 and seasonal average effective EER of 3.32) and since that the real efficiency of the utilization subsystems is higher than the reference one. This in particular because pipes and pipes pass in conditioned rooms and, therefore, most of the thermal losses are recovered.

The share of renewable energy tends to decrease, moving from Turin to Palermo; this is due to the presence of the heat pump and to the increase in the weight of cooling service (the ambient energy is in fact considered renewable only if extracted for heating and not in cooling mode).

By lowering the performance level of the generators (configuration 2), the limits on cooling efficiency are no longer verified in Turin and Rome, while for Palermo it remains verified with very little margin. The verification on the heating efficiency remain instead satisfied for all the locations, also in virtue of the presence of the heat recovery system and thanks to the utilization subsystems.

It should be noted that the actual heating efficiency in the first two system levels is greater than the unit. This fact, which at first sight may seem strange, is instead due to the presence of heat recovery system which, for the same flow rates and useful thermal requirement ideally, it reduces the primary energy for heating considerably compared to a system without heat recovery or with natural ventilation. It is therefore proven that by removing the heat recovery unit, the heating efficiency is lower than 1 (technical building system level 3). Even in the absence of a recovery unit, however, efficiency requirements are verified. The presence of a recovery unit is therefore not strictly necessary for the fulfilment of the requirements.

With regard to the performance of the utilization subsystems (emission, regulation, distribution and possible accumulation) it is possible to conclude that the reference efficiency, both for hydronic systems and for aeraulic or mixed ones, is in some cases underestimated.

The real efficiency, considering good design practices (e.g. good thermal insulation of the piping and passage of the latter inside the insulated building envelope) is generally higher than the reference one. This also considering the presence of electrical auxiliaries. This is particularly true for residential and non-residential buildings that are not too complex, especially those with only hydronic distribution. In fact, it has been verified how, using the analytical calculation methodologies referred to by the MD, as far as the hydronic network is concerned, the losses of the pipes (however minimal considered a good thermal insulation and low temperatures of the heat transfer fluid) are compensated by the recovery from the electrical auxiliaries. Even the losses of the aeraulic pipelines, if they run in air-conditioned environments, are fully recovered.

This, together with the fact that the emission and regulation efficiency settle in any case on values higher than 0.95, thus allows the real building to have a certain margin with respect to the notional reference one.

In light of the foregoing, an improved proposal, with a view to revising the requirements of the MD, could be to increase the reference utilization efficiency, possibly by differentiating the utilization efficiency between residential and non-residential to avoid penalizing and making checks too severe.

As for the reference generation efficiencies, it is considered that they are well calibrated. It should be noted that, while on the one hand, the nominal efficiency of most of the best generation systems are higher than the reference efficiency, their actual efficiency may also be of several lower points. This aspect is linked to the decrease in performance, calculated with the reference technical legislation and partial load factors (even very low in the milder periods). Therefore, it is considered correct to maintain slightly precautionary reference efficiencies.

With regard to the RES obligations, Legislative Decree 28/2011 establishes, in the case of new buildings or those subject to refurbishment, the minimum coverage for heating, cooling and DHW services as well as an electric power from renewables that must be installed.

Regarding the share from renewables, for the sum of heating, cooling and DHW a 50% quota is required. For DHW, a 50% share is always required.

From several studies and simulations carried out, it was evident that these requirements preclude the use of certain technologies, leaving the designer with few technological alternatives. In particular, the following scenarios emerged, summarized below:

- For residential buildings in Northern Italy where the heating service is preponderant, the choice must be directed towards heat pumps (better if electric) or biomass combustion. The presence of only solar thermal for the production of DHW often does not guarantee the achievement of the requirements. In the presence of cooling service, the use of photovoltaics becomes fundamental. Technologies using gas combustion are automatically excluded.
- For non-residential buildings in Northern Italy the same considerations apply as for non-residential, with greater criticality regarding cooling, for

which a massive presence of photovoltaic is required, and with regard to DHW in certain uses (for e.g. hotels).

- For the residential and non-residential buildings in Southern Italy the weight of cooling is accentuated, so the installation of photovoltaic is fundamental. For DHW the possible alternatives are heat pumps and / or solar thermal.

From the scenarios described above, it emerges that the critical issues arise in those cases where, due to the limited availability of the roof surface, the presence of shading or other technical constraints, it is not possible to ensure sufficient energy production from photovoltaic and solar thermal. In such cases, and especially in situations where cooling service is predominant, even the use of a heat pump does not ensure the fulfilment of the requirements.

In general, therefore, considering the whole framework, the combinations that come out winning are, in the presence of the cooling energy need, heat pump + photovoltaic; in the presence of heating only and DHW also biomasses in the North and solar thermal in the South. This for residential buildings.

For the tertiary sector the same combinations are valid, with possible additional criticalities related to the greater intrinsic needs for certain uses.

1.5.7 Conclusions

The present research has been focused on four case studies referring to the most common building typologies in Italy and it has been investigated with reference to different design and technological features (both for building and for the technical building systems). The analysis shown the need for more investigations on the study of the correct application of the MD.

The application of the different case studies shown that in order to obtain a NZEB there is not a single project combination but in general there is a field of existence that satisfies all the legislative energy requirements set by the MD.

The less experience in the field of summer cooling and related requirements, leads to suggest the need for further study on the theme of summer conditioning with the aim of assessing the actual buildings behaviour when this service is most used.

Some issues concerning the notional reference building approach have been pointed out. The following suggestions are provided to overcome the limitations of the approach:

- the thermal bridge effect should be evaluated separately from the building envelope component *U*-value;
- the actual technical building system auxiliaries should be attributed to the notional reference building, so as to easily calculate the electricity demand by energy service;
- the thermal systems characteristics (except for the thermal system efficiency) of the notional reference building are assumed the same of the design building;

– the mean global seasonal efficiency of a technical building system is expressed as the ratio of the energy need, calculated in reference conditions, to the total primary energy, as to represent the actual system.

This research allowed me to publish various researches and technical articles. Below some references are reported.

- V. Corrado, I. Ballarini, D. Dirutigliano, and G. Murano. Verification of the new Ministerial Decree about minimum requirements for the energy performance of buildings, presented to the 71st Conference of the Italian Thermal Machines Engineering Association, ATI 2016, 14-16 September 2016, Turin, Italy, Energy Procedia 101C (2016)
- V. Corrado, G. Murano, S. Paduos, and G. Riva. On the refurbishment of the public building stock toward the nearly zero-energy target: two Italian case studies, presented to the 71st Conference of the Italian Thermal Machines Engineering Association, ATI 2016, 14-16 September 2016, Turin, Italy, Energy Procedia 101C (2016)
- G. Murano, R. Nidasio, A. Panvini, and L. Terrinoni. The critical points in the design and implementation of refurbishment interventions of nearly zero-energy buildings (NZEBs): practical, regulatory and legislative implications. Evolution of optimal energy requirements of NZEBs, ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), Ministry of Economic Development, 2016, In Report RdS/2016/127 (*In Italian*), [253]
- G. Murano, R. Nidasio, A. Panvini, and L. Terrinoni. Study on the technical parameters of the notional reference building and minimum energy requirements of lighting energy systems, elevators and escalators. ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), Ministry of Economic Development, 2016, In Report RdS/2016/128 (*In Italian*), [254]
- G. Murano, R. Nidasio, A. Panvini, and L. Terrinoni. Evolution of optimal energy requirements of NZEBs: study of the parameters of the notional reference building: thermal transmittance, thermal bridges and H'_T requirement on the existing buildings, ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), 2017 (*In Italian*), [255]
- V. Corrado, G. Murano, S. Paduos, and G. Riva. The transformation of public buildings into NZEB (Nearly Zero-Energy Building), LA TERMOTECNICA, 2017, pages 46 - 51 ISSN: 0040-3725 *(In Italian)*

1.6 Notional Reference Building Approach

The building energy performance requirements in the regulations are usually expressed by means of fixed value or a variable value defined through a formula or the notional reference building approach (NRBA). The aim of this research is to enhance the application of the NRBA in the energy performance legislation. To this purpose, a detailed dynamic simulation is performed on an Italian residential NZEB located in two different climatic zones. Guidelines concerning the choice both of the reference parameters and of the neutralising parameters, and the level of detail in the description of the notional reference building are provided.

The Directive 2010/31/EU establishes that Member States define minimum EP requirements for building elements that have a significant impact on the energy performance with a view to achieving cost-optimal levels (European Union, 2010) [1]. The EPBD does not impose a specific way to express the energy performance. EPBD mentions in article 3: "*the energy performance of a building shall be expressed in a transparent manner and may include a* CO_2 *emission indicator*".

Nearly all countries have adopted a methodology that sets performance-based requirements of whole building (holistic-based approach) whereby single element requirements in many cases were tightened. In some cases, the single element requirements are just supplementary demands to the energy performance requirements ensuring the performance of individual building components are sufficient (e.g. Denmark). In others, the requirements act as alternative methods where the two approaches exist in parallel (e.g. Spain, Poland); the first based on the performance of single elements and the second on the overall energy performance of a building. In Switzerland, the holistic approach is used for new buildings (or sometimes in cases of deep renovation) while the single element approach is used for shallow or deep renovations. The authorization to install summer air conditioning is subordinated to showing that the envelope design allows to minimize energy needs for cooling (S. Attia et al., 2017) [17]. In countries where the performance-based approach of elements is the main form of requirement, the prescriptive criteria are already integral parts of the methodology. Additional elements such as RES, summer comfort, indoor climate complete the requirement framework and are embedded in the methodology (B. Atanasiu et al., 2014) [18]. A scheme is shown below. Regarding the holistic-based approach, the EU countries in their regulations gradually abandoned the fixed limit approach (Concerted Action EPBD, 2016) [19] in favor the notional reference buildings (NRB), this approach is in fact more flexible.

In the NRB the choice of the reference parameters varies from one country to another; for instance, a reference thermal transmittance is common to all countries, while just some States use the envelope air tightness as reference parameter (e.g. Germany and England) and only some impose specific technologies for the technical building systems (e.g. Greece).

The threshold values of the parameters can be different and can vary in function of the climatic zone, the building category, etc. For example, the reference *U*-values of the Italian and Greek notional reference buildings are provided in function of the climatic zone, while in Germany and in England the *U*-values differ in function of the envelope component types (e.g. cavity wall vs solid wall, vertical window vs skylight).

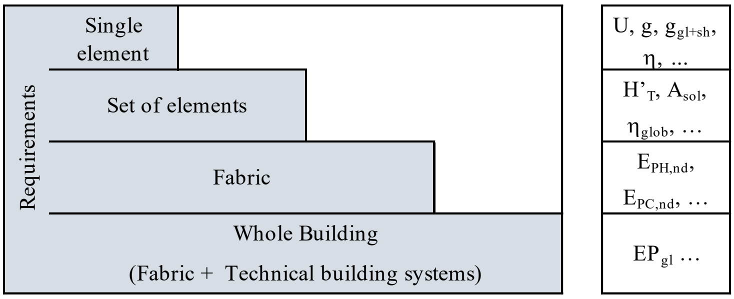


Figure 1 Possible verification approach of building energy requirement

In the EU, the reference parameter values have been identified by each Member State through the cost-optimality comparative methodology framework (European Union, 2010 [64],[241]).

Table 35 Type of assessment of the building energy requirement, indicator of energy performance, and calculation method of building energy performance

		AT	BE	BG	CY	HR	DK	EE	FI	FR	DE	EL	UK	IE	IT	LV	LT	LU	MT	NL	PL	PT	CZ	RO	SK	SI	ES	SE	HU
Type of assessment of Requirement	FA		●	●		●	●									●	●		●	●							●		
	FV	●							●	●															●	●			
	NRB		●		●			●			●	●	●	●	●			●			●	●	●	●				●	●
Indicators of performance	EP	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●		●		●	●			●
	OH		●				●	●		●																			
	CO_2	●											●	●				●						●			●		
	TS						●			●			●										●						
Calculation method	SS	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	DD						●	●		●																			

FV: Fixed value, FA: Formula approach, NRB: Notional Reference Building

EP:Envelope performance, OH: Overheating indicator, CO_2:Carbon emissions, TS:Performance of technical building systems

SS: Quasi-steady-state, DD: Detailed Dynamic

As regards technical standards, ANSI/ASHRAE/IES Standard 90.1 [21] provides minimum energy efficient requirements for design and construction, and a plan for operation and maintenance of new buildings or portions of buildings and their systems, new systems and equipment in existing buildings. The standard also provides criteria for determining compliance with these requirements by using a notional reference building, the so-called baseline building. The baseline building approach is used for calculating the baseline building performance for rating above-standard design. The design building performance and the baseline building performance shall be calculated using the same simulation program, weather data, energy price, building model, space use and schedules. The baseline building differs from the design/actual building for the *U*-value of the envelope components, the amount of glazing and its thermal properties, the type of lighting control, the HVAC system requirements.

In recent years it has increased the focus on the energy performance of buildings. The requirements of the buildings to catch this goal are described and fixed in the standards and in the national regulations. The fixed values take in account the state of the actual technology and the evolution of itself.

In Europe the EPBD, European Union (2010) [1], promoted a common framework of evaluation of the building energy performance and to support the design of buildings calling “NZEBs" (nearly Zero Energy Buildings). These latter are the buildings that use renewable energy sources in a significant proportion.

The Member States of Europe developed their national legislation based on EPBD but similar laws are been promulgated also in the rest of the world, as Ionescu et al.(2015) show [20].

The building code requirements can be based on the respect of an absolute value, generally expressed in kWh/m^2 or CO_2 emissions, or on a percentage improvement requirement based on a notional reference building. Some countries (e.g. Belgium) express the EP requirement as having to meet a defined “E value” on a 0 to 100 scale, or on an A+ to G scale (e.g. Italy and Cyprus). The different prescriptive can be based on element related to requirements associated with building energy codes such as max *U*-values, max indoor air temperatures, minimum ventilation rates and boiler and/or air conditioning building thermal system efficiency.

Table 36 Approaches used by member states in the energy verification of regulation requirements of the buildings

Country	Further requirements to be checked								Notional Reference Building											Legislative Reference
	U	H'_T	WWR	SF	n_{50}/V	EC	ψ	TBS	U	g	SH	WWR	ψ	AI	HR	R	G	HW	D	
AT	●																			OIB Guideline 6
BE	●				●				●	●	●	●	●	●	●	●	●	●	●	Executive Order of 22 June 2012
BG																				Ordinance No. 7 for energy efficiency
CY	●			●		●			●	●	●	●	●	●	●	●	●	●	●	Κ.Δ.Π. 432/2013
HR	●																			OG 97/2014, 130/2014, 128/15
DK	●			●		●	●													BR2010
EE	●							●	●	●	●	●	●	●	●	●	●	●	●	Building Act
FI	●				●		●	●												National Building Code
FR	●				●															RT 2012
DE		●			●			●												EnEV 2015
EL	●	●				●	●	●	●						●		●		●	KENAK
UK						●			●	●	●	●	●	●	●	●	●	●	●	L1A, L2A, L2B
IE	●						●	●	●	●	●		●	●	●	●	●	●	●	Building Regulations Part L
IT		●		●				●	●	●	●			●	●	●	●	●	●	MD 26/06/2015
LV	●	●																		LBN 002-15
LT						●														Law on Construction, Law on Energy
LU	●	●		●	●		●		●	●	●	●		●	●	●	●	●	●	RGD 2010
MT	●			●				●												EPB Regulations LN 376
NL	●																			-
PL	●		●	●	●			●												-
PT								●	●	●	●	●	●	●	●	●	●	●	●	DL 118/2013
CZ						●			●	●	●	●	●		●	●	●	●	●	Decree 78/2013
RO	●	●		●				●	●	●	●	●	●	●	●	●	●	●	●	Building regulation
SK	●	●		●				●												-
SI	●	●		●				●												PURES 2010
ES																				Decree 235/2013
SE		●																		BFS 2011:6
HU	●	●				●		●												Decree 40/2012

Legend:

U=U-value, H'_T= Max allowable value of the mean overall heat transfer coefficient by thermal transmission, WWR=Window-to-Wall Ratio, SF= maximum Solar factor, n_{50}/V=Air exchange rate, EC=Energy class, ψ=thermal bridges, TBS= Technical Building Systems, g=g-value, SH=solar Shading, AI= Air infiltration, HR= Heat Recovery, R= Regulation (minimum efficiency for regulation), G= Generation (minimum efficiency for heating generators), HW=Domestic Hot water, D= Distribution (efficiency or minimum levels of insulation of the heating and cooling distribution networks).

In Denmark the law Building Regulations 2010 (BR2010) [22] indicates the minimum requirements of the energy performance. They are defined depending on the intended use and in function of the building surface. There are three levels of minimum energy performance requirements expressed in primary energy. The two highest are voluntary "*Low-energy Class 2015*" and "Building Class 2020". Buildings design with the two voluntary classes must prove that they have a good thermal indoor climate during hot periods through monthly quasi-stationary calculation or via a dynamic simulation tool.

In German, according to the EnEV 2013 (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2013) [145], the notional reference building is characterised by technical features (air tightness, *U*-value of envelope components, total solar energy transmittance of glazing, characteristics of the shading device, thermal bridges effect, solar absorption coefficient of the external opaque surface, building automation, reference technical systems). The maximum primary energy demand of the building in question may not exceed the primary energy demand of the notional reference building. Beyond this limitation, there are a requirement which limits the average specific heat transmission coefficient to ensure a proper thermal quality; several additional requirements for technical buildings systems (heating, DHW, ventilation, air-conditioning) and a requirement for summer comfort provisions to avoid energy use for cooling of buildings. In the non-residential buildings lighting is an additional aspect to verify. Furthermore, the description of the reference notional building is quite extensive for buildings equipped with sophisticated ventilation and air-conditioning systems.

The Greek Law 3661/2008 "*Measures to reduce energy consumption in buildings and other provisions*" integrates the Directive 2002/91/EC. Based on this law, in 2010 the Regulation for Energy Efficiency of Buildings (KENAK) [146] was issued. According to the KENAK, each new or fully renovated building should achieve an Energy Performance level of at least "Category B". The Regulation defines the minimum requirements of the new or fully renovated buildings. The KENAK provide the following parameters for the NRB: maximum *U*-value for walls, windows, roofs etc., at least 50% heat recovery in the central air-conditioning units, minimum levels of insulation of heating and cooling distribution networks, at least 60% DHW production from solar panels, minimum requirements for lighting and minimum efficiency for heating generators. Additionally, this regulation divides the country in 4 different climate zones (A, B, C, D), based on heating degree days (HDD). For new buildings, upon completion of the construction, the quality Assurance (QA) and compliance checking is performed.

Therefore, the KENAK use the general calculation approach in accordance to EN ISO 13790 (method of semi-steady state of the monthly step), the use of a NRB is used for benchmarking and building energy labelling [156].

For the calculations of EP and energy classification of buildings, which are part of the Energy Efficiency Study, the KENAK TEE software is used to be evaluated by the Special Energy Inspectors Service (EYEPEN) of the Ministry of the Environment, Energy and Climate Change (YPEKA).

In Czech Republic the reference notional building as stated in Decree 78/2013 [155] is used to evaluate the EP of an existing or a planned building and for their classification. The reference parameters of notional reference building are relating to building construction and Heating Ventilation and AC systems (HVAC), lighting and hot water supply. It is also used for the design of a Nearly Zero-Energy Building as defined in the Energy Management Act 406/2000. For the definition of NZEB are considered the following energy indicators: average *U*-value of the building envelope; delivered energy (without taking into account on-site renewables); non-renewable primary energy. Thermal bridges are not analysed to a great extent in the national regulations for new buildings, and even less so for the renovation of existing buildings.

Across the reference notional building the Decree 78/2013 [155] gradually decreases the minimum requirement for EP indicator (non-renewable primary energy).

In Romania, the notional reference building is used only for the existing buildings, the actual building characteristics are compared with a reference building having the same shape and the U-values max. For new buildings is adopted another approach, the requirements depend on building type and on the envelope of the building. The regulation indicates the thermal requirements for the minimum thermal resistance corrected with thermal bridges; the maximum thermal transmittance corrected with thermal bridges and the maximum overall thermal coefficients [2].

In Cyprus, the minimum building's EP requirements are defined by ministerial order of 2013 (Κ.Δ.Π. 432/2013) [158]. The EP calculation is based on the comparison of the real building with a notional reference building. The minimum requirement (EPC in a B category) is achieved only if the building needs the same or less primary energy than the notional reference building. The definition of NZEB for residential and non-residential buildings is prescribed by ministerial order of 2014 (Κ.Δ.Π. 366/2014) laying down punctual technical requirements as, for example, the maximum primary energy consumption for residential and non-residential buildings, the maximum *U*-value of walls, roof, floors, windows, the maximum average power lighting installed in the office buildings and at least 25% of primary energy consumption covered by RES [17].

In Belgium, type and level of requirements for new buildings are different for type of the building, it includes the following checks: (a) max primary energy demand per square meter of conditioned floor area, (b) max primary energy consumption of the building compared to the primary energy demand of NRB (different from the NRB in the Flemish Region), (c) max index that depends on the average *U*-value and the compactness of building [17].

In Luxembourg, the EP calculation of new and existing residential buildings is based on energy needs (heating, DHW, ventilation and auxiliary needs). The results are expressed in terms of levels of primary energy needs, heating energy demand and CO2 emissions. For non-residential buildings, in addition there are the energy needs for air- conditioning (AC), lighting, humidification and dehumidification. The results are expressed as ratio to a notional reference building (defined in the annex of the RGD 2010) where there are 26 different types of technical equipment and envelope characteristics [17].

In Portugal the EP calculation methodologies are based on using a notional reference building for comparison, and include the following parameters related to thermal behaviour, energy and indoor air quality (U-value of envelope included the thermal bridge, solar factor and shading device of windows, ventilation, indoor air quality, infiltration), systems efficiency (minimum efficiency for heating, ventilation and AC systems and lighting systems – only for non-residential) with, in addition, a threshold of maximum energy need and primary energy consumption. For the non-residential buildings the requirements also include the minimum outdoor air supply, indoor air quality and infiltrations [17].

In China a standard for public buildings was developed in 2005 with the aim to reduce annual energy consumptions by 50% relevant to a typical 1980 building. For calculating the energy performance is used the notional building approach calling "custom budget" which is similar to that used in USA and indicated in ASHRAE 90.1. However, in several other Asian countries is adopted the "fixed budget" approach.

The same custom budget approach is used for not-public building and the mandatory requirements are specified for the main climate zones, with provisions outlined for thermal envelope components and energy efficiency requirements for heating, cooling, hot water and plumbing systems.

In England and Wales, EP requirements, are set out in National Calculation Methodology (NCM) modelling guide (for buildings other than dwellings in England and Wales). The Building Regulations sets requirements for the conservation of fuel and power [51]. The Regulations require that the EP of new buildings, based on annual carbon dioxide emissions, must not exceed the Target CO2 Emission Rate (Target Emission Rate - TER), which is determined by means of the notional building. This building has the same size and shape as the actual building but with specified properties, such as thermal transmittance and thermal capacity of envelope components, air permeability of enclosures, parameters for lighting, technical system efficiencies, etc. (HM Government, 2014a, b).

In Ireland the EP requirement, definite by the Building Regulations (TGD Part L Amendment 2017), are based on the primary energy consumption and on CO_2 emissions of the building being assessed with regard to a notional reference building. Both parameters must be lower at the defined thresholds by regulation. In the Appendix C are given the performance specification for each parameter (U-value of each envelope component, linear *U*-value for each thermal Bridge, for the transparent envelope *g*-Value and Light Transmittance, air Permeability, lighting luminaire, occupancy control, daylight control, heating efficiency, cooling efficiency, etc… The reference notional building uses a “mixed mode” servicing strategy (heating and mechanical ventilation) and its performance would correspond to a BER (Building Energy Rating) of C3.

Kurnitski et al. (2018) [184] have compared the national NZEB requirements of Estonian, Finnish, Swedish, and Norwegian regulations through a reference building and a common calculation method (prEN 16798-1 [224] input data and the EN ISO 52000-1:2017 [232] conversion factors in primary energy). The objective of the study was to compare NZEB characteristics implemented in the notional reference building and their energy performance respect to the reference of EC EU Recommendations no1318 (2016) [15]. The results have shown that the building with gas boiler is very close to EC recommendation values, and the building with district heating system slightly exceeds the limit. Comparing the NZEB energy performance of countries to the corresponding EC recommendation values, the national requirement was fulfilled in all cases with the exception of the Estonian case where the regulation is more strictest where the simulations have revealed that national input data and primary energy factor normalized NZEB requirements complied with EC recommendation only in Estonia. Then, the building energy simulations have revealed that national input data and primary energy factor normalized NZEB requirements complied with EC recommendation only in Estonia. In the case of district heating, the primary energy use was higher by a factor of 1.4, 1.6, and 1.7 in Norway, in Finland, and in Sweden, respectively.

In Italy, the minimum requirements are defined by the Inter-Ministerial Decree (MD) 26/06/2015 (Italian Ministry of Economic Development, 2015) [143]. The minimum requirements for existing buildings are differentiated according to the degree of renovation. The MD defines the reference parameters for the notional reference building, also named reference building or target building. For each parameter it is characterised by reference values: thermal transmittance of the envelope components, total solar energy transmittance of windows in presence of shading device, efficiency of the heat utilization and heat generation subsystems of the space heating, space cooling and DHW systems, and features of lighting and ventilation systems.

1.6.1 Objective of the Research

Even if the NRB approach seem to be more flexible than the formula approach, some questions arise in the moment of the generation of the notional reference building starting from the model information available in the actual building. Until now the NRB approach has been mainly used in the quasi-steady-state calculation method. As seen in the Table 36, each member state has chosen different reference parameters of notional reference building. In the transition to using the approach with dynamic method there is the question of defining the detail level used for the model description. This issues are addressed in the Section "*Theory and method"*. The present research activity aims improving the application of the NRB approach in the context of Energy Performance of Buildings Regulations. A first analysis was conducted through the application of the standard *quasi-steady-state* calculation method, underlining the restrictions of the NRB approach in the Italian regulation.

In this deepening, the investigation of the NRB is combined with a dynamic simulation carried out using the software EnergyPlus. The case studies are reference residential NZEBs located in Milano and Palermo. A sensitivity analysis of some parameters concerning both the thermal building envelope and the technical building systems, is carried out.

The objective of work is verifying to which extent these parameters, which are specified as reference features of the NRB influence the building energy performance and can be really constitute a reference. Furthermore, the building features can be described with different levels of detail and complexity leading to more comprehensive analyses and better decision support during design and construction. The final purpose of the research is to verify if the reference parameters implemented in the current regulation provide adequate information to correctly calculate the *EP* index of the NRB even when a detailed simulation analysis is performed. The deviancy in the outcomes are indicated and recommendations to give robustness to the NRB approach are specified.

1.6.2 Theory and Method

1.6.2.1 Notional Reference Building Definition

The NRB approach is used to verify the EP requirements of a generic building, either under design or subject to refurbishment. In this approach, the calculated energy needs of the building are compared with the estimated energy needs of a theoretical building, commonly called NRB or *baseline building*. The NRB is also a method approach for evaluating energy saving measures.

The NRB is a version of the *actual building* adapted to conform to a clearly defined set of standards and features relating to glazing area, constructions and system characteristics. The purpose of NRB is to provide a benchmark or target against which to measure the EP of the actual building.

The *actual building* is the building model as designed or realized, but subject to standard patterns of the occupancy and technical building systems operation.

A Detailed definition of NRB and actual building is provided in the following document [225]. The NRB has some features of the *actual building* and other features characterized by predetermined parameters (reference values). The NRB is derived automatically from the *actual building*. If the estimated energy needs of the *actual building* are not higher than the estimated energy needs of the NRB, the building requirements are met. According to [225] the NRB is a variation of the *actual building* modified in accordance with rules relating to glazing area, thermal insulation, system efficiency and other factors.

With the use of the NRB, the influences of some factors on the EP calculation are reduced or neutralized. The building parameters that are replaced by *reference values* are excluded from the energy requirements, so their effects on the building EP are neutralized. These parameters can be identified as *neutralizing parameters.*

1.6.2.2 Neutralizing Parameters

In the NRBA, energy affecting parameters such as the size and shape of the building are neutralized by comparing the calculated energy need for the given building or building design with the calculated energy need for the same building or building design in which these parameters are not replaced by reference values, but kept as the actual values. The neutralization is aimed at, either: (a) *annulling the effect of the boundary conditions, as the driving forces of the building thermal behavior (i.e. environmental factors), or* (b) *promoting or penalizing specific design choices (i.e. technical features).*

Van Dijk and Spiekman (2004) [226] have grouped the parameters into two categories:

a) parameters can be **neutralized intentionally** where *the reasons of neutralization are political or practical. An example of political reason is the neutralization of the building size:* if the size parameter is not neutralized, the construction of smaller size buildings might be stimulated. *Other reasons for intentional neutralization are either the small influence of certain parameters on the building EP or too complex effects to be taken into account (e.g. the effects of various control systems).*
b) parameters can be **neutralized unconsciously**. This category includes cases in which the energy implications are not known or not aware of energy implication.

The environmental factors include weather/climate data *and building use data (e.g. indoor air temperature, ventilation rate, occupancy profile). The technical features of the building include, for instance, the building type (*e.g. building size and shape, window orientation*) and the energy carrier.*

The modification of the impact of certain parameters is necessary to avoid excessive imbalances between the technologies used and consequent market disturbances. The technological level is adapted to climate, type of use, etc. as to achieve the technical and economic optimization of the building. More details are available in Table 37.

1.6.2.3 Reference Parameters

A complex issue is the choice of the reference parameters of the notional reference building. To this purpose, three main steps are suggested.

1) *Firstly, it should be investigated which building features have a significant impact on the building EP. A sensitivity analysis should be carried out to detect the most important parameters, whose number generally depends on*

the complexity of the technological systems adopted in the building and is higher for responsive envelopes and advanced technical systems.

2) *Then, it should be chosen the calculation method of the building energy performance to be applied both to the actual building and to the notional reference one.*
3) *Finally, it is necessary to define the level of detail to describe the features of the building. For instance, the wall properties can be simply described through a lumped parameter (e.g. the U-value) or in a detailed way, specifying the characteristics of the layers of the wall.*

The above steps are not strictly sequential. The notional reference building features should be chosen considering their effect on the building EP and the reference parameters should be defined taking into account the EP calculation method. In fact, the level of detail of the calculation method affects the level of detail of the parameters. A higher number of parameters is usually required by a detailed calculation method, while lumped parameters are used in a simplified method. Anyway, in case of features with little influence on the EP, it does not make sense to provide high detail even using a detailed simulation model.

Table 37 Example of possibly elements that may be neutralised intentionally or unconsciously [226]

		Reason		
Possibly neutralised element	Reason	Policy	Practical	Legal
Wheather Climate	To have same level of technologies despite different climate zones Same climatic data in reference calculation and in actual energy calculation□ If neutralised it leads to different EP in different climatic zones.	●	●	
Building function	Different use, therefore different design, occupation and feasible technologies	●		
Building size	If not neutralised small buildings are stimulated.	●		
Building shape	To allow the design of different architectural shape If not neutralised compact shapes are stimulated.	●		
Window size and/or orientation	To allow the design of different architectural shape To limit free solar heat gains If not neutralised high WWR are allowed.	●	●	
Amount of ventilation	To avoid penalty for better indoor air quality	●	●	
Shading by surroundings		●	●	●
Thermal bridges	If not neutralised it leads to the design of different architectural shape. If not neutralised high presence of thermal bridge are allowed.	●	●	
Technical building systems and sub systems	Allow or disallow the use of specific technologies	●		●
Indoor temperature setpoint heating season	To avoid that EP becomes function of choice of indoor temperature setpoint	●		
Indoor temperature setpoint cooling season		●		

(*) Free solar heat gains are limited by an additional parameter, high WWR ratio would be discouraged since they cause high cooling loads.

1.6.2.4 Improving of the Notional Reference Building Approach

The study *provides an application of the above described methodology aimed at improving the notional reference building approach as used in the legislation on the energy performance of buildings.*

The same neutralizing parameters as established by the current Italian legislation (i.e. building geometry, use, location, types of technical systems) are assumed in this study, because they derive from a political choice.

The three steps of the methodology are applied as follows:

1. *As a starting point, a sensitivity analysis is carried out on the reference parameters already defined in the national legislation (i.e. U-values of the envelope components,* solar transmittance with shading device *of the windows, efficiencies of the* technical building systems).
2. *The whole analysis is performed through a detailed dynamic calculation tool (EnergyPlus v8.3). Compared with the quasi-steady-state method specified by the national regulations, the dynamic simulation better mirrors the real thermal behavior of the building for the following main reasons:*
    - *it takes into account the high time variability of the thermal driving forces that can determine relevant thermal storage effects and mismatch between opposite effects (e.g. heat gains vs. heat transfer, power demand vs. power on-site production),*
    - *it considers systems described by non-linear models (e.g. thermal plants, passive solar systems, advanced thermal control systems).*

The dynamic numerical simulation is also an effective instrument to carry out sensitivity analyses by means of different procedures and methodologies, as performed for instance by Ballarini and Corrado (2011).

The description of the reference building features is performed by using a high level of detail as required by the dynamic simulation tool. Different technical solutions characterized by the simplified reference parameter value set by the national regulation are analyzed

1.6.3 Case Study

1.6.3.1 Notional Reference Building Object of Study

The case study is a two-storey single-family house, located in two different locations, Milan (2404 HDD) and Palermo (751 HDD). The main geometric data and the model of the building are reported in Table 38.

Table 38 Geometric data of the case study

Model of the building	Symbol	Unit	Value
	$A_{\mathrm{f,net}}$	m^2	158
	V_{g}	m^3	646
	V_{net}	m^3	458
	$A_{\mathrm{env}}/V_{\mathrm{g}}$	m^{-1}	0.74
	A_{w}	m^2	25.3
	$A_{\mathrm{w}}/A_{\mathrm{f,net}}$	-	0.16
	$A_{\mathrm{w}}/A_{\mathrm{env}}$	-	0.054

The reference parameters values for the building envelope of the notional reference building are provided by the MD 26/06/2015 and listed in Table 39. *They refer to the requirements of a NZEB. The U-values are defined in function of the climatic zone (heating degree-days).*

Table 39 Thermal properties of the building envelope of the NRB (MD 26/06/2015). Base case

Parameter	Unit	Climatic zone E 2101<HDD < 3000 (Milano)	Climatic zone B 900 > HDD (Palermo)	
U_{wl}	$\mathrm{W{\cdot}m^{-2}K^{-1}}$	0.26	0.43	
U_{r}	$\mathrm{W{\cdot}m^{-2}K^{-1}}$	0.22	0.35	
$U_{\mathrm{fl,up,un}}$	$\mathrm{W{\cdot}m^{-2}K^{-1}}$	0.31	0.5	*
$U_{\mathrm{wl,un}}$	$\mathrm{W{\cdot}m^{-2}K^{-1}}$	0.43	0.72	*
$U_{\mathrm{fl,gr}}$	$\mathrm{W{\cdot}m^{-2}K^{-1}}$	0.26	0.44	**
U_{w}	$\mathrm{W{\cdot}m^{-2}K^{-1}}$	1.40	3.00	
$g_{\mathrm{gl+sh}}$	-	0.35		***

* attached to an unconditioned space
** equivalent thermal transmittance (EN ISO 13370)
*** shading devices not installed on windows at North

Two configurations of technical systems are investigated in the case study: (1) a biomass boiler for space heating and a split air conditioner system for space cooling, (2) a reversible air-to-water heat pump for space heating and space cooling. The reference mean seasonal efficiencies of the heat generation subsystems are provided by the MD 26/06/2015 and listed in Table 40.

Table 40 Reference parameters of the heat generation subsystems (MD 26/06/2015). Base case

Parameter	**Unit**	**Energy service**	
		Heating	**Cooling**
η_{gn} (biomass)	-	0.72	-
COP (heat pump)	-	3.00	-
EER (split/heat pump)	-	-	2.50

1.6.3.2 Sensitivity analysis of the reference parameters

The sensitivity analysis of the thermal transmittance consists in assuming, for each envelope component, a higher and a lower U-value compared to the actual reference value reported in Table 39. *More specifically, for each component and location, the thermal transmittance reference values established by the MD for the two closest climatic zones are tested. In Palermo, as a closer climatic zone with a higher U-value does not exist, it has been applied the same percentage increase as it occurs between the closest climatic zone with lower U-value and the U-value of the actual climatic zone. The analyzed cases are listed in* Table 41. *The case ID no. 00 concerns the base case (*Table 39*).*

A second sensitivity analysis concerns the total solar energy transmittance of glazing with a shading device. It consists in applying the g_{gl+sh}*-values and the different features of glazing and shading device as reported in* Table 42. *For each location, all variants allow the required thermal transmittance value of windows to be met (see Table 2).*

The thermal transmittance values of the notional reference building reported in Table 2 are applied in the sensitivity analysis of the total solar energy transmittance. Likewise, the g_{gl+sh}*-value of* Table 39 *is assumed in all case studies concerning the sensitivity analysis of the thermal transmittance.*

As regards the heat generation subsystem, the sensitivity analysis takes into account three levels of the nominal efficiency value of biomass boiler, split and heat pump, as reported in Table 6. For each heat generator, the nominal efficiency value of the base case leads to the mean seasonal efficiency of Table 40. *The upper and the lower nominal values have been set with respect to the nominal value of the base case, as follows:*

- *±2% of the average efficiency of the biomass boiler;*
- *±0.5 of the coefficient of performance (COP) of the heat pump in heating mode;*
- *±0.5 of the energy efficiency ratio (EER) of the split and the heat pump in cooling mode.*

Table 41 Sensitivity analysis of the envelope components thermal transmittance. Case studies

ID case study	**Description**	***U*** **[W·m^{-2}K^{-1}]**				
		U_{wl}	U_r	$U_{fl,up,un}$	$U_{wl,un}$	U_w
MI-00	**Milan – base case**	0.26	0.22	0.31	0.43	1.40
MI-SA-TT-01	Milan – higher *U*-value	0.29	0.26	0.37	0.48	1.80
MI-SA-TT-02	Milan – lower *U*-value	0.24	0.20	0.29	0.40	1.10
PA-00	**Palermo – base case**	0.43	0.35	0.50	0.72	3.00
PA-SA-TT-01	Palermo – higher *U*-value	0.52	0.37	0.53	0.87	3.80
PA-SA-TT-02	Palermo – lower *U*-value	0.34	0.33	0.47	0.57	2.20

Table 42 Sensitivity analysis of the total solar energy transmittance of glazing with shading device. Case studies

ID case study	**Description**	g_{gl+sh} [-]	$g_{gl,n}$ [-]	$\tau_{sol,sh}$ [-]	$\rho_{sol,sh}$ [-]	Shading device position
MI-00	**Milan – base case**	0.35	0.67	0.15	0.70	internal
MI-SA-TST-01	Milan – lower g_{gl+sh}-value	0.09	0.67	0.10	0.70	external
MI-SA-TST-02	Milan – higher g_{gl+sh}-value	0.67	0.67	no shading device		
PA-00	**Palermo – base case**	0.35	0.75	0.15	0.70	internal
PA-SA-TST-01	Palermo – lower g_{gl+sh}-value	0.05	0.75	0.00	0.70	external
PA-SA-TST-02	Palermo – higher g_{gl+sh}-value	0.75	0.75	no shading device		

Table 43 Sensitivity analysis of the heat generator efficiency. Case studies

ID case study	**Description**	**Biomass**	**Split**	**ID case study**	**Description**	**Heat pump**	
		η	***EER***			***COP***	***EER***
MI-00-BS	**Milan – base case**	0.73	2.59	**MI-00-HP**	**Milan – base case**	3.63	3.25
MI-SA-BS-01	Milan – higher efficiency	0.75	3.09	MI-SA-HP-01	Milan – higher efficiency	4.13	3.83
MI-SA-BS-02	Milan – lower efficiency	0.71	2.09	MI-SA-HP-02	Milan – lower efficiency	3.13	2.19
PA-00-BS	**Palermo – base case**	0.8	2.81	**PA-00-HP**	**Palermo – base case**	2.93	3.43
PA-SA-BS-01	Palermo – higher efficiency	0.822	3.31	PA-SA-HP-01	Palermo – higher efficiency	3.43	3.93
PA-SA-BS-02	Palermo – lower efficiency	0.78	2.31	PA-SA-HP-02	Palermo – lower efficiency	2.43	2.93

Table 44 Envelope components configurations with fixed thermal transmittance. Case studies

ID case study	Description	Envelope component	U [W·m^{-2}K^{-1}]	Y_{ie} [W·m^{-2}K^{-1}]	m_s [kg·m^{-2}]	κ_i [kJ·m^{-2}K^{-1}]
MI-00	**Milan - base case**	wall (EXT)	0.26	0.04	260	49.5
	External insulation	roof (EXT)	0.22	0.05	249	63.5
	Heavy thermal mass	upper floor (UNC)	0.31	0.04	335	62.1
		wall (UNC)	0.43	0.08	258	50.1
MI-DE-TT-01	Milan	wall (EXT)	0.26	0.06	260	24.5
	Internal insulation	roof (EXT)	0.22	0.07	249	25.8
	Heavy thermal mass	upper floor (UNC)	0.31	0.03	335	24.2
		wall (UNC)	0.43	0.11	258	25.1
MI-DE-TT-02	Milan	wall (EXT)	0.26	0.09	153	14.0
	Internal insulation	roof (EXT)	0.22	0.07	249	25.8
	Light thermal mass	upper floor (UNC)	0.31	0.03	335	24.2
		wall (UNC)	0.43	0.18	152	16.6
PA-00	**Palermo - base case**	wall (EXT)	0.43	0.09	257	50.1
	External insulation	roof (EXT)	0.35	0.09	247	64.0
	Heavy thermal mass	upper floor (UNC)	0.50	0.08	333	62.4
		wall (UNC)	0.72	0.25	217	52.9
PA-DE-TT-01	Palermo	wall (EXT)	0.43	0.11	257	24.8
	Internal insulation	roof (EXT)	0.35	0.12	247	25.7
	Heavy thermal mass	upper floor (UNC)	0.50	0.06	333	25.1
		wall (UNC)	0.72	0.31	217	29.8
PA-DE-TT-02	Palermo	wall (EXT)	0.43	0.18	152	16.6
	Internal insulation	roof (EXT)	0.35	0.12	247	25.7
	Light thermal mass	upper floor (UNC)	0.50	0.06	333	25.1
		wall (UNC)	0.72	0.46	127	23.2

Table 45 Configurations of glazing and shading device with fixed total solar energy transmittance. Case studies

ID case study	Description	g_{gl+sh} [-]	$g_{gl,n}$ [-]	$\tau_{sol,sh}$ [-]	$\rho_{sol,sh}$ [-]	Shading device position
MI-00	**Milan - base case** Low-e double glazing, white and medium translucent shading device	0.35	0.67	0.15	0.70	internal
MI-DE-TST-01	Milan Low-e double glazing, dark and high translucent shading device	0.35	0.67	0.45	0.25	external
MI-DE-TST-02	Milan Low-e triple glazing, pastel and semi-opaque shading device	0.35	0.46	0.10	0.50	internal
PA-00	**Palermo - base case** Uncoated double glazing, white and medium translucent shading device	0.35	0.75	0.15	0.70	internal
PA-DE-TST-01	Palermo Uncoated double glazing, black and translucent shading device	0.35	0.75	0.30	0.05	external
PA-DE-TST-02	Palermo Low-e double glazing, white and medium translucent shading device	0.35	0.67	0.15	0.70	internal

1.6.4 Features of the Notional Reference Building

The detailed dynamic numerical simulation method requires a high detail in the description of the notional reference building features. For example, the building envelope components are described by the thermal properties of single layers. In such a way, various technical solutions for each envelope component can lead to the same thermal transmittance value established by the national decree (see Table 39*).*

As shown in Table 41*, three different envelope configurations are tested for each location, taking into account a different position of the thermal insulation layer and a different thermal mass. It can be noted that a specific envelope component may have different dynamic thermal characteristics while achieving the same thermal transmittance value.*

The MD 26/06/2015 provides all climatic zones with a unique reference value of the total solar energy transmittance of glazing with shading device (see Table 39*). As for the thermal transmittance, different technical solutions using different types of glazing and shading devices would allow to achieve the same reference value of* g_{gl+sh}*. The configurations listed in* Table 42 *are tested for the notional reference building.*

For the dynamic modelling the heat generation subsystem, a very detailed description of the system is required.

For the biomass boiler, the following main parameters are required: nominal power, nominal efficiency and flow temperatures. The performance curve, which is a bi-cubic function implemented within EnergyPlus, uses, as input data, the load factor and the temperature in the water inlet into the boiler.

The main input parameters for the split system are the EER and the nominal power. The hourly power can be determined by means of two performance curves. The first one requests, as input, the wet-bulb temperature of the air entering in the cooling coil and the dry-bulb temperature of the air entering in the air-cooled condenser coil. The other curve requires the ratio of the actual air flow rate across the cooling coil to the rated air flow rate.

The air-to-water heat pump for the heating season is described with heating nominal power, nominal COP at reference temperatures of air and water, respectively at the inlet temperature of the evaporator and condenser. The COP at each time step is determined taking into account the partial load ratio (PLR) and in function of inlet temperature of evaporator and condenser. Concerning the heat pump cooling operation, the nominal power, the nominal EER at the outlet chilled water temperature and at the inlet condenser fluid temperature are needed. The performance curves available in Energy Plus have been considered in the analysis. In particular, in these simulations was used biquadratic performance curve. The boiler efficiency depends by part load ratio (PLR) and water-outlet temperature.

1.6.5 Results and Discussion

1.6.5.1 Energy performance of the notional reference building

The Italian MD 26/06/2015 requires to calculate the EP of the notional reference building by means of the UNI/TS 11300 series, which specifies a quasi-steady-state calculation method based on EN ISO 13790 and EN 15316 series. In Figure 2, a comparison between the results of the quasi-steady-state method and the detailed dynamic simulation (EnergyPlus) are shown for Milan and Palermo. The EP is expressed in terms of net energy need for space heating and space cooling normalized on the conditioned net floor area of the notional reference building object of study.

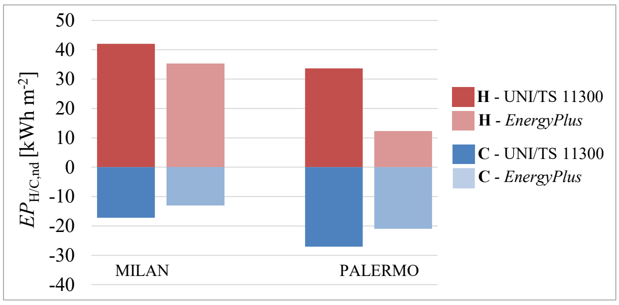


Fig. 2 Comparison between UNI/TS 11300 and EnergyPlus.

As pointed out by Corrado et al. (2016), the quasi-steady state method overestimates the energy need both for heating and for cooling. The overestimation of space heating energy need significantly increases in Palermo, where higher outdoor air temperature and higher solar radiation occur.

In addition, some critical points were identified, specifically concerning the effect of thermal bridges and of the technical system auxiliaries in the reference building approach.

In this work, the values of thermal transmittance of the building façades components considers also the contribution of thermal bridges. *The results reveal the limits of the simplified method in predicting the energy needs of low-energy buildings, as introduced in the Section "Theory and method".*

Therefore, in the present work, a detailed dynamic simulation has been chosen as reference calculation method to investigate the notional building approach.

1.6.5.2 Results of the sensitivity analysis

The results of the sensitivity analysis are reported in Fig. 3. *In* Fig. 3.a, *the percentage variation of the EP in terms of annual net energy need for space heating and space cooling normalized on the building net floor area is plotted against the percentage variation of the average U-value of the building envelope (H'_T), which is expressed through (1).*

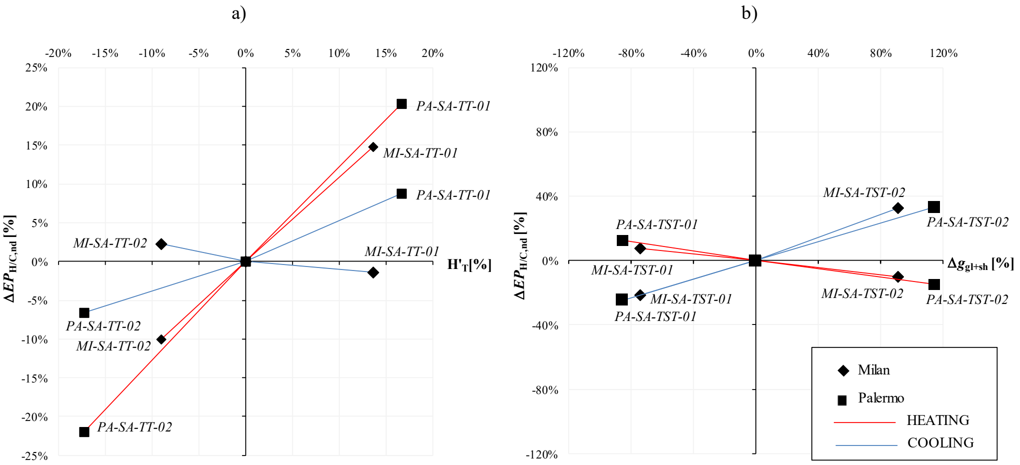


Fig. 3 Sensitivity analysis of a) the thermal transmittance and b) the total solar energy transmittance

Considering a variation of –9÷14% of H'_{T} *(see* Fig. 3.a*), the net energy need for space heating is more sensitive (−10÷15%) than the net energy need for space cooling (below ±2%) for the building located in Milan.*

In Palermo, a variation of about ±17% of H'_{T} *determines deviation of about −22÷20% of the net energy need for space heating and of about −7÷9% of the net energy need for space cooling.*

On the contrary, the total solar energy transmittance (see Fig. 3.b*) affects more the energy need for space cooling (−22÷32% in Milan and −25÷33% in Palermo) than for space heating (−10÷7% in Milan and −15÷13% in Palermo). The influence of the* $g_{gl+sh\text{-}value}$ *on the building EP is however lower than the influence of the U-value.*

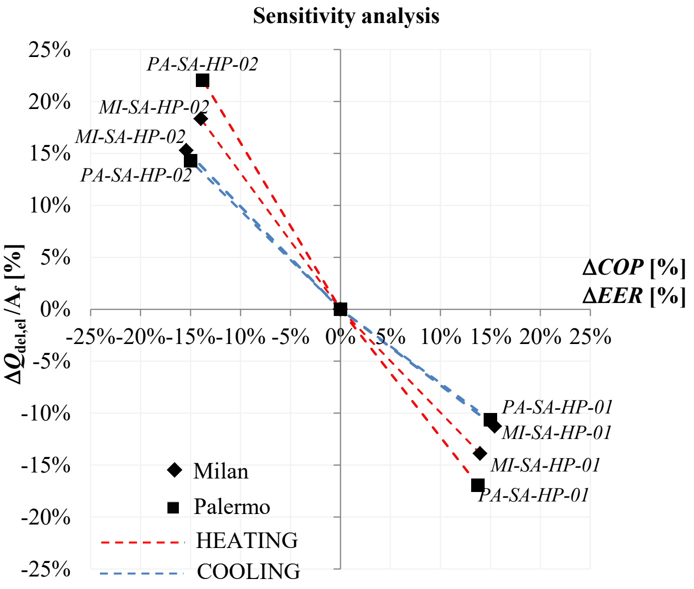


Fig. 4 Sensitivity analysis of the heat generator efficiency. Heat pump.

Table 46 Sensitivity analysis of the heat generator efficiency. Biomass boiler and split system.

ID case study	$\Delta\eta$ [%]	$\Delta Q_{del,bio}$ [%]	ΔEER [%]	$\Delta Q_{del,el}$ [%]
MI-00-BS	-	-	-	-
MI-SA-BS-01	3%	-3%	19%	-15%
MI-SA-BS-02	-3%	2%	-19%	22%
PA-00-BS	-	-	-	-
PA-SA-BS-01	2%	-1%	18%	-15%
PA-SA-BS-02	-2%	3%	-18%	22%

The sensitivity analysis of the heat generator efficiency (Fig. 4 and Table 46) highlights the high influence of the COP on the delivered energy both in Milan and in Palermo. As regards the EER effect, there isn't an appreciable difference between Milan and Palermo.

The analyzed parameters of both building envelope and thermal systems demonstrate to affect the building EP with considerable extent. Thus the related building features can be really considered as reference for characterizing the notional reference building.

1.6.5.3 Results of the building features description

The analyzed envelope configurations, which are characterized by the same thermal transmittance value and different thermal dynamic parameters, determine a variation of the EP as shown in Table 10.

In Milan, while the deviation in the annual net energy need for space heating is negligible, the space cooling presents an increment of about 12% in both configurations with the thermal insulation layer on the internal side. In Palermo, the variation of the energy need for space cooling is very high (about 45%) in both configurations.

The results of the analyzed configurations of glazing and shading device, which determine the same g_{gl+sh}*-value, are shown in* Table 47*. For the building in Milan, the EP is strongly affected by the type of glazing and the shading device features. Specifically, in this case, the variation of the total solar energy transmittance of glazing affects the EP more than the position of the shading device.*

Table 47 Results of a) the envelope components configurations, b) configurations of glazing and shading device

a)

ID case study	$EP_{H,nd}$ [kWh·m^{-2}]	Δ% (base case)	$EP_{C,nd}$ [kWh·m^{-2}]	Δ% (base case)
MI-00	31.74	-	12.77	-
MI-DE-TT-01	31.54	−0.63%	14.39	12.70%
MI-DE-TT-02	31.92	0.57%	14.34	12.30%
PA-00	13.86	-	14.65	-
PA-DE-TT-01	12.15	−12.30%	21.29	45.30%
PA-DE-TT-02	12.32	−11.10%	21.02	43.40%

b)

ID case study	$EP_{H,nd}$ [kWh·m^{-2}]	Δ% (base case)	$EP_{C,nd}$ [kWh·m^{-2}]	Δ% (base case)
MI-00	31.74	-	12.77	-
MI-DE-TST-01	31.28	−1.46%	13.55	6.17%
MI-DE-TST-02	33.87	6.71%	9.46	-25.90%
PA-00	13.86	-	14.65	-
PA-DE-TST-01	14.02	1.17%	13.87	-5.37%
PA-DE-TST-02	13.51	−2.49%	14.65	0.01%

The results of the building features description highlight that significant deviations in the building EP may occur if an insufficient number of parameters is assumed for the reference building when using a dynamic simulation method. This aspect *implies that the legislation should provide more detailed information to characterize the notional reference building.*

With reference to the analyzed case studies and building features, suggestions for improving the notional building approach are provided as follows.

Besides a lumped thermal transmittance value, one or more thermal dynamic features of the envelope component should be provided, either adopting neutralizing parameters (e.g. the areal heat capacity of the notional building is the same of the building under design with a margin tolerance), or fixing reference values or ranges.

The total solar energy transmittance of glazing with shading device should be complemented with other parameters, as for instance the position of the shading device and the g_{gl}*-value. The former might be fixed as external, the latter might be considered a neutralizing parameter.* In the glazing surfaces the thermal properties were assigned using the detailed optical properties. Window frames were taken into account.

1.6.5.4 Conclusion

The study is aimed at enhancing the application of the notional reference building approach in the legislation on the energy performance of buildings.

The analysis, performed on an Italian single-family NZEB in two different climatic zones, demonstrates that the reference parameters established by the national regulations have been correctly chosen, as they significantly influence the building EP. Anyway, the level of detail used to describe the notional reference building by the Italian legislation, even if suitable for a quasi-steady-state numerical method, is not sufficient to model the building by means of a dynamic simulation tool. A more detailed information about the thermal envelope and the technical systems would be necessary.

An improved procedure for specifying a notional reference building has been addressed in the article and is shown in Fig. 5. The building category and the boundary conditions influence the choice of the calculation method that, in turn, determine the choice of the parameters. The sensitivity analysis is useful to identify the main parameters affecting the EP. A clear distinction is also needed between reference parameters and neutralizing parameters. The last ones are usually defined by political choice. Afterwards, the level of detail of the building features should be provided, consistently with the calculation method. Finally, a single value or a value range should be established for each reference parameter, taking into account specific aspects, as for instance technical feasibility and economic viability.

A future research is going to enlarge the analysis by investigating more building features and their level of detail. In addition, open issues will be addressed, such as how to take into account the thermal bridges effect in the notional building and more specific features related to technical systems (e.g. system auxiliaries).

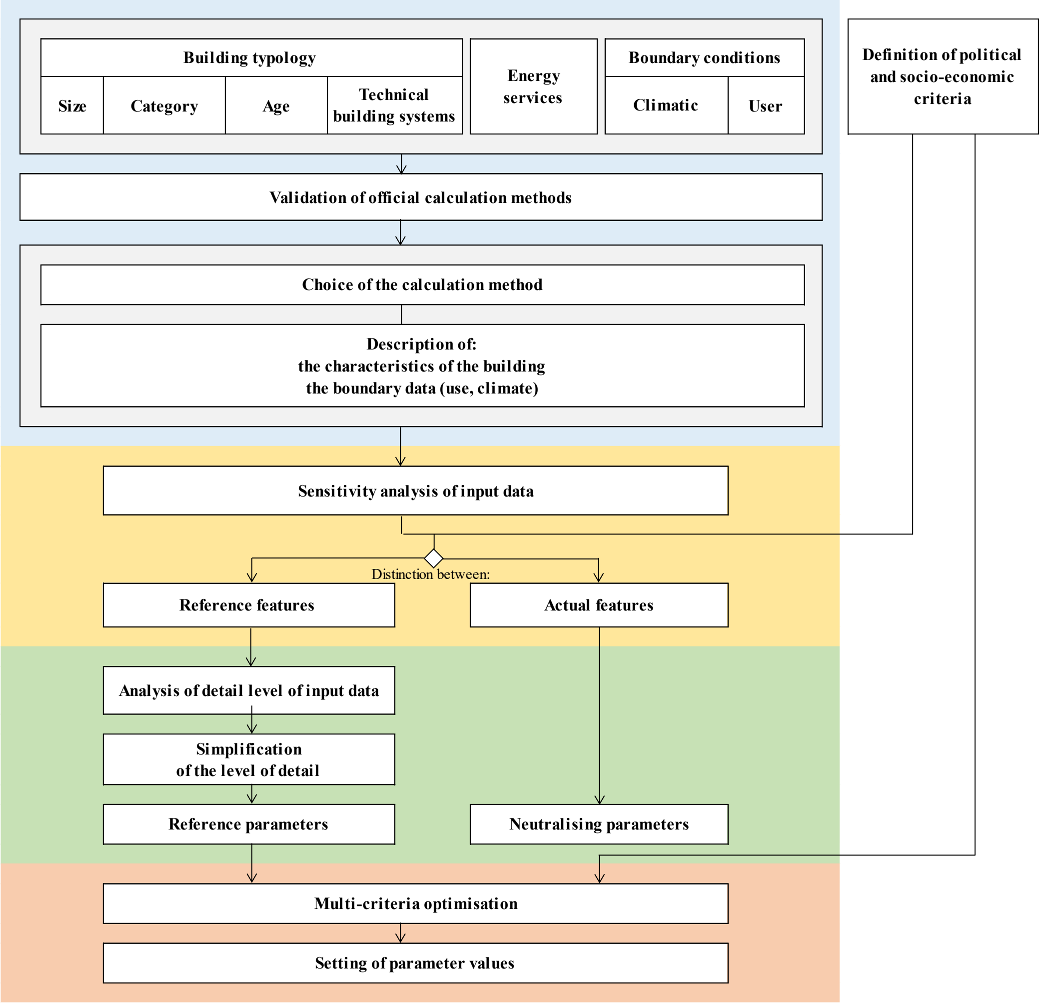


Fig. 5 Flowchart of the proposed procedure for specifying a notional reference building

This study allowed me to publish various researches and articles. Below are some references:

- D. Dirutigliano, I. Ballarini, G. Murano, and V. Corrado, (2017) *Reference Building Approach Combined with Dynamic Simulation in Designing NZEBs*, 7-9 August 2017 San Francisco, Building Simulation 2017
- G. Murano, R. Nidasio, A. Panvini, and L. Terrinoni, (2017) *Evolution of the optimal energy requirements of NZEBs: study on the parameters of the notional reference building: thermal transmittance, thermal bridges and* H'_T *requirement on existing buildings*, ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), Ministry of Economic Development, (In Italian)
- G. Murano, R. Nidasio, A. Panvini, and L. Terrinoni, (2016) *Study on the technical parameters of the notional reference building and minimum energy requirements of lighting systems, elevators and escalators*, ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), Ministry of Economic Development, Report RdS/2016/128

Chapter 2

2 Calculation models of building energy performance

2.1 Calculation models comparison

2.1.1 Introduction

This chapter analyses the calculation of energy needs for heating and cooling of buildings, determined through two calculation methods, in order to be able to appreciate how much they influence the results and which are the respective characteristics of strength.

The normative references currently in force are analyzed, such as UNI EN ISO 13790, UNI/TS 11300-1 and EN ISO 52016-1, underlining the main differences contained in the various methodologies in order to understand how the calculation procedures they have evolved over the years and how they can weigh on the results of the simulation. The scientific literature on the calculation of energy performance of buildings includes, among the last works, numerous writings concerning the comparison of dynamic simulation methods, and other papers that aim to verify the fundamental hypotheses of quasi-steady methods.

The most commonly used calculation methods for estimating the *EP* of buildings are of three types:

- quasi-steady methods, where the calculation of the thermal balance considers a sufficiently long time (typically, a month or an entire season), this method take into account the dynamic effects through an empirically determined use factor of the heat gain and / or dispersions;
- simple hourly methods, is simplified detailed method generally based on the simplification of the heat transfer function. The heating / cooling energy needs are calculated for each hour. Some examples of these methods are in EN ISO 13790 (5R1C) [234] and in the new EN ISO 52016-1 [245].
- dynamic methods, where the calculation of the thermal balance considers a short time steps (typically one hour) that take into account the accumulated and released heat from the thermal building mass. Some usual programs that implement these methodologies are EnergyPlus and TRNSYS (Transient System Simulation Tool).

- In relation to the thermal conduction of the building envelope, the same areas, materials, layers were used in the two methods.
- In order to set the same surface resistances, the pre-defined values given in EN ISO 6946and EN ISO 10077-1 were used. Coherently with the quasi-steady method the inside and outside convective and radiative heat transfer coefficients were held constant throughout simulations.
- The internal heat capacities of the building constructions were represented explicitly in the EnergyPlus, while in the UNI/TS 11300-1 was calculated via the use of the total internal heat capacity factor.
- For solar heat gains, the detailed optical properties were used, while for the UNI/TS 11300-1 was used the solar energy transmittance (g-value).
- Window frames were taken into account.

The chapter does not investigate the hourly calculation methodology contained in EN ISO 13790 [234] as it is now superseded by the revision of EN ISO 52016 [245]. There are some software on the market that apply the latter, however these tools still have to wait for the application indications defined at national level which will be processed by the CTI and available by the end of this year.

In this chapter the results that derive from the application of the quasi-steady state calculation method with the detailed ones are compared (UNI/TS 11300 versus EnergyPlus). The ultimate goal is to understand whether the quasi-steady state calculation method can be applied to the design of NZEB or whether in the calculation of the energy performance detailed dynamic simulation must always be applied. In fact, as seen in the previous chapters, to date the majority of EU member states apply Quasi-Steady State Method in the EPBD context. The comparison of the two calculation methods was undertaken in terms of the annual energy needs for space heating and cooling and the main implications of using the different calculation methods was examined with parametric analysis.

2.1.2 Application of Quasi-Steady State Approach

The monthly calculation method presented in the EN ISO 13790 standard [234] is a quasi-steady analysis procedure that provides reliable results on an annual basis but which may present large relative errors in the months close to the end or at the beginning of the heating and cooling seasons.

Quasi-steady methodologies use correlation factors to take into account dynamic effects such as fluctuations in external air temperature, solar irradiance and occupancy values.

As for heating, there is a heat transfer utilization factor that takes into account the fact that only a part of heat contributions is actually used to reduce the need for thermal energy, while the remaining part has no beneficial effects in which causes an undesired rise in the internal temperature above the set value.

For cooling, two methodologies are proposed in EN ISO 13790 [234]; in the first one a factor of utilization of the dispersions is used in opposite way to what has been done for the heating, in order to consider that not all the part of dispersions due to ventilation and transmission are used to reduce energy need as they can occur during periods of time, such as the night, where the needs are very limited, if not even zero.

A second method uses instead a factor of utilization of the contributions, in this case analogously to what has been done for heating, which, similarly to what has been previously explained, evaluates the fact that only a portion of the internal and solar thermal contributions is balanced by heat exchange for ventilation and transmission, while the remaining part leads to cooling requirements aimed at maintaining a fixed internal temperature value.

In a conceptually identical way, also in the UNI/TS 11300-1 [235], a quasi-steady method is presented aimed at calculating the energy needs of buildings; the only difference is inherent in the sole possibility, for the calculation referring to the cooling period, to use the factors of utilization of the contributions. In order to make the two procedures more similar and therefore make a comparison more feasible and easier to read, it was therefore decided to also use the factors for the use of the contributions for the monthly calculation method implemented with the EN ISO 13790 standard.

These methodologies turn out to have a calculation procedure that is not excessively complex, which, if desired, can even be done by hand. For ease of implementation and, in order to make the procedure easily modifiable and repeatable, it was decided to proceed with a writing on an Excel spreadsheet.

Table 48 shows the main differences in the calculation models.

The analysis in question considers both the energy performance of each building unit and the energy performance of the whole building. The issues analysed are two: (a) the Quasi-Steady State Approach still able to estimate the *EP* of NZEB? (b) Is it correct to reason in terms of overall building requirements, or would it be more correct for the NZEB buildings to examine the energy performance of a single building unit?

According to Micono and Zanzottera (2015) [228] the energy performance calculation method plays a key-role to reach the NZEB target. Also Cellura et al. (2015) [227] and Barthelmes et al. (2015) [229] have based their NZEBs study on dynamic simulation models with TRNSYS and EnergyPlus.

The research chapter examines the accuracy of the Quasi-Steady State Approach, employed according to the Italian technical specification UNI/TS 11300 [235]. Both the terms of the building energy balance and the Steady State parameters are evaluated by comparing the numerical analysis results.

The research takes into account six levels of thermal insulation of the building envelope. A national reference apartment block for residential use is used as a case study, with different thermal mass properties. The *EP* is calculated for four Italian climatic zones (Belluno, Turin, Rome and Palermo).

Table 48 Main differences between technical standard and calculation methods

	Technical standards / Calculation procedure				
	EN ISO 13790 Monthly calculation	EN ISO 13790 Hourly calculation	UNI/TS 11300-1 Monthly calculation	EN ISO 52016-1 Monthly calculation	EN ISO 52016-1 Hourly calculation
Approximation models of the elements	-	Five resistances, one capacitance (5R1C) model	-	-	Model with a number of resistances and variable capacities depending on the characteristics of the building element considered (RC)
Solar heat gain	The solar contributions deriving from opaque and transparent envelope components, as well as the extra heat flow are considered in the same mode and make up the final value of the solar contributions.		The only solar contributions derived from transparent components make up the total solar contributions, while the contributions on opaque components and the extra heat flow are calculated together with the dispersions of the building envelope.		
Zoning	Five criteria are defined for defining thermal zones		To the five criteria mentioned above, a sixth is added to the latent loads.	A ten step procedure is defined, aimed at identifying the thermal zones.	
Adiancent unconditioned spaces	Only one type of adjacent non-conditioned zone is defined The b_{tr} coefficient is applied to the heat exchange coefficients		Only one type of adjacent non-conditioned zone is defined The correction coefficient b_{tr} is applied to the heat exchange coefficients	Two types are defined to treat the adiancent unconditioned spaces The correction coefficient b_{tr} applies to temperatures	
Intermittent heating or cooling	The correction coefficient a_{red} is applied to the thermal energy needs	Given the calculation method, the intermittence is not calculated.	The correction coefficient a_{red} is applied to the thermal energy needs	The correction coefficient ared is applied to the air temperatures for the heating case; for the summer case it is instead applied to the cooling energy needs, with particular attention to the weekend.	Given the calculation method, the intermittence is not calculated.
Humidification and dehumidification	-	-	Referred to the difference in incoming and outgoing water vapor flow rates as well as to internal production.	Referred to the difference in incoming and outgoing water vapor flow rates as well as to internal production; for dehumidification it is related to the cooling energy need.	Referred to the difference in incoming and outgoing water vapor flow rates as well as to internal production and other parameters

2.1.3 Case Study

Twenty-four case studies (each of which consists of twelve building units) are concerned in the analysis. They consist in the same apartment block with a fixed geometry, located in four different Italian climatic zones. The case study is an apartment block for residential use with a rectangular plan composed of four floors above ground; the building has a plane roof. Each floor consists of three residential building units of different useful area. The conditioned spaces include twelve building units, while the attic space, the cellar and the staircases are unconditioned areas.

This building was selected because of its statistical relevance in the Italian residential building stock and it has been modelled based on statistical data.

The main features are recalled in Table 49. The *U*-value of the building envelope components is the same (six level) for the considered locations. As regards the thermal mass, heavy building structure with thermal insulation placed on the external side were considered. Some summary parameters relating to the opaque and transparent casing are shown in the Table 50.

Table 49 Geometric data of case study

Apartment block (AB)

V_g [m^3]	V_n [m^3]	A_f [m^2]	A_{env} [m^2]	A_w [m^2]	A_{env}/V_g [m^{-1}]	WWR [-]
4288	3311	1226	1904	151	0.44	0.22

Building unit code	Storey	V_g [m^3]	V_n [m^3]	A_f [m^2]	A_{env} [m^2]	A_w [m^2]	A_{env}/V_g [m^{-1}]	WWR [-]
BU0A	0	255	205	76	187	11.1	0.73	0.15
BU0B		184	153	57	108	8.7	0.58	0.29
BU0C		389	320	118	246	18	0.63	0.18
BU1A	1-2	285	230	85	116	11.1	0.41	0.14
BU1B		184	153	57	46	8.7	0.25	0.29
BU1C		389	320	118	116	18	0.3	0.18
BU3A	3	285	230	85	201	11.1	0.71	0.14
BU3B		184	153	57	108	8.7	0.58	0.29
BU3C		389	320	118	246	18	0.63	0.18

With the aim of consider all the possibilities proposed by the technical standards, the monthly and hourly calculation methodologies have been applied in cases of continuous operation. The façade includes the solar shading devices. **Table 50** shows some summary data that provide respectively information on the thermal characteristics of the opaque (H'$_T$) and transparent casing ($A_{sol,sum}/A_f$).

Table 50 Summary parameters related to the opaque and transparent envelope

	H'$_T$ [W·m^{-2}·K^{-1}]						$A_{sol,sum}/A_f$
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	[-]
BU0A	0.15	0.27	0.38	0.50	0.61	0.73	0.016
BU0B	0.17	0.29	0.42	0.54	0.67	0.79	0.016
BU0C	0.16	0.29	0.41	0.54	0.67	0.79	0.017
BU1A	0.18	0.31	0.44	0.57	0.70	0.83	0.015
BU1B	0.26	0.42	0.58	0.73	0.89	1.05	0.016
BU1C	0.23	0.39	0.54	0.70	0.85	1.01	0.015
BU3A	0.15	0.27	0.38	0.50	0.61	0.73	0.021
BU3B	0.17	0.29	0.42	0.54	0.67	0.79	0.016
BU3C	0.16	0.29	0.41	0.54	0.66	0.79	0.017

2.1.4 Calculation Method

The $EP_{H/C,\mathrm{nd}}$ of the case studies is calculated by two different approaches: a Quasi-Steady State method and a detailed dynamic energy simulation.

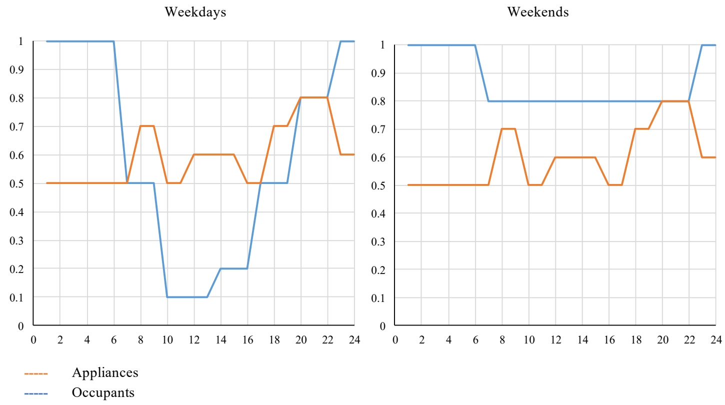
The dynamic simulation is performed by means of EnergyPlus (version 8.5).

To determine the internal heat gains on an hourly basis, the data proposed by the prEN 16798-1 for the residential (detached house) were considered.

Some consistency options are assumed to compare the EP obtained by the quasi-steady state approach and the dynamic models:

- The full consistency between the TMYs of the locations, got from CTI (Italian Thermo-Technical Committee [252]), and the monthly values weather data applied to the quasi-steady state calculation method is verified.
- The values of internal heat gains on an hourly basis that have been used are shown in Table 51. The same table reports the usage schedule for weekdays and weekends. For the calculation of the ventilation flow, on the other hand, the data proposed by the UNI/TS 11300-1 was used with ventilation flow rate is equal to an average value of 0.30 h^{-1} (equal to 0.055 $m^3 \cdot s^{-1}$). The internal heat gains in the spaces were the same for two methods.
- In the quasi-steady state model the adjustment factors, $b_{tr,U}$, (factor that allow to consider the transmission heat transfer between the conditioned space and the external environments via unconditioned spaces) has been calculated in accordance with EN ISO 13789 standard [233]. Instead, in EnergyPlus has been considered the actual space configuration.
- The effect of thermal bridges was not considered in either of the two approaches. The assumption has been that the thermal transmittance of the building envelope elements takes in account also the effect of thermal bridges.

Table 51 Internal heat gains on an hourly basis and Usage schedule. Sorce: FprEN 16798-1:2016

Residential, Detached house	Internal heat gains	
		$W\cdot m^{-2}$
	Occupant (Dry)	1.9
	Appliances	2.4
	Lighting	-

2.1.5 Results

Results are presented in terms of rating outputs from the various calculation methods. The results shown in Table 54 (Udine), Table 55 (Turin), Table 56 (Rome), and Table 57 (Palermo) are reported both of building units and whole building. The building units characterized by a difference between the $EP_{\mathrm{H,nd}}$ calculated with two calculation methods with overestimation / underestimation less than 20% have been indicated with an asterisk (*). The following formula was applied.

$$\Delta EP_{\mathrm{S,nd}}\% = \frac{EP_{\mathrm{S,nd}(11300)} - EP_{\mathrm{S,nd}(E+)}}{EP_{\mathrm{S,nd}(E+)}} \tag{7}$$

The results show that:

- in cold locations (Udine and Turin), the quasi-steady calculation method overestimates the $EP_{\mathrm{H,nd}}$ and underestimates the $EP_{\mathrm{C,nd}}$, regardless of the thermal insulation of the building envelope. For Udine and Turin with the increase of the level of thermal insulation decreases the overestimation of the $EP_{\mathrm{H,nd}}$. Therefore, the energy performance values calculated by applying the UNI/TS 11300 tend to get close those calculated with EnergyPlus. This occurs for all building units. It is interesting to note how each building unit has a different overestimation of $EP_{\mathrm{H,nd}}$. In any case, level 5 is the one that offers the closest $EP_{\mathrm{H,nd}}$ results between the two methods.
- In hot location (Rome and Palermo), the case study that offers the lowest $\Delta EP_{\mathrm{H,nd}}\%$ is the thermal insulation level n. 1 if the individual building units are examined. Instead, if the building as a whole are considered, the lowest $\Delta EP_{\mathrm{H,nd}}\%$ is represented by the building envelope insulation level n.3.
- Generally, the results show that the quasi-steady calculation method underestimates the energy need for cooling, However, this statement is no longer valid in cold locations and for highly insulated buildings.
- It should also be considered that for very low energy needs, deviations from the target value may appear more important.
- In Table 52 and Table 53 are reported the EP homogeneity indexes defined as the coefficients of variation (or relative standard deviation) of the energy performance of building unit respect the energy performance of whole building.

$$\sigma_{EP} = \sqrt{\frac{\sum_1^n \left(EP_{\mathrm{S,nd,BU}} - EP_{\mathrm{S,nd,WB}}\right)}{n_{\mathrm{BU}} - 1}} \tag{8}$$

Where:

- $EP_{S,nd,BU}$ is the energy need of the considered energy service of the building unit;
- $EP_{S,nd,WB}$ is the energy need of the considered energy service of the whole building;
- n_{BU} is the number of building units in the case study.

From the table it can be seen that for cold locations (Belluno and Turin) the heating index $\sigma_{EP,H,nd}$ has values higher than those of other locations to a greater extent for the levels concerning low levels of thermal insulation (i.e. L1, L2, and L3). Moreover, again for the same locations, it can be noted that the indexes concerning the heating energy needs calculated with UNI/TS 11300-1 have higher values than those calculated with EnergyPlus. This means greater inhomogeneity in the energy performance of the individual building units. In the case of the warmer localities (Rome and Palermo) the variations are more contained.

As far as the $\sigma_{EP,C,nd}$ index is concerned, in the case of Belluno, with the variation of thermal insulation level, the value remains almost unchanged. This concerns the results calculated with detailed energy simulation.

Differently from the previous case, concerning the energy needs calculated with UNI/TS 11300, with the increasing of thermal insulation, greater unevenness in the $EP_{C,nd}$ between the housing units are occurred.

For Palermo and Rome, the indexes calculated with reference to energy performance with EnergyPlus and UNI / TS 11300 present an opposite trend. With reference to the UNI/TS 11300 results, as the level of thermal insulation increases, the index $\sigma_{EP,C,nd}$ increases. With reference to EnergyPlus results, as the level of thermal insulation increases, the index $\sigma_{EP,C,nd}$ decreases.

Table 52 The $EP_{H/C,nd}$ homogeneity index for Belluno and Turin

	BELLUNO				TORINO			
Level	$EP_{H,nd}$		$EP_{C,nd}$		$EP_{H,nd}$		$EP_{C,nd}$	
	11300-1	E+	11300-1	E+	11300-1	E+	11300-1	E+
L.1	26.72	16.99	4.84	3.98	21.23	15.17	6.43	8.46
L.2	21.95	14.36	5.29	3.74	17.47	12.67	6.62	7.54
L.3	17.21	11.58	5.94	3.57	13.63	10.02	6.83	6.60
L.4	12.50	8.69	6.23	3.48	9.74	7.34	7.19	5.73
L.5	7.83	5.56	6.72	3.44	5.95	4.71	7.49	4.74
L.6	3.46	1.26	7.39	3.43	2.64	1.03	8.44	3.67

Table 53 The $EP_{H/C,nd}$ homogeneity index for Rome and Palermo

	ROMA				PALERMO			
Level	$EP_{H,nd}$		$EP_{C,nd}$		$EP_{H,nd}$		$EP_{C,nd}$	
	11300-1	E+	11300-1	E+	11300-1	E+	11300-1	E+
L.1	11.15	10.35	7.53	12.60	6.46	7.80	9.42	14.84
L.2	8.71	8.36	7.75	11.26	4.82	5.74	9.97	13.20
L.3	6.44	6.33	8.06	9.81	3.02	3.61	10.58	11.45
L.4	4.17	4.27	8.41	8.31	1.49	1.66	11.50	9.59
L.5	1.67	2.02	8.94	6.44	0.15	0.40	12.97	7.30
L.6	0.00	0.06	9.82	4.35	0.00	0.00	15.07	4.75

Table 54 Belluno. Energy performance of the building units calculated with Steady-State and Dynamic Codes. Comparison of results.

Level of Thermal insulation		$EP_{\mathrm{H,nd}}$		Δ%		$EP_{\mathrm{C,nd}}$		Δ%	
		11300-1	E+			11300-1	E+		
L.1	BU0A	115.73	73.33	57.8%		1.00	6.91	-85.5%	
	BU0B	103.41	63.44	63.0%		5.00	7.04	-29.0%	
	BU0C	114.02	75.49	51.1%		0.00	3.28	-100.0%	
	BU1A	59.65	42.61	40.0%		5.71	8.72	-34.5%	
	BU1B	52.38	34.15	53.4%		15.42	9.91	55.6%	
	BU1C	64.58	45.79	41.0%		3.82	4.87	-21.6%	
	BU2A	99.34	74.99	32.5%		8.15	13.67	-40.4%	
	BU2B	103.13	66.39	55.3%		10.20	15.35	-33.6%	
	BU2C	114.93	78.00	47.3%		3.02	9.35	-67.7%	
	Building	84.76	57.63	47.1%		5.44	7.96	-31.7%	
L.2	BU0A	92.80	61.74	50.3%		2.53	7.73	-67.2%	
	BU0B	84.02	53.32	57.6%		8.10	8.10	0.1%	*
	BU0C	92.94	64.35	44.4%		1.61	3.94	-59.2%	
	BU1A	47.13	36.02	30.9%		8.29	9.39	-11.7%	*
	BU1B	41.93	28.85	45.4%		18.22	10.95	66.4%	
	BU1C	52.63	39.11	34.6%		5.77	5.58	3.6%	*
	BU2A	79.47	63.26	25.6%		10.60	13.50	-21.5%	
	BU2B	84.02	55.86	50.4%		12.85	15.58	-17.5%	*
	BU2C	94.07	66.41	41.6%		4.55	9.33	-51.3%	
	Building	68.54	48.86	40.3%		7.62	8.54	-10.8%	*
L.3	BU0A	70.13	49.57	41.5%		4.82	8.88	-45.8%	
	BU0B	64.96	42.73	52.0%		12.22	9.59	27.4%	
	BU0C	71.93	52.56	36.9%		3.35	4.91	-31.8%	
	BU1A	34.89	29.07	20.0%		10.84	10.41	4.1%	*
	BU1B	31.71	23.32	36.0%		21.63	12.46	73.6%	
	BU1C	40.74	32.05	27.1%		8.38	6.56	27.7%	
	BU2A	59.64	50.87	17.2%	*	14.39	13.64	5.6%	*
	BU2B	64.93	44.80	44.9%		16.78	16.17	3.8%	*
	BU2C	73.51	54.10	35.9%		7.04	9.59	-26.5%	
	Building	52.50	39.61	32.5%		10.42	9.45	10.2%	*
L.4	BU0A	47.94	37.13	29.1%		9.33	10.49	-11.1%	*
	BU0B	45.95	32.03	43.5%		16.81	11.61	44.8%	
	BU0C	51.34	40.37	27.2%		6.49	6.23	4.1%	*
	BU1A	23.05	21.87	5.4%	*	14.02	11.80	18.8%	*
	BU1B	21.95	17.71	23.9%		25.69	14.30	79.6%	
	BU1C	29.10	24.63	18.2%	*	11.05	7.91	39.7%	
	BU2A	40.32	37.92	6.3%	*	18.27	14.13	29.3%	
	BU2B	45.92	33.34	37.7%		20.81	17.23	20.8%	
	BU2C	53.09	41.08	29.2%		10.40	10.18	2.2%	*
	Building	36.78	30.01	22.6%		13.87	10.74	29.2%	
L.5	BU0A	26.63	23.81	11.9%	*	14.58	13.01	12.1%	*
	BU0B	27.55	20.76	32.7%		22.97	14.50	58.4%	
	BU0C	31.16	27.05	15.2%	*	11.30	8.26	36.9%	
	BU1A	12.24	14.58	-16.1%	*	18.52	13.71	35.2%	
	BU1B	12.90	12.07	6.8%	*	30.76	16.70	84.2%	
	BU1C	17.96	17.00	5.7%	*	14.55	9.89	47.1%	
	BU2A	22.00	24.68	-10.8%	*	23.79	15.23	56.2%	
	BU2B	27.59	21.91	25.9%		26.29	18.86	39.3%	
	BU2C	33.00	27.48	20.1%		14.23	11.31	25.8%	
	Building	21.73	20.03	8.5%	*	18.45	12.66	45.7%	
L.6	BU0A	8.38	2.06	306.3%		23.25	16.56	40.4%	
	BU0B	11.08	1.62	583.4%		31.79	18.34	73.3%	
	BU0C	12.55	3.32	278.5%		18.11	11.43	58.4%	
	BU1A	4.07	0.00		*	24.76	16.17	53.1%	
	BU1B	5.25	0.00		*	37.47	19.64	90.8%	
	BU1C	8.20	0.00		*	19.44	12.63	53.9%	
	BU2A	7.03	0.00		*	32.08	17.16	86.9%	
	BU2B	11.15	0.00		*	33.93	21.22	59.9%	
	BU2C	14.39	0.00		*	20.09	13.21	52.1%	
	Building	8.64	0.62	1290.7%		25.02	15.36	63%	

(*) Δ% < 20%

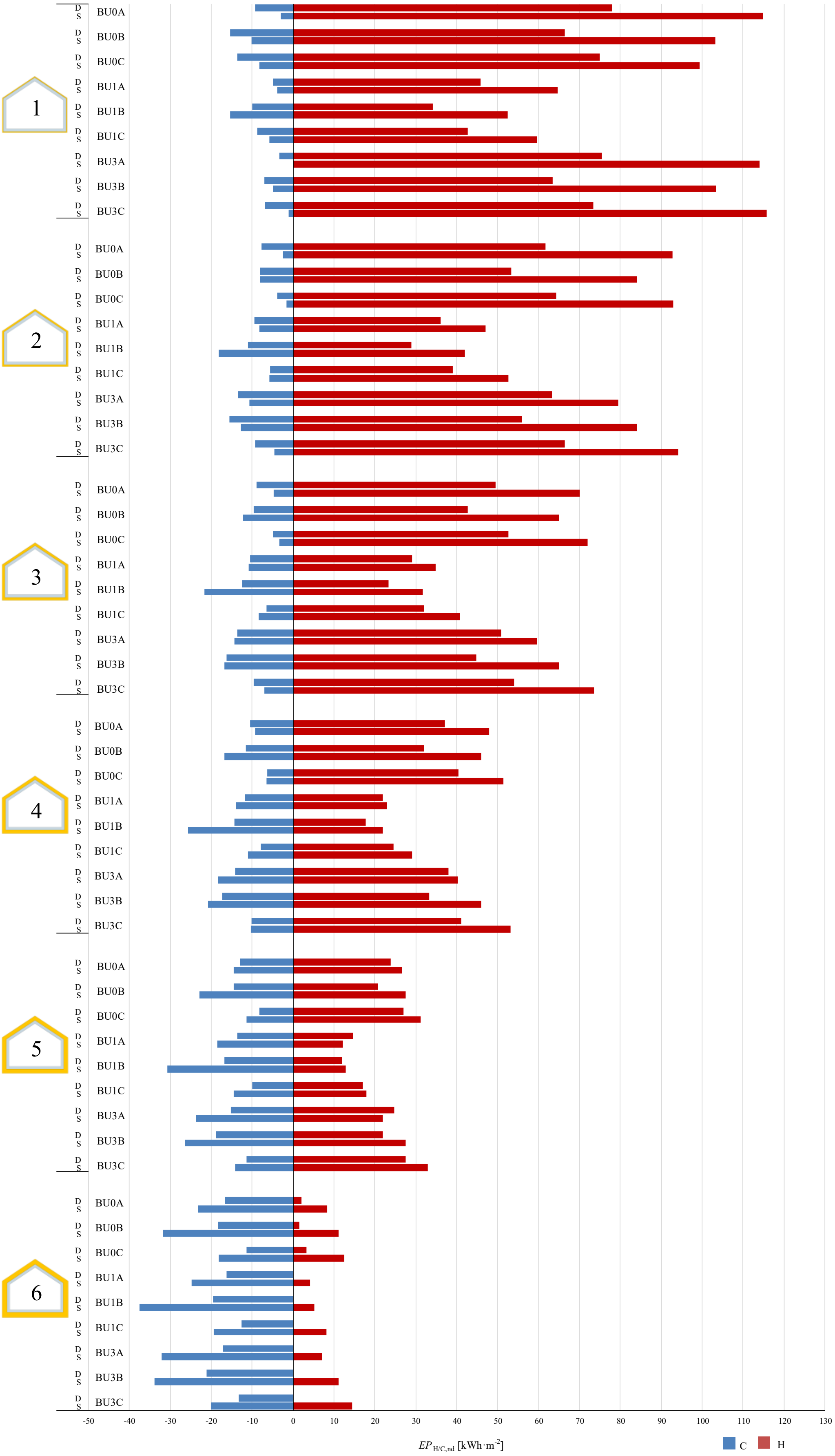


Fig. 6. Belluno. Energy performance of the building units calculated with Steady-State and Dynamic Codes. Comparison of results.

Table 55 Turin. Energy performance of the building units calculated with Steady-State and Dynamic Codes. Comparison of results.

Level of Thermal insulation		$EP_{\mathrm{H,nd}}$		Δ%		$EP_{\mathrm{C,nd}}$		Δ%	
		11300-1	E+			11300-1	E+		
L.1	BU0A	88.43	63.33	39.6%		15.01	14.03	7.0%	*
	BU0B	76.09	51.22	48.5%		20.88	14.91	40.1%	
	BU0C	87.61	61.18	43.2%		11.97	13.16	-9.0%	*
	BU1A	44.66	35.06	27.4%		19.62	17.82	10.1%	*
	BU1B	35.70	24.98	42.9%		29.77	21.05	41.4%	
	BU1C	48.68	34.82	39.8%		16.25	18.16	-10.5%	*
	BU2A	75.62	63.00	20.0%		27.53	30.61	-10.1%	*
	BU2B	75.90	52.81	43.7%		28.34	35.96	-21.2%	
	BU2C	88.43	62.86	40.7%		18.77	30.37	-38.2%	
	Building	63.77	46.33	37.6%		19.85	20.77	-4.4%	*
L.2	BU0A	70.39	52.29	34.6%		17.37	15.04	15.5%	*
	BU0B	60.83	42.01	44.8%		23.71	15.96	48.6%	
	BU0C	71.06	51.47	38.1%		14.06	13.74	2.4%	*
	BU1A	34.75	28.98	19.9%	*	21.52	18.56	15.9%	*
	BU1B	27.58	20.70	33.2%		32.71	21.64	51.1%	
	BU1C	39.13	29.42	33.0%		17.96	18.44	-2.6%	*
	BU2A	59.72	52.49	13.8%	*	29.45	29.40	0.2%	*
	BU2B	60.71	43.79	38.6%		30.45	34.99	-13.0%	*
	BU2C	71.95	53.04	35.6%		20.20	28.76	-29.7%	
	Building	50.94	38.70	31.6%		21.88	20.88	4.8%	*
L.3	BU0A	52.60	40.75	29.1%		20.16	16.47	22.4%	
	BU0B	45.64	32.56	40.2%		27.07	17.53	54.4%	
	BU0C	54.50	41.28	32.0%		16.54	14.65	12.9%	*
	BU1A	25.13	22.83	10.0%	*	24.26	19.60	23.8%	
	BU1B	19.95	16.34	22.1%		35.72	22.65	57.8%	
	BU1C	29.73	23.77	25.1%		19.96	19.05	4.8%	*
	BU2A	44.04	41.46	6.2%	*	31.87	28.50	11.8%	*
	BU2B	45.61	34.41	32.5%		33.11	34.28	-3.4%	*
	BU2C	55.46	42.69	29.9%		21.94	27.40	-19.9%	*
	Building	38.30	30.76	24.5%		24.35	21.33	14.1%	*
L.4	BU0A	35.10	29.27	19.9%	*	23.67	18.28	29.5%	
	BU0B	30.71	23.44	31.0%		31.37	19.22	63.3%	
	BU0C	38.17	30.87	23.6%		19.58	15.92	23.0%	
	BU1A	16.05	16.66	-3.7%	*	27.04	20.69	30.7%	
	BU1B	12.81	11.84	8.2%	*	39.23	23.45	67.3%	
	BU1C	20.69	18.11	14.3%	*	22.78	19.87	14.6%	*
	BU2A	28.99	30.17	-3.9%	*	35.41	28.03	26.3%	
	BU2B	30.79	24.94	23.5%		36.72	33.71	8.9%	*
	BU2C	39.20	31.91	22.9%		24.14	26.72	-9.7%	*
	Building	26.04	22.71	14.6%	*	27.43	22.01	24.6%	
L.5	BU0A	18.73	17.57	6.6%	*	28.90	20.55	40.6%	
	BU0B	16.84	14.01	20.2%		37.05	21.70	70.7%	
	BU0C	22.41	19.98	12.2%	*	24.01	17.87	34.3%	
	BU1A	8.12	10.31	-21.2%		30.34	21.77	39.4%	
	BU1B	6.42	7.20	-10.8%	*	43.59	24.82	75.7%	
	BU1C	12.25	12.23	0.2%	*	25.72	21.03	22.3%	
	BU2A	15.09	18.83	-19.9%	*	39.41	28.08	40.3%	
	BU2B	17.00	15.38	10.5%	*	40.97	33.07	23.9%	
	BU2C	23.53	20.97	12.2%	*	27.55	26.18	5.2%	*
	Building	14.61	14.46	1.1%	*	31.28	23.04	35.8%	
L.6	BU0A	5.03	1.68	199.0%		35.84	22.81	57.1%	
	BU0B	5.22	1.30	302.6%		44.64	24.55	81.8%	
	BU0C	8.48	2.73	211.3%		29.48	20.13	46.5%	
	BU1A	1.86	0.00			35.94	22.12	62.4%	
	BU1B	1.47	0.00			50.06	25.99	92.6%	
	BU1C	5.00	0.00			29.63	21.85	35.6%	
	BU2A	3.82	0.00			46.04	27.30	68.6%	
	BU2B	5.30	0.00			47.40	31.85	48.8%	
	BU2C	9.45	0.00			31.66	26.07	21.4%	
	Building	4.94	0.51	872.7%		36.75	23.86	54.0%	

(*) Δ% < 20%

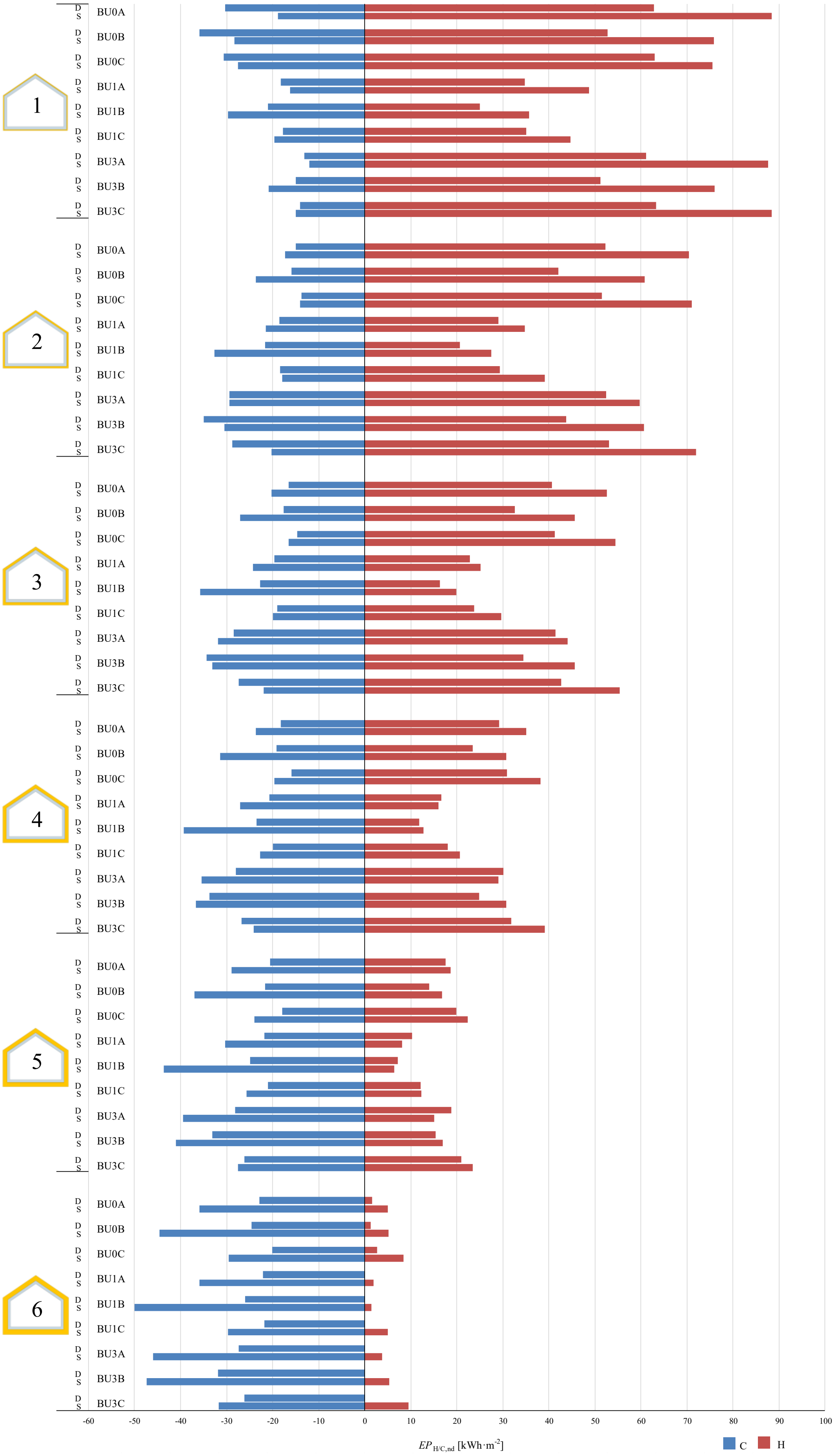


Fig. 7. Turin. Energy performance of the building units calculated with Steady-State and Dynamic Codes. Comparison of results.

Table 56 Rome. Energy performance of the building units calculated with Steady-State and Dynamic Codes. Comparison of results.

Level of Thermal insulation		$EP_{\mathrm{H,nd}}$		Δ%		$EP_{\mathrm{C,nd}}$		Δ%	
		11300-1	E+			11300-1	E+		
L.1	BU0A	35.43	33.74	5.0%	*	29.90	20.43	46.4%	
	BU0B	33.78	29.55	14.3%	*	35.00	18.01	94.4%	
	BU0C	38.21	35.31	8.2%	*	25.24	17.28	46.1%	
	BU1A	12.93	10.92	18.4%	*	32.08	25.85	24.1%	
	BU1B	11.78	7.53	56.5%		42.81	25.45	68.2%	
	BU1C	17.06	12.95	31.8%		27.10	23.88	13.5%	*
	BU2A	27.72	23.34	18.8%	*	44.57	46.26	-3.7%	*
	BU2B	32.57	19.58	66.4%		43.95	48.72	-9.8%	*
	BU2C	37.97	25.72	47.7%		33.48	42.83	-21.8%	
	Building	24.63	19.71	24.9%		33.18	28.43	16.7%	*
L.2	BU0A	25.20	26.18	-3.8%	*	31.62	20.76	52.3%	
	BU0B	24.68	22.64	9.0%	*	37.38	18.81	98.7%	
	BU0C	28.55	28.28	1.0%	*	26.54	17.59	50.9%	
	BU1A	8.35	7.95	5.0%	*	33.95	25.53	33.0%	
	BU1B	7.77	5.27	47.5%		45.47	25.62	77.5%	
	BU1C	12.20	10.16	20.1%		28.73	23.65	21.5%	
	BU2A	19.71	18.31	7.7%	*	46.04	43.60	5.6%	*
	BU2B	24.27	15.05	61.2%		45.68	46.50	-1.8%	*
	BU2C	28.90	20.83	38.8%		33.95	40.22	-15.6%	*
	Building	17.79	15.37	15.8%	*	34.83	27.81	25.2%	
L.3	BU0A	16.09	18.52	-13.1%	*	33.85	21.43	57.9%	
	BU0B	16.54	15.77	4.9%	*	40.69	20.20	101.4%	
	BU0C	19.21	21.08	-8.9%	*	28.53	18.20	56.8%	
	BU1A	4.14	5.05	-18.0%	*	36.27	25.58	41.8%	
	BU1B	4.05	3.12	30.1%		48.89	26.42	85.0%	
	BU1C	7.71	7.20	7.0%	*	30.71	23.77	29.2%	
	BU2A	12.20	12.90	-5.4%	*	48.01	41.05	17.0%	*
	BU2B	16.32	10.22	59.7%		47.84	44.42	7.7%	*
	BU2C	20.18	15.64	29.0%		34.92	37.77	-7.5%	*
	Building	11.41	10.90	4.7%	*	37.01	27.52	34.5%	
L.4	BU0A	7.86	10.93	-28.1%		37.29	22.38	66.6%	
	BU0B	9.10	9.12	-0.2%	*	44.79	21.78	105.7%	
	BU0C	10.98	13.97	-21.4%		31.30	19.01	64.6%	
	BU1A	1.09	2.36	-53.7%		39.80	25.46	56.4%	
	BU1B	1.28	1.24	3.1%	*	52.90	26.97	96.1%	
	BU1C	3.53	4.36	-18.9%	*	33.21	23.96	38.6%	
	BU2A	5.28	7.37	-28.4%		50.96	38.54	32.2%	
	BU2B	8.97	5.47	63.9%		50.78	42.11	20.6%	
	BU2C	12.05	10.03	20.1%		36.69	35.53	3.2%	*
	Building	5.78	6.49	-11.0%	*	40.01	27.26	46.7%	
L.5	BU0A	1.47	3.43	-57.2%		42.81	24.16	77.2%	
	BU0B	2.53	2.66	-4.9%	*	50.72	24.45	107.4%	
	BU0C	3.72	6.41	-41.9%		35.38	20.72	70.8%	
	BU1A	0.00	0.41	-100.0%		43.93	25.72	70.8%	
	BU1B	0.00	0.15	-100.0%		57.67	28.21	104.5%	
	BU1C	0.70	1.57	-55.6%		36.91	24.71	49.4%	
	BU2A	0.60	2.12	-71.8%		55.83	35.99	55.1%	
	BU2B	2.50	1.28	95.8%		55.45	39.62	40.0%	
	BU2C	4.61	4.46	3.3%	*	39.44	33.40	18.1%	*
	Building	1.55	2.34	-33.6%		44.24	27.50	60.9%	
L.6	BU0A	0.00	0.00			51.41	25.94	98.2%	
	BU0B	0.00	0.00			58.98	27.34	115.7%	
	BU0C	0.00	0.19			42.22	23.14	82.4%	
	BU1A	0.00	0.00			51.41	25.10	104.8%	
	BU1B	0.00	0.00			65.10	28.72	126.7%	
	BU1C	0.00	0.00			41.47	25.42	63.1%	
	BU2A	0.00	0.00			63.86	32.45	96.8%	
	BU2B	0.00	0.00			62.18	36.38	70.9%	
	BU2C	0.00	0.00			44.51	31.35	42.0%	
	Building	0.00	0.02	-100.0%		50.82	27.48	85%	

(*) Δ% < 20%

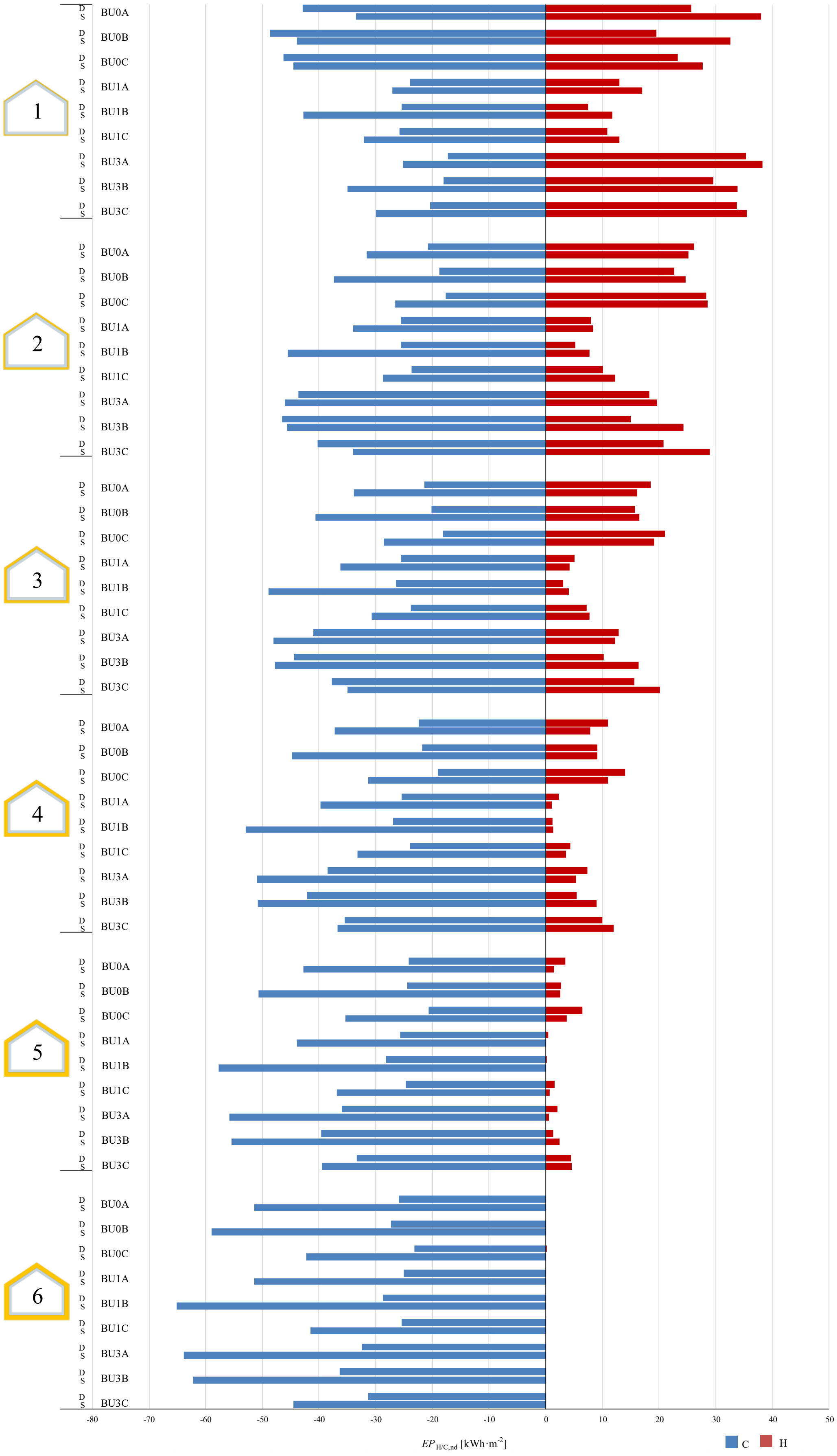


Fig. 8. Rome. Energy performance of the building units calculated with Steady-State and Dynamic Codes. Comparison of results.

Table 57 Palermo. Energy performance of the building units calculated with Steady-State and Dynamic Codes. Comparison of results.

Level of Thermal insulation		$EP_{\mathrm{H,nd}}$		Δ%		$EP_{\mathrm{C,nd}}$		Δ%	
		11300-1	E+			11300-1	E+		
L.1	BU0A	17.58	19.47	-9.7%	*	36.83	22.31	65.1%	
	BU0B	10.18	15.69	-35.1%		45.07	20.10	124.2%	
	BU0C	18.85	21.85	-13.7%	*	31.26	18.99	64.7%	
	BU1A	5.01	2.66	88.2%		37.99	29.29	29.7%	
	BU1B	0.76	0.92	-17.8%	*	54.13	29.08	86.1%	
	BU1C	6.73	3.80	77.0%		32.51	27.63	17.7%	*
	BU2A	12.37	7.67	61.3%		51.99	52.94	-1.8%	*
	BU2B	10.39	4.78	117.2%		54.39	56.20	-3.2%	*
	BU2C	18.70	9.47	97.4%		39.70	49.66	-20.1%	
	Building	10.21	8.20	24.5%		40.29	32.45	24.1%	
L.2	BU0A	11.44	13.76	-16.8%	*	38.05	22.74	67.3%	
	BU0B	5.95	10.43	-42.9%		48.15	20.92	130.2%	
	BU0C	13.41	16.25	-17.4%	*	32.45	19.47	66.7%	
	BU1A	2.47	1.55	59.4%		39.68	28.58	38.9%	
	BU1B	0.00	0.49	-100.0%		57.47	28.83	99.3%	
	BU1C	4.05	2.48	63.1%		34.28	27.17	26.2%	
	BU2A	7.66	5.09	50.5%		53.57	49.66	7.9%	*
	BU2B	6.09	2.88	111.7%		56.52	53.35	5.9%	*
	BU2C	13.44	6.81	97.3%		40.08	46.33	-13.5%	*
	Building	6.55	5.69	15.2%	*	42.03	31.53	33.3%	
L.3	BU0A	6.28	8.01	-21.6%		40.54	23.48	72.7%	
	BU0B	2.38	5.40	-55.9%		51.71	22.40	130.8%	
	BU0C	7.94	10.60	-25.0%		34.11	20.21	68.8%	
	BU1A	0.78	0.75	4.9%	*	41.83	28.17	48.5%	
	BU1B	0.00	0.20	-100.0%		61.69	29.31	110.5%	
	BU1C	1.74	1.33	30.6%		36.19	26.98	34.2%	
	BU2A	3.48	2.73	27.6%		55.31	46.57	18.8%	*
	BU2B	2.49	1.44	73.0%		58.90	50.51	16.6%	*
	BU2C	7.96	4.07	95.8%		41.04	43.23	-5.1%	*
	Building	3.37	3.32	1.4%	*	44.24	30.92	43.1%	
L.4	BU0A	2.03	3.07	-33.9%		43.68	24.30	79.8%	
	BU0B	0.00	1.74	-100.0%		56.54	24.09	134.7%	
	BU0C	3.49	5.19	-32.8%		37.05	21.12	75.4%	
	BU1A	0.00	0.26	-100.0%		44.96	27.80	61.7%	
	BU1B	0.00	0.03	-100.0%		67.39	29.84	125.8%	
	BU1C	0.00	0.57	-100.0%		38.72	26.88	44.0%	
	BU2A	0.81	1.12	-27.9%		58.37	43.40	34.5%	
	BU2B	0.00	0.51	-100.0%		62.76	47.27	32.8%	
	BU2C	3.31	1.90	74.5%		42.94	40.36	6.4%	*
	Building	1.00	1.43	-30.4%		47.48	30.39	56.3%	
L.5	BU0A	0.00	0.45	-100.0%		48.58	25.82	88.1%	
	BU0B	0.00	0.20	-100.0%		63.98	26.60	140.5%	
	BU0C	0.33	1.26	-73.7%		41.02	22.65	81.1%	
	BU1A	0.00	0.00	-100.0%		49.44	27.36	80.7%	
	BU1B	0.00	0.00			74.99	30.07	149.4%	
	BU1C	0.00	0.14	-100.0%		42.37	27.05	56.6%	
	BU2A	0.00	0.28	-100.0%		63.34	39.57	60.1%	
	BU2B	0.00	0.08	-100.0%		68.91	43.30	59.1%	
	BU2C	0.34	0.53	-36.0%		45.78	37.60	21.7%	
	Building	0.08	0.31	-75.1%		52.19	29.95	74.3%	
L.6	BU0A	0.00	0.00			57.47	27.29	110.6%	
	BU0B	0.00	0.00			76.74	28.79	166.5%	
	BU0C	0.00	0.00			48.07	25.10	91.5%	
	BU1A	0.00	0.00		*	56.48	25.96	117.5%	
	BU1B	0.00	0.00		*	83.96	29.59	183.7%	
	BU1C	0.00	0.00		*	47.77	27.25	75.3%	
	BU2A	0.00	0.00		*	72.27	34.58	109.0%	
	BU2B	0.00	0.00		*	80.24	38.74	107.1%	
	BU2C	0.00	0.00		*	51.41	34.23	50.2%	
	Building	0.00	0.00			59.75	29.18	105%	

(*) Δ% < 20%

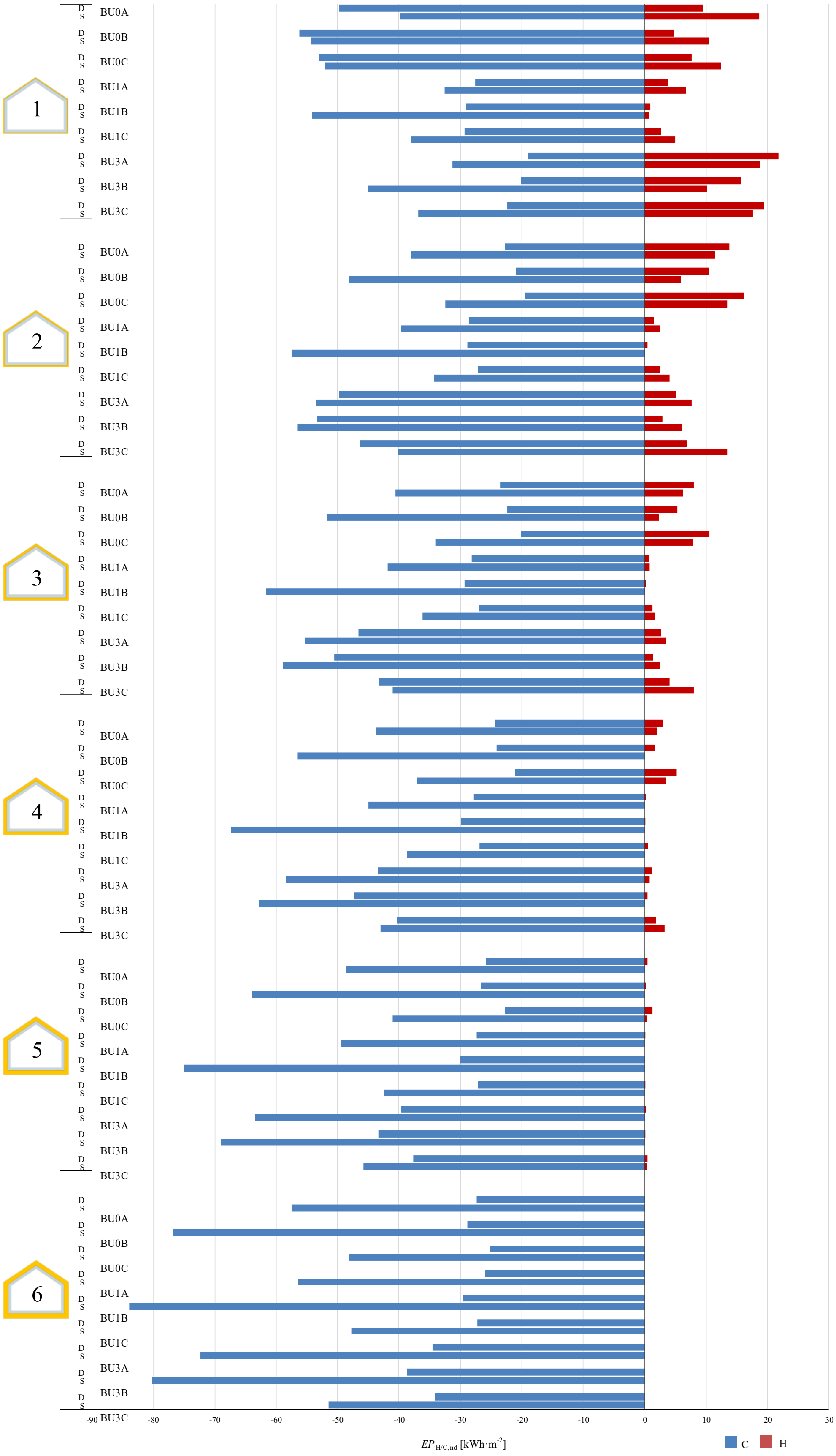


Fig. 9. Palermo. Energy performance of the building units calculated with Steady-State and Dynamic Codes. Comparison of results.

In the charts the thermal insulating levels start at L.1 (poorly insulated building envelope) to L.6 (highly insulated building envelope).

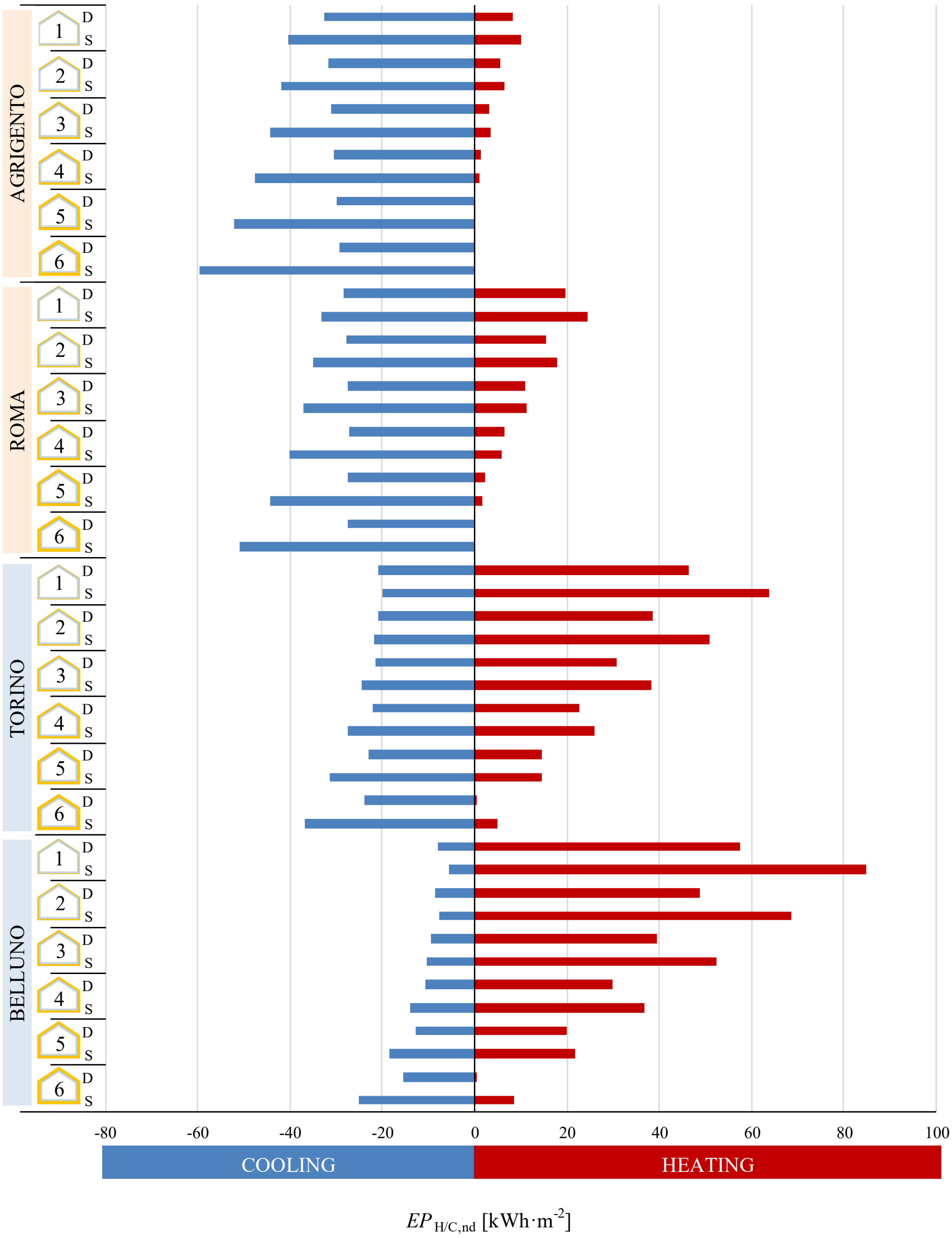


Fig. 10. Comparison of the energy performance of the whole building calculated with Dynamic energy simulation - EnergyPlus (D) and Quasi-Steady State Method (S)

2.1.6 Conclusions

The main conclusion of this chapter concerns the limits of the Quasi-Steady State method (monthly method of EN 13790) to predict the energy needs of NZEB accurately.

In order to compare the thermal energy need obtained with the two calculation models analysed (quasi-steady methodology and detailed numerical simulation code), a study was carried out aimed at making the calculation procedures and the input data homogeneous.

In particular, on the one hand I proceeded to standardize the climate data from the hourly climate file, on the other hand I have made some changes to the detailed model in order to adapt it to a comparison with the quasi-steady methodology.

In the technical literature there are several studies that compare the two methods of calculation. However, no study seen goes into detail considering both the building and its building units.

In the chapter, the influence of thermal insulation levels on the convergence results between the two approaches have been studied. Regardless the application of consistency options, huge deviations appear in warm climates both for heating and cooling energy needs. For the studied building the deviations for a highly insulated building can exceed even 80%. If, on the other hand, the individual building units are examined, the deviations are even greater than 120%. However, it should be noted that, despite the percentage variations of thermal performance are very large, there occur for very isolated buildings and hot locations and therefore for buildings with very low energy needs.

For Turin, in the case of assessments of the $EP_{\mathrm{C,nd}}$ of the whole building, for thermal insulation levels L.1, L.2 and L.3 the Quasi-Steady State Approach allows to obtain representative results with a 20% deviation from the results calculated with EnergyPlus. The same consideration applies to Belluno with regard to thermal insulation levels L.2 and L.3. For Turin, for the $EP_{\mathrm{C,nd}}$ assessments of the whole building, for thermal insulation levels L.5, L.6 the Quasi-Steady State Approach allows to obtain representative results with a 20% deviation from the results calculated with EnergyPlus. Important deviations appear in warm localities (Rome and Agrigento), prevalently in the heating energy need.

In any case, the more important deviation appears in the assessment of single building units where there are no compensations between energy needs. It follows that the verification of the whole building without adequate attention to the individual building units may involve to significant design errors. Another aspect that stands out regards the cooling energy needs. In fact, while for some levels of thermal insulation, and for some locations, heating energy need are very low or nearly to zero, for all case studies there is always a non-negligible cooling energy need. It is therefore conceivable that in the coming years the industry will focus on technical building systems capable of responding adequately to summer energy need.

Regardless the application of consistency options, huge deviations occur in the energy needs of the quasi-steady (UNI/TS 11300) and dynamic (*Energy Plus*) methods. The probable introduction of the hourly calculation procedures as a reference calculation methodology in the MD and in technical standards is advisable to accurately assess the *EP* of NZEBs.

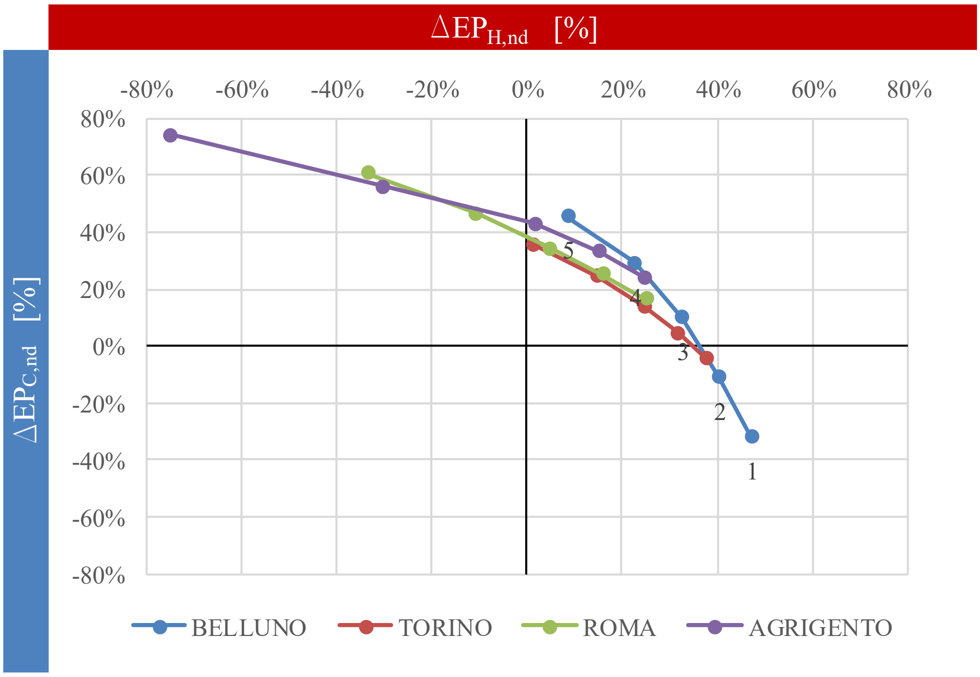


Fig. 11. Percentage variation of the thermal performance of the whole building between the two calculation methods for the analysed location

Chapter 3

3 Design of NZEB

According to EPBD Recast (2010), the design of buildings should promote passive heating and cooling elements, solar shading, indoor air-quality, adequate natural light and design of the building by the means of passive cooling techniques. Therefore, the design of buildings should be focused on measures which avoid overheating to maintain the envisaged temperature conditions of the building, such as natural ventilation, solar shading and an adequate thermal capacity. Therefore, the EPBD Recast consider necessary passive design applications in buildings.

The main objective of this chapter is to identify the energy efficient technical solutions applicable to the design of NZEBs. The success of the conversion of existing buildings in NZEBs depends on the containment of their thermal energy needs of fabric.

The traditional design and legislative requests focus essentially on aspects related to the thermal insulation, and on the limitation of thermal bridges of the building envelope. These indications have good results mainly in cold climates with different results depending on the type of building studied (construction period of the building). A further "*weak link in the chain*" in the design of high energy performance buildings is the availability and characteristics of transparent surfaces. The transparent building envelope in fact, especially in the NZEBs, can contribute to the summer overheating of the building rooms. As seen in the previous sections almost all low or nearly zero-energy buildings are characterized by high cooling energy need (that is, they have generally higher cooling energy needs than heating ones). Finally, the construction of high-performance buildings should be based on measures which are technically, functionally and economically feasible. Current analyses indicate that the conversion of existing buildings to NZEBs is not economically viable. The NZEB design studies are rather general and similar, as is the approach to the problem. Therefore, the need to expand the field of investigation with the aim of contemplating the effect of the design choices on the building energy needs emerges. In this context the attention is shifted from an approach related to the whole building to that of the single building unit. This chapter aims to investigate the conditions and extent to which the thermal insulation of a building envelope is beneficial for containing overall energy needs and to maximise the overall EP of the building. A survey methodology is proposed for carrying out a parametric analysis on case studies in order to understand in which boundary conditions the importance of the building envelope design increases (thermal bridge, opaque building envelope, transparent building envelope). These aspects are addressed in the following paragraphs.

3.1 Minimization of Thermal Bridges

The evaluation of heat loss through thermal bridges is a strongly debated topic at national and international levels in the evaluation of NZEBs. The interest in this topic is mainly due to the impact that thermal bridges have on the energy needs of buildings, especially in colder climates.

In the Intelligent Energy Europe project ASIEPI "*Assessment and Improvement of the EPBD Impact (for new buildings and building renovation)*"[23], there is a review of the various approaches used by MS to include thermal bridges in their regulations, the research has evaluated their impact on the *EP* of buildings.

From the IIE project [23], although now dated, it emerges that the problems related to thermal bridges are still an important topic throughout Europe, since the impact of thermal bridges on the heating energy need of buildings in the heating period can be on average over 30%. On the other hand, this problem is often not solved by individual MS which, at legislative and regulatory levels, do not set minimum requirements or control the constructive quality of technical details. Only some MSs have included in their regulation specific requirements concerning the quality of building junctions (maximum linear *U*-value or minimum dimensionless temperature factors).

The international scientific studies address different areas of investigation: (a) the thermal behaviour of a structural node affected by multidimensional thermal exchanges in order to optimize the technological choice, (b) the impact of multidimensional thermal exchanges on the dynamic energy requirements of buildings, and (c) the development of a calculation codes or models to support the dynamic *simulation-codes* currently on the market.

The impact of thermal bridges on the energy needs is more pronounced in the building energy retrofit of existing buildings where their effect is not controllable (since it depends within the characteristics of the architectural project) and it represent the starting point for the implementation of whichever measures of energy restructuring. For example, among the typical thermal bridges are considered those due to pillars, beams, lintels, thresholds, jambs and walls situated under windows.

The Italian MD 26.06.2015 allows a 30% derogation on limit values of thermal transmittance of existing buildings opaque walls in two cases: thermal insulation of the inner part of building elements or insufflation with thermal insulating materials in cavity walls.

Evola et al. (2011) [24] have shown that some thermal bridge correction solutions adopted in terraced and short-term residential buildings, although they allow to reduce energy needs (21% reduction on primary energy needs in winter), are not economically viable, since the return period of the investment is greater than 25 years or in some cases even greater than the useful life of the building.

Zedan et al. (2016) [25] have highlighted the importance of reducing thermal bridging effects resulting from mortar joints in walls by maintaining the continuity of the thermal insulation layer in order to reduce energy needs in buildings.

Ge and Baba (2015) [26] have investigated the effect of thermal bridges on the energy performance of residential buildings with high thermal mass under the cold climate of Canada (in the province of British Columbia, Canada). The results obtained with dynamic simulation have shown that the effect of thermal bridges: (a) in case of concrete construction increases the heating energy need by 38÷42% and decreases the cooling energy need by 8÷26%, and (b) for brick veneer buildings increases the heating energy needs by 24–28%. The authors established that, compared to the 3D dynamic modelling approach, the energy need can be underestimated by up to 13% by the equivalent thermal transmittance method (adjust the value of thermal conductivity of the thermal insulation level of the one-dimensional multi-layered component such as that its *U*-value is equal to the overall *U*-value including the thermal bridges, the other thermos-physical properties of multi-layered components are kept unchanged) and up to 10% by the equivalent wall method (equivalent structure characterized by the same dynamic thermal characteristics as the complex wall to account for the thermal inertia effect of thermal bridges).

Stazi et al. (2015) [27] have studied the effect of both high thermal insulation and high thermal mass techniques in the envelope of buildings in Mediterranean climates. The authors have compared the solutions in terms of comfort, energy performance and global cost. The research has allowed to define a dynamic design solution of the building envelope that offers good energy performances both in winter and in summer through the maximization of the internal thermal capacity and the insertion of an external thermal insulation layer sealed in winter and ventilated in the cooling period. This dynamic thermal insulation system reduces energy needs, respectively, of about 20% in the winter and 43% in the summer compared to the worst retrofit solution (the case study is located in central Italy in a locality characterized by 1647 DD).

According to Balaras and Argiriou (2002) [28] the effect of thermal bridges on the energy needs, causes heat losses during heating season and heat gains during cooling season; in addition they are delicate parts of buildings by increasing the risk of mould formation due to condensation as a consequence of the decrease in the cooling season of the air-temperature of the interior surfaces.

The heat exchange under steady-state conditions through the thermal bridges can be determinated using the technical standard EN ISO 10211 [247] which presents both detailed and simplified methods to calculate thermal losses through thermal bridges.

Thermal bridges can also be identified visually by means of thermographic building inspections. In the scientific literature there are several studies that have been published. Garrido et al. (2018) [29] have deepened thermal-based analysis for the detection and characterization of thermal bridges in buildings. By means photogrammetric technique and thermal images the thermal bridges can be used as reference for geometrical measurement. In order to improve the geometric analysis, the proposed methodology has introduced image rectification (the procedure to measure the differences between the position of a point on the rectified image and its real position in the face envelope) and other thermal criteria to discard a thermal bridge that does not present a linear thermal transmittance value within a definite range.

In the refurbishment of existing buildings, built for the most part from the '70s through the '90s, the percentage incidence of thermal bridges on the limit values of building envelope transmittance is extremely significant. In general, the energy refurbishment of the enclosures of these buildings is carried out through thermal insulation, the positioning of the layer to the interior side or, in the case of walls with an empty case, with a layer of thermal insulation in the cavity. In general, these interventions do not allow to completely correct some thermal bridges which also, following the building interventions, continue to significantly influence the value of envelope heat transfer coefficient.

The purposes of this study are (a) improving the existing methodological framework concerning the verification of thermal performance of nearly zero-energy buildings through the methodology of the notional reference building by proposing, in the light of the results obtained, the adaptation of the approach including thermal bridges - whose effect is currently included in the *U*-value of the current section of the opaque components-, and (b) demonstrating, even for a single location, that the impact of thermal transmission due to thermal bridges is not negligible.

In proposing a solution to the problem, without modifying the verification criteria of the MD 26/06/2015 [143], a study was carried out to evaluate a possible archive of linear thermal transmittance values for the most common types of thermal bridges (referred to Italian climatic zones and common thermal insulation techniques).

3.1.1 Theory and Method

The software Iris of ANIT based on EN ISO 10211 [247] calculates the linear thermal transmittance of thermal bridges considering several boundary conditions (indoor and outdoor air temperature), geometric features (dimensions of walls, roofs, and other building envelope elements) and thermal properties of materials in the building elements (thermal conductivity, thermal resistance, etc.).

The calculation method used for the evaluation of the thermal energy needs of the building for heating service is provided by the UNI/TS 11300-1, but for a more realistic calculation, the detailed simulation (*EnergyPlus*) was used in this study. The standard climatic data of UNI 10349-1 ([130], [252]) have been considered.

For the building energy simulations, we used the dynamic computer program EnergyPlus. The effect of thermal bridges on the $EP_{\mathrm{H/C,nd}}$ of case studies was evaluated through whole building energy modelling using the equivalent *U*-value method while the material thermal properties of the multi-layered element are kept unchanged. As highlighted by Hua and Baba (2017) ([26],[230]) and Mao and Johannesson, (1997)[231] this method neglects the thermal inertia effect of thermal bridges. Therefore, this way of proceeding represents a simplification since the presence of thermal bridges not only increases the *U*-value but also changes the dynamic overall characteristics of the single elements and of the whole building.

3.1.2 Case Study

Two very common Italian constructions are analysed: (a) the first is a building intended for residential use with a floor area of 1226 m^2 divided into four floors above conditioned ground, while the staircase and the attic are not conditioned; and (b) the second is a single-family house with a floor area of 160 m^2.

The buildings are considered as a single air-conditioned heating zone for the heating period at a temperature of 20°C and for the cooling period at 26°C. The simulations of the energy performance of buildings are carried out in the Turin climate. The opaque envelope has an intermediate colour external surface (solar absorption coefficient of external opaque surfaces, $\alpha = 0.6$) and is made up of brick walls with thermal transmittance equal to 0.26 $W \cdot m^{-2}K$.

Table 58 Main geometric characteristics of the case studies

Single-family house (SFH)							Apartment block (AB)						
													
V_g	V_n	A_f	A_{env}	A_w	A_{env}/V_g	WWR	V_g	V_n	A_f	A_{env}	A_w	A_{env}/V_g	WWR
$[m^3]$	$[m^3]$	$[m^2]$	$[m^2]$	$[m^2]$	$[m^{-1}]$	[-]	$[m^3]$	$[m^3]$	$[m^2]$	$[m^2]$	$[m^2]$	$[m^{-1}]$	[-]
584	428	159	392	58	0.73	0.25	4288	3311	1226	1904	151	0.44	0.22

Table 60 shows the wall configurations analysed in the building refurbishment. The windows consist of a glazed system (double low emissivity glass) with U_w transmittance of 1.40 $W \cdot m^{-2}K$. The total solar transmittance by incidence normal glazing $g_{gl,n}$ is 0,67 [-]. The features of the building envelope have been chosen taking into account the indications of the MD 26/06/2015 [143] with regard to the notional reference building.

The ventilation rate is fixed at 0.3 h^{-1} constant both in the heating and cooling periods, while the unconditioned staircase and attic have been hypothesized without ventilation, both inwards and outwards.

The class of steam concentration adopted within the environments is n. 3 of UNI EN ISO 13788 [248] (environments without VMC - buildings with unknown crowding index) corresponding to a medium condition (note however that the present study is aimed at determining the energy parameters - Ψ of reference).

Thermal conductivities of involved construction materials are provided by the technical standards UNI 10351 [249], EN ISO 10456 [250] and UNI/TR 11552 [251].

3.1.3 Thermal Bridge

The characterization of a linear thermal bridge occurs through its linear thermal transmittance (ψ), which expresses the thermal flow transmitted through the thermal bridge by unit length and by unit of temperature difference between the air-conditioned and the external environment. The typical thermal bridge junctions related to the case studies identified in this research are: (a) intermediate floor junction; (b) intermediate wall/window junction; (c) balcony junction; (d) balcony sliding door junction; (e) partition wall junction; (f) roof junction; and (g) below-grade wall junction. For each type of thermal bridge, linear thermal transmittance has been determined through finite difference calculations according to the EN ISO 10211 standard [247], when the significant design parameters and the type of vertical opaque envelope vary. In order to compare the incidence of thermal bridges on building energy performance for three different construction technologies, the same case studies were evaluated respectively for: (i) external walls with insulation on the inside (INT); (ii) external walls with external insulation (EXT); and (iii) external walls with insulation in the cavity (CAV). Overall, 36 different thermal bridge configurations were considered.

The thickness of the thermal insulation used for each thermal bridge case is assessed in relation to the specific limit of thermal transmittance expected for the time horizon 2019/2021 (Table 1, Appendix B of the MD 26/06/2015 [143]) and approximated for excess in relation to the thicknesses of the materials.

Fig. 59 shows the following information: thermal characteristics of the vertical envelope (first row), and of the component that fits into the envelope (first column); for each intersection between row and column is reported the internal and external linear thermal transmittance of the junction.

The parameter that most influences the value of linear thermal transmittance is the type of vertical wall, for this reason all the possibilities for redevelopment have been considered in the study.

Each thermal bridge is identified by a code composed of the following sections:

Envelope component – Thermal insulation position – Typology of wall (INT – thermal insulation on the inner side, EXT thermal insulation on the outer side, CAV, cavity wall). For some of the thermal bridges analysed, corresponding to situations not optimal from the point of view of continuity of thermal insulation, some technological solutions that lead to the reduction of the thermal flow have been identified. The first case B1 corresponds to the unchanged thermal bridge (insulation of the external vertical wall). The other thermal bridges take into account a further correction of other constructive elements (e.g. thermal insulation of balcony junction) that modify the thermal flow. In Table 61 more alternative solutions are presented in order of thermal performance. It is evident that the thermal bridge on which there is less possibility of intervention is the one connected relative to the building envelope with thermal insulation placed on the inner side. In fact, in this case the reduction of the linear thermal transmittance value is very low.

The examined case studies are reported in the Table 59. Each case study considers the combination of different thermal bridges. For each typology of external wall, the ‘zero case’ corresponds to a building realized according to the standards value of the MD 26/06/2015 [143], but in which there are no thermal bridges. The Level 1, instead, corresponds to the positioning of the thermal insulation of the building envelope components, on the inside, towards the heated rooms (on the hot side of the building envelope). On the contrary, level 2 has the thermal insulation placed on the external side (on the cold side of the building envelope).

Table 59 Summary of the analysed case studies (position of thermal insulation in building envelope) and related thermal bridges

Case study	CAV			INT			EXT		
Thermal bridge	0	1	2	0	1	2	0	1	2
RF	-	RF-I_W-C	RF-E_W-C	-	RF-I_W-I	RF-E_W-I	-	RF-I_W-E	RF-E_W-E
GF	-	GF-I_W-C	GF-E_W-C	-	GF-I_W-I	GF-E_W-I	-	GF-I_W-E	GF-E_W-E
FL	-	FL-I_W-C	FL-E_W-C	-	FL-I_W-I	FL-E_W-I	-	FL-I_W-E	FL-E_W-E
IF	-	IF_W-C	IF_W-C	-	IF_W-I	IF_W-I	-	IF_W-E	IF_W-E
w	-	w_W-C	w_W-C	-	w_W-I	w_W-I	-	w_W-E	w_W-E
B	-	B-1 B-4	B-1 B-4	-	B1-B3	B1-B3	-	B1-B3	B1-B3

Fig. 12 shows for the apartment block and for each combination, the variation of the global heat transfer coefficient for transmission based on the position of thermal insulation. The percentage contribution of each thermal bridge present is also visible. Regarding the cavity wall thermal insulation, it can be noted that the thermal bridges that have greater relevance on the transmission losses are the B (external wall-balcony), P (external wall-pillar) and IF (external wall - intermediate floor). In comparison to the refurbishment with internal thermal insulation, the thermal bridges that weigh most on the overall heat transfer for transmission are: W (external wall - window); IF (external wall - inter-floor slab). Concerning the external thermal insulation (ETICS), the thermal bridges that have the greatest relevance on the transmission losses are the W (external wall - window) and the B (external wall -Balcony). The best combination in terms of performance is EXT_2_B3.

Table 60 Linear thermal transmittance of some thermal bridges

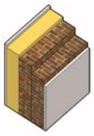
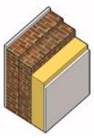
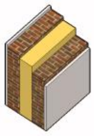
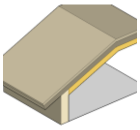
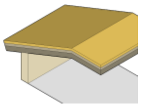
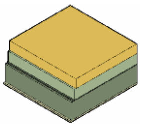
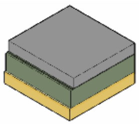
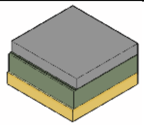
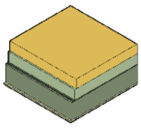
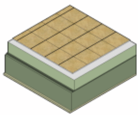
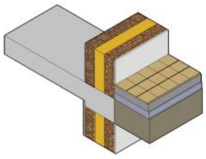
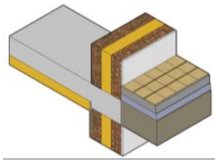
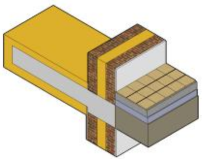
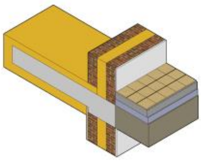
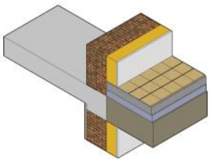
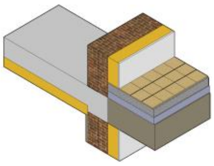
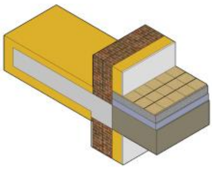
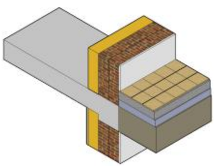
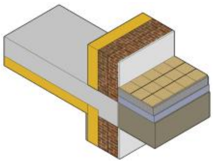
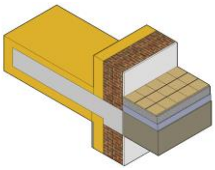
					Wall [W]				
					INT	**EXT**	**CAV**		
									
Wall [WL]			U [W·m^{-2}K^{-1}]		0,260	0,260	0,260		
			κ_{i} [kJ·m^{-2} K^{-1}]		23,76	57,56	63,00		
			|Y_{ie}| [W·m^{-2}K^{-1}]		0,051	0,035	0,053		
			M_{s} [kg·m^{-2}]		428,52	428,52	428,52		
Roof [RF]	INT		U [W·m^{-2}K^{-1}]	0,220	RF-I_W-I 0,036 -0,180	RF-I_W-E 0,245 -0,027	RF-I_W-C 0,176 -0,040	INT EXT	ψ[W·m^{-1}K^{-1}]
			κ_{i} [kJ·m^{-2} K^{-1}]	24,84					
			|Y_{ie}| [W·m^{-2}K^{-1}]	0,047					
			M_{s} [kg·m^{-2}]	474,8					
	EXT		U [W·m^{-2}K^{-1}]	0,220	RF-E_W-I 0,459 0,243	RF-E_W-E 0,507 0,301	RF-E_W-C 0,500 0,284	INT EXT	ψ[W·m^{-1}K^{-1}]
			κ_{i} [kJ·m^{-2} K^{-1}]	62,75					
			|Y_{ie}| [W·m^{-2}K^{-1}]	0,019					
			M_{s} [kg·m^{-2}]	474,8					
Ground floor [GF]	INT		U [W·m^{-2}K^{-1}]	0,342	GF-I_W-I 0,249 -0,086	GF-I_W-E 0,215 -0,104	GF-I_W-C 0,179 -0,140	INT EXT	ψ[W·m^{-1}K^{-1}]
			κ_{i} [kJ·m^{-2} K^{-1}]	44,75					
			|Y_{ie}| [W·m^{-2}K^{-1}]	0,091					
			M_{s} [kg·m^{-2}]	171,0					
	EXT		U [W·m^{-2}K^{-1}]	0,342	GF-E_W-I 0,313 0,003	GF-E_W-E 0,204 -0,106	GF-E_W-C 0,237 -0,072	EXT EXT	ψ[W·m^{-1}K^{-1}]
			κ_{i} [kJ·m^{-2} K^{-1}]	28,78					
			|Y_{ie}| [W·m^{-2}K^{-1}]	0,122					
			M_{s} [kg·m^{-2}]	171,0					
Floor vs. unconditioned space (attic) [FL]	INT		U [W·m^{-2}K^{-1}]	0,312	FL-I_W-I 0,058 -0,115	FL-I_W-E 0,142 -0,032	FL-I_W-C 0,189 0,015	INT EXT	ψ[W·m^{-1}K^{-1}]
			κ_{i} [kJ·m^{-2} K^{-1}]	25,02					
			|Y_{ie}| [W·m^{-2}K^{-1}]	0,078					
			M_{s} [kg·m^{-2}]	227,0					
	EXT		U [W·m^{-2}K^{-1}]	0,312	FL-E_W-I 0,406 0,228	FL-E_W-E 0,172 -0,006	FL-E_W-C 0,373 0,195	INT EXT	ψ[W·m^{-1}K^{-1}]
			κ_{i} [kJ·m^{-2} K^{-1}]	62,39					
			|Y_{ie}| [W·m^{-2}K^{-1}]	0,096					
			M_{s} [kg·m^{-2}]	227,0					
Intermediate floor	INT		U [W·m^{-2}K^{-1}]	0,453	IF_W-I 0,576 0,467	IF_W-E 0,106 0,000	IF_W-C 0,660 0,551	INT EXT	ψ[W·m^{-1}K^{-1}]
			κ_{i} [kJ·m^{-2} K^{-1}]	63,05					
			|Y_{ie}| [W·m^{-2}K^{-1}]	0,142					
			M_{s} [kg·m^{-2}]	250,5					
Window	WIN		U [W·m^{-2}K^{-1}]	1,40	w_W-I 0,076 0,076	w_W-E 0,127 0,127	w_W-C -0,070 -0,070		
			$g_{\mathrm{gl,n}}$ [-]	0,67					
			$g_{\mathrm{gl+sh}}$ [-] **	0,35					
Pillars					0,080 0,080	0,071 0,071	0,623 0,623		
Internal wall					0,112 -0,083	0,028 -0,001	0,028 -0,001		
Corner					0,032 -0,177	0,244 0,027	0,498 0,298		

Table 61 Linear thermal transmittance of balcony junction

Balcony	**B1**	**B2**	**B3**	**B4**
Junction	B1_W-C	B2_W-C	B3_W-C	B4_W-C
ψ_i [$W \cdot m^{-1} K^{-1}$]	0,896	0,823	0,673	0,612
ψ_e [$W \cdot m^{-1} K^{-1}$]	0,782	0,709	0,559	0,498
CAV				
Junction	B1_W-I	B2_W-I	B3_W-I	
ψ_i [$W \cdot m^{-1} K^{-1}$]	0,851	0,826	0,735	
ψ_e [$W \cdot m^{-1} K^{-1}$]	0,736	0,712	0,621	
INT				
Junction	B1_W-E	B2_W-E	B3_W-E	
ψ_i [$W \cdot m^{-1} K^{-1}$]	0,947	0,787	0,454	
ψ_e [$W \cdot m^{-1} K^{-1}$]	0,833	0,673	0,340	
EXT				

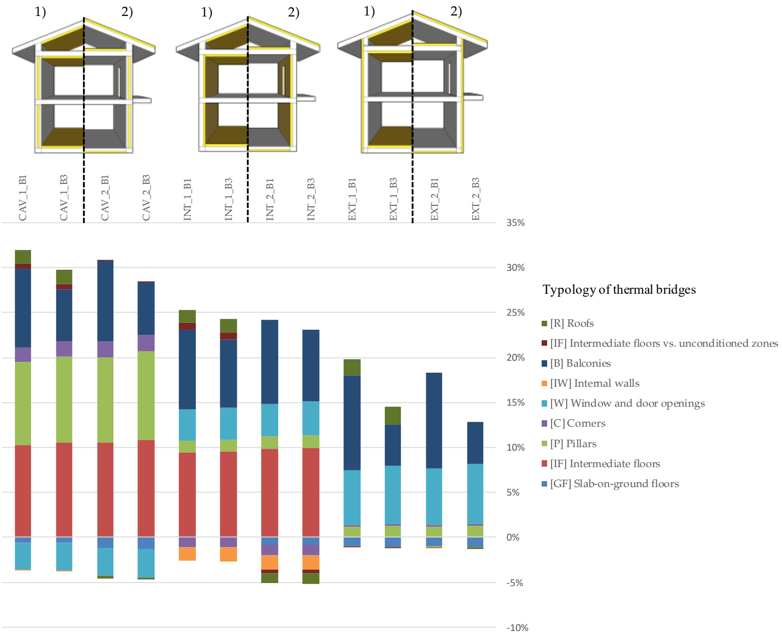


Fig. 12 Apartment block. Percental contribution related to thermal bridges on the overall heat transfer coefficient

The last part of the work has concerned the determination of the incidence of the various thermal bridges on the energy performance of the building. The incidence has been calculated both on heating and cooling energy requirements.

In Table 62 the results concerning the apartment block with thermal insulation in cavity wall for the combination B1 (lower correction of the thermal bridge) and B4 (greater correction of the thermal bridge) are reported.

This combination of thermal bridges has an impact on the heating energy need of about 40% while the contribution on cooling energy needs (negative) is negligible less than 1%.

Table 62 Apartment block (AB). Results for building with thermal insulation in cavity wall

Apartment block (AB)		**CAV_1**			**CAV_2**		
		0	**B1**	**B4**	**0**	**B1**	**B4**
$EP_{H,nd}$	$[kWh\cdot m^{-2}]_a$	19.6	26.92	26.02	19.6	27.75	26.81
Δ	%		37.36%	32.77%		41.60%	36.81%
$EP_{C,nd}$	$[kWh\cdot m^{-2}]_a$	18.75	18.63	18.64	18.72	18.59	18.6
Δ	%		-0.66%	-0.59%		-0.68%	-0.62%
H'_T	$[W\cdot m^{-1}K^{-2}]$	0.38	0.51	0.49	0.38	0.53	0.51
Δ	%		35.54%	31.13%		39.59%	35.18

In the combinations INT_1 and INT_2 the contribution of thermal bridges on the heating energy need is lower than in the previous case (about 25% in the heating case, and between 1% and 2% in the cooling case).

Table 63 Apartment block (AB). Results for building with thermal insulation on the inside

Apartment block (AB)		**INT_1**			**INT_2**		
		0	**B1**	**B3**	**0**	**B1**	**B3**
$EP_{H,nd}$	$[kWh\cdot m^{-2}]_a$	19.56	24.45	24.42	19.66	25.7	25.36
Δ	%		24.97%	24.84%		30.75%	29.00%
$EP_{C,nd}$	$[kWh\cdot m^{-2}]_a$	18.92	18.75	18.75	18.9	18.53	18.57
Δ	%		-0.89%	-0.88%		-1.94%	-1.76%
H'_T	$[W\cdot m^{-1}K^{-2}]$	0.38	0.46	0.46	0.38	0.48	0.48
Δ	%		23.55%	21.76%		29.33%	27.54

The last combination for the energy redevelopment of the building envelope concerns the use of external thermal insulation. In this example, a different performance is evident between the combination of B1 (lower correction of the thermal bridge of balcony) and B4 (greater correction of the thermal bridge of balcony). In the first case the thermal bridges have an incidence of about 25% on heating energy needs, in the other case the value is reduced to about 15%. In this particular case it is advisable to correct the thermal bridge relative to the balcony according to solution B3.

Table 64 Apartment block (AB). Results for building with thermal insulation on the external side

Apartment block (AB)		EXT_1			EXT_2		
		0	B1	B3	0	B1	B3
$EP_{H,nd}$	$[\mathrm{kWh\cdot m^{-2}}]_a$	19.66	24.09	22.5	19.61	25.53	22.94
Δ	%		22.53%	14.44%		25.12%	16.99%
$EP_{C,nd}$	$[\mathrm{kWh\cdot m^{-2}}]_a$	18.51	18.7531	18.19	18.49	18.29	18.32
Δ	%		-1.08%	-1.74%		-1.09%	-0.91%
H'_T	$[\mathrm{W\cdot m^{-1}K^{-2}}]$	0.38	0.45	0.43	0.38	0.46	0.44
Δ	%		20.66%	13.01%		23.15%	0.1551

Table 65, Table 66, and Table 67 report the analysis of the incidence of thermal bridges on a single-family house. The conclusions are the same for the apartment block. An interesting aspect concerns the percentage incidence on the global heat transfer coefficient for transmission which is in all cases very similar to the incidence on the thermal energy thermal requirement. This may allow to make estimates of the incidence of thermal bridges without necessarily calculating the energy performance of buildings.

Table 65 Single-family house (SFH). Results for building with thermal insulation in cavity wall.

Case study (SFH)		CAV_1 (ISO vs INT)			CAV_2 (ISO vs EXT)		
		0	B1	B4	0	B1	B4
$EP_{H,nd}$	$[\mathrm{kWh\cdot m^{-2}}]_a$	51.48	68.4	66.92	51.31	71.23	69.72
Δ	%		32.87%	30.00%		38.82%	35.89%
$EP_{C,nd}$	$[\mathrm{kWh\cdot m^{-2}}]_a$	35.63	34.84	-34.89	35.45	34.55	34.59
Δ	%		-2.23%	-2.10%		-2.54%	-2.43%
H'_T	$[\mathrm{W\cdot m^{-1}K^{-2}}]$	0.45	0.6	0.59	0.45	0.63	0.62
Δ	%		33.02%	29.97%		39.12%	0.3606

Table 66 Single-family house (SFH). Results for building with thermal insulation on the inside

Case study (SFH)		INT_1 (ISO vs INT)			INT_2 (ISO vs EXT)		
		0	B1	B3	0	B1	B3
$EP_{H,nd}$	$[\mathrm{kWh\cdot m^{-2}}]_a$	51.7	61.56	60.93	51.46	65.53	64.85
Δ	%		19.06%	17.84%		27.34%	26.04%
$EP_{C,nd}$	$[\mathrm{kWh\cdot m^{-2}}]_a$	35.87	-34.9	-34.99	35.61	34.86	-34.88
Δ	%		-2.72%	-2.45%		-2.12%	-2.05%
H'_T	$[\mathrm{W\cdot m^{-1}K^{-2}}]$	0.45	0.54	0.53	0.45	0.58	0.57
Δ	%		18.68%	17.44%		27.22%	25.99

Table 67 Single-family house (SFH). Results for building with thermal insulation on the external side

Case study (SFH)		EXT_1 (ISO vs INT)			EXT_2 (ISO vs EXT)		
		0	B1	B3	0	B1	B3
$EP_{H,nd}$	$[\mathrm{kWh\cdot m^{-2}}]_a$	51.45	60.69	58.04	51.34	62.64	59.9
Δ	%		17.96%	12.79%		22.02%	16.68%
$EP_{C,nd}$	$[\mathrm{kWh\cdot m^{-2}}]_a$	35.2	-34.47	-34.63	35.08	-34.24	-34.39
Δ	%		-2.05%	-1.61%		-2.39%	-1.97%
H'_T	$[\mathrm{W\cdot m^{-1}K^{-2}}]$	0.45	0.53	0.51	0.45	0.55	0.53
Δ	%		17.25%	11.95%		21.03%	0.1572

3.1.4 Conclusions

In order to evaluate the weight of thermal losses through thermal bridges and the effectiveness of the interventions adopted on energy consumption, the $EP_{\mathrm{H,nd}}$ and $EP_{\mathrm{C,nd}}$ of two buildings was calculated in the climatic conditions of Turin.

The strategy typically used to correct thermal bridges at connections is to move the thermal insulation by the inner side to the external side of the structural element.

The technological solutions for minimizing thermal bridges that provide for thermal insulation from the outside are characterized by lower linear transmission coefficients than other possible solutions for intervention and by a lower risk of mould and internal surface condensation problems. Although this solution is therefore preferable, also in this case the contribution of thermal bridges, determined with calculation to the finite elements according to EN ISO 10211 [247], is not completely cancelled. Research has shown that the influence of thermal bridges also on NZEBs cannot be neutralized using any thermal insulation technique, although the external thermal insulation represents the most effective technique.

In the case of the construction of new buildings it is therefore appropriate that the legislation on energy performance in building stimulates and induces the designers to correct the thermal bridges using to the best possible construction techniques. In the case of new buildings, it is proposed that the notional reference building approach is updated with the integration of their contribution. This can be done by splitting the thermal transmittances of the notional reference building into transmissions in the current section and reference thermal bridges.

3.2 Opaque Envelope. The Influence of Thermal insulation

The effectiveness of applied thermal insulation in reducing energy needs and the maintenance of the thermal comfort conditions in the building is a combination of properties of the construction materials and the position of the thermal insulation for the opaque structural elements of the building envelope.

According to the European Parliament resolution of 13 September 2016 on an EU Strategy on Heating and Cooling (2016) [1], thermal insulation reduces energy needs by preventing heat loss through the building envelope and costs for consumers and contributing to alleviating energy poverty as well as creating qualified local jobs. Furthermore, buildings that have good thermal insulation are of benefit both to the environment and to the user, who enjoys lower energy bills.

High energy efficiency, high-performance thermal insulation and the use of renewable energy sources and recovered heat are fundamental priorities for the EU's heating and cooling strategy; the 'energy efficiency first' principle should be respected, as energy efficiency offers one of the highest and fastest rates of financial return available and is a key part of the strategy for achieving a successful transition towards a secure, resilient and smart heating and cooling sector.

Also the recent Directive (EU) 2018/844 (2018) [3] on the energy performance of buildings insists on a better characterization of the building envelope and in particular on a better, complete, and homogeneous thermal insulation of the whole building including thermal bridges (balconies, fenestrations, roofs, walls, doors and floors) with attention to the verification of Hygrothermal performance of building components and building elements. Furthermore, according to the World Health Organization (2009) [4] better performing buildings provide higher comfort levels and wellbeing for their occupants and improve health.

The European Commission, in this latest legislative document, has confirmed the high ambition in the definitions of NZEB, which should not be below the cost-optimal level requirements [5]. In addition, the European Commission remembers to employ the best technology available with a high market penetration, and to take into account legal and policy considerations at the national level. The four pillars on which a NZEB is to be designed are the integration of renewables, adequate levels of IAQ, a high level of energy performance, and comfort of building users.

Figueiredo et al. (2016) [12] have demonstrated that in Portugal, in the redevelopment of the existing housing with the use of traditional materials, there may be long periods of thermal discomfort for the heating season and long periods of overheating during the summer. They have studied the interaction between annual heating energy need and the summer overheating of the Passive Houses. For the analysis they resorted to multi-objective optimization. The conclusions established that Passive House concept is viable for the Portuguese climate if adaptable technical and constructive solutions are diversified for regions.

Considered the not negligible impact of cooling energy need, Attia et al. (2017) [17], in addition to the reduction of solar and internal heat gains, recommend the implementation of requirements related to passive cooling systems or efficient active cooling systems.

Sarran et al. (2017) [30] have studied how energy efficient buildings can adapt perturbations in a city’s heat and power grids. They have investigated the capacity of buildings to provide good indoor comfort in relation to variation of delivered heating power (passive flexibility). The authors have calculated the duration of the comfort period after a cut-off of heating. An increase of WWR has a positive impact on reducing the heating peak but its effect on the comfort duration period is negative. In fact, in the short term solar heat gains help to increase the indoor temperature but, on the contrary, in the long term thermal losses are dominant. The thermal insulation of a building envelope is the parameter showing the largest impact on flexibility, with the improvement of thermal transmittance of windows can multiply the duration of the comfort until up to four times. The relative height of this peak in relation to the peak power in normal conditions is greatly influenced by the insulation thickness and U-value. The effect of thermal inertia investigated through the variation of thickness of the concrete layers shows a negligible influence. Unlike, Despina and Georgakis (2012) [54] have shown that the positioning of the thermal mass in the building envelope is an important aspect in the design of building with significant effects on heating and cooling energy needs.

According their studies is always preferable position the thermal mass on the inner side of the building envelope, differently the increase of thermal mass in the outside layer leads increases in energy needs.

These results are confirmed by Chiesa et al (2018) [256]. The authors have analyzed a one-story building with a rectangular plan with the aim of evaluate the influence of internal heat capacity of the thermal zone on energy need for space cooling. The authors have concluded that for most buildings higher amounts of thermal mass at the inner side of the building envelope are beneficial to improving thermal comfort and reducing the energy need. These conclusions are consistent with those of Verbeke and Audenaerta (2018) [257].

Loukaidou et al. (2017) [53] have studied the optimal thermal features of the building envelope (thermal insulation and windows) in order to achieve NZEBs in the climate conditions of Cyprus (Limassol, Nicosia and the mountainous area of Saittas). The procedure has taken into account levels of EP leading to minimum life-cycle cost. The study has demonstrated that (a) for the opaque envelope, the cost-optimal energy performance levels of reference buildings are higher than the national minimum requirements, while the optimal U-value for windows is significantly lower than national minimum requirements; and (b) a linear correlation between optimal mean U-value coefficient and A_e/V ratio (an increase in the ratio leads to a different optimal U-value coefficient).

Among the limits of the research, it should be noted that the author did not take into account the characteristics of the solar shading but he has considered a variability of the $g_{gl,n}$-value of windows. Moreover, in the simulations performed with EnergyPlus, a reference cell with different A_e/V ratio was considered without the evaluation of entire buildings.

As seen in Italy, the definition of NZEB has been specified by the MD [143], the national strategy focuses on the building envelope (Zinzi et al., 2017 [55]), enforcing the U-values. Moreover, several studies have shown the use of significant thermal insulation thickness to satisfy the heating requirements could lead to the overheating of the interior spaces and, consequently, to an increase of the cooling energy need. Assuring the best trade-off between $EP_{H,nd}$ and $EP_{C,nd}$ is of crucial importance to decrease the overall building energy needs.

Several studies ([88],[94],[95]) have considered the role of the building envelope in reaching the NZEB level and shown the incongruity between the envelope requests and the summer building energy performance.

Chvatal and Corvacho (2009) [88] and Chvatal et al. (2005) [90] have examined summer overheating in relation of building envelope features (thermal insulation and inertia). They have shown that when solar and internal heat gains are not adequately controlled, with the increase of thermal insulation there is also an increase of discomfort for internal locals.

Sameni et al. (2015) [91] emphasised the risk of overheating in a hyper-insulated social housing, categorising the most critical building unit on the basis of both occupants' behaviour and geometric features.

Within this background, the choice of an optimal thermal insulation level would avoid overheating and ensure the lowest overall energy need.

This application focuses on a typical Italian residential building and carries out a sensitivity analysis including different thermal insulation levels and climatic zones. The imbalance of the energy needs and its effect on the overall primary energy for heating and cooling are discussed for four representative apartments, highlighting the different behaviour for storey location and climatic condition.

3.2.1 The Imbalance of NZEBs

The continuous lowering of *U*-values in EU Southern countries imposed by EPBD regulation is leading to a shift in the building design paradigm [32].

Pajek and Košir (2018) [58] have demonstrated that by 2050 buildings in Central European locations could be dominated by cooling energy needs owing to climatic changes. The studies conducted in the UK, Belgium, and the Netherlands for different Passive House projects reported overheating periods during summer [57]. Badescu et al. (2015) [59] in their research reported excessive overheating hours in Romanian thermal insulated buildings and suggested the inclusion of active cooling systems. Premrov, Žegarac Leskovar, and Mihalič (2018) [62] have demonstrated that in some cases less compact buildings are more energy efficient.

Košir et al. (2018) [60] have analyzed for some locations the impact of building shape (form, orientation and openings) on its overall energy performance (heating, cooling and lighting energy consumption) through a study executed with dynamic thermal simulation analysis. A long building form, characterized by envelope elements built according to actual legislation and standards, allows larger window areas with more efficient solar energy harvesting. This may be advantageous for the heating period but represents a potential problem during the cooling season. They have determined the optimum configuration regarding the cumulative yearly energy consumption. In this study, the influence of internal heat gains was excluded. For buildings with low WWR and high thermal insulation the difference of energy performance between the cubical and the elongated shape is quite small; therefore, a less compact building form does not cause any significant increase of thermal energy need and allows better access to solar radiation and daylight. Furthermore, the extended building shape in the Central European climate allows for large south oriented windows and thus more solar energy gains.

According to Bellia et al. (2011) [83], for Palermo, in the case of offices, the insulated building envelope leads to a relevant increase in cooling energy need compared to the uninsulated building (69% with no solar protection devices, 59% with solar protection devices).

Collins et al. (2010) [84] have examined the effect of the use of conditioning technical systems in restructured UK generic dwelling types in terms of carbon emissions, gas and electricity energy needs with projections up to 2080. They have considered various scenarios dependent on occupant behavior, different climatic location (Cardiff, Edinburgh, London, Manchester), thermal transmittance and the ventilation rate of the building envelope.

Unlike the results found in other research, according to the authors, heating service will remain the main energy need until the 2080s.

The urban heat island effect has not considered in the simulations. The research also shows that the high insulated building envelope is not meaningfully better in the containment of summer overheating.

Frank (2005) [85] has analysed the impact of climate and thermal insulation of the building envelope on office buildings in Switzerland for the time horizon 2050-2100. In the simulation a multi-storey building with different thermal insulation levels and internal heat gains has been considered.

According to the author, during the period 2050÷2100, there will be a visible imbalance of energy needs, in fact the energy simulations show a 36÷38% diminution in the annual heating energy need and an increase of 223÷1050% of annual cooling energy need. The author suggests some indications to limit the summer energy needs as the use of solar shading protection and free cooling night ventilation strategies.

Wang et al. (2010) [86] have investigated the possible influence of climate change on heating and cooling energy needs of residential buildings in Australia. The results show total H/C energy need variations of -26%-101% by 2050 and -48%-350% by 2100. For all the analysed locations (Alice Springs, Darwin, Hobart, Melbourne and Sydney), the increase in cooling energy needs is much greater than the decrease in heating energy need.

These indications could be useful for decision makers in defining energy efficiency measures and therefore the minimum requirements in the conversion of the existing building stock into NZEB. In fact, excessive levels of thermal insulation may not be justified taking into account the global warming in progress. Chan (2011) [87] presents a similar search for Hong Kong.

The decrease of the thermal transmittance of building envelope causes the reduction of the energy need for space heating; by contrast, the hyper thermal insulation can cause higher energy need for space cooling and indoor overheating, especially in warm and temperate climates [95].

This relationship has been confirmed by numerous studies. Chvatal et al. (2009) [89] have realized a parametric study with the purpose of quantifying the influence of the increase of the building envelope thermal insulation upon the energy performance of buildings. They have noted that for residential buildings, above all in summer, the solar heat gains should be avoided, particularly if ventilation rates are low. According to the authors, when solar heat gains are relevant, an increased use of thermal insulation will induce greater summer discomfort and energy need for air conditioning.

In the case of office buildings this phenomenon is more evident because the internal heat gains are high, as they are dependent on equipment and people, and cannot be reduced. The building envelopes in the study have a high level of thermal mass.

Other studies have been supported by buildings monitoring, for instance Gaterell et al. (2015) [90] and Pathan et al. (2017) [93] have demonstrated through the adaptive thermal comfort method that, in the future, housing buildings in London will face a significant risk of overheating. In the scientific literature, other authors ([94],[96],[97],[98]) have compared the effect of the building envelope thermal properties on the EP of building.

Serghides and Georgakis (2012) [54] have studied the variables of thermal capacity and thermal insulation in combination with other design parameters and their effect on the heating and cooling energy needs. The study considered four different reference building shapes typical in Cyprus.

Regarding the thermal capacity, the building energy simulations have shown that (a) when the thermal mass was internally varied the energy needs of each shape varied from 8÷18% of savings for the heating and of 2% for the cooling. The increase of the internal heat capacity of the zone increased the potential to retain the coolness during the night and it was contributed at the reduction of the cooling energy need; differently, (b) when the increase of thermal mass was from the outside layer, the simulations shown that there are higher energy needs varying from 47÷54% for heating and from 20÷42% for cooling.

The research also demonstrated that the effect of the measures on energy needs are influenced by the complexity of the building shape.

Respecting the parametric study on the thermal insulation, the study considered various relations: (a) thermal insulation and building shape, (b) thermal insulation thickness, (c) position of thermal insulation layer, and (d) extent of thermal insulation (intervention on wall, roof and first floor). With reference to the link between thermal insulation and building shape, it was observed that the square shape achieved the largest amounts of energy savings (overall for cooling and heating energy needs). The increasing of thermal insulation above a certain threshold always has positive effects, however it negatively influences the payback period of the investment.

Regarding the position of thermal insulation layer in the building envelope, the authors [54] observed that energy savings, for both cooling and heating, increased if the thermal insulation layer moved from the internal side to the external surface of the building envelope. Therefore, this design technique offers significant potential energy savings (25% more than when applied internally).

The last part of the research focused on the position of the thermal insulation in the building envelope with different energy refurbishment scenarios: (a) thermal insulation on the roof only (b) thermal insulation additionally on the walls (c) thermal insulation additionally on the floor. Extending the thermal insulation on the roof only and/or additionally on the walls incurred higher energy conservation for cooling than for heating. On the contrary, the addition of thermal insulation on the ground floor have shown adverse effects of on the building energy performance.

This chapter aims to explore in which conditions a *significant energy needs imbalance* for heating and cooling occurs by reducing the thermal transmittance of the notional reference building envelope according to the limits imposed by national legislation.

In fact, despite the decrease of the heating energy need due to the limitation of the heat transfer through the building envelope, there might be the risk that the cooling energy need may increase and necessarily measures for avoiding an overheating environment should be adopted. The building energy performance is calculated by means of a two calculation methods: a quasi-steady-state calculation method and detailed dynamic numerical simulation. In the present chapter the following points are investigated: (a) the feasibility of technical solutions to get NZEBs; (b) solutions aimed at reducing heating and cooling energy needs; and (c) solutions aimed at decreasing peak loads. The energy simulations are performed for different building types, a single-family house, an apartment block and an office building, in different climatic locations. Some results are in [95].

3.2.2 Parametric Analysis: Opaque Envelope

For the dynamic numerical simulation, we used the dynamic computer software *EnergyPlus* that shows the impact of different design integrated and/or simultaneous strategies on overall energy performance. It is a console-based software that reads input and writes output to text files. The software provides hourly data for heating, cooling, ventilation loads, and volumetric airflows between zones. Each building unit has been modelled as a single thermal zone. The software is based on fundamental heat balance principles and it solves, under transient hourly or sub hourly conditions, a convective heat balance equation on the internal air node of the building thermal zone. As the analysis of technical building systems is out of the scope of this section, the net energy needs for space heating and space cooling was calculated assuming infinite powers of heating and cooling at set point temperatures.

3.2.3 Case Study

The case-study consists of a four-story building aligned in a North-South layout, studied in a previous work (Murano et al., 2016 [253]). It is not a real building, but an archetype; i.e., is a "theoretical building" characterised by a set of geometrical properties identified though statistical investigation of a large sample of existing buildings with similar attributes. It is supposed to be located in several locations indicated in Table 80.

Fig. 13 Case study for the calculation of effects on the energy performance of thermal insulation on the whole building and single building units

The apartment block consists of 12 building units. For the energetics analysis several representative units were selected to cover a wide range of the shape factor values, design features (WWR, floor area, and kinds of adjacent spaces) and orientation. The main geometric data are reported in Table 81.

Table 68 Main climatic data of the analysed locations

Cities	Heating period		Cooling period		
	Duration [h]	HDD $_{20\ °C}$	Duration [h]	CDD $_{26\ °C}$	$H_{sol,gl,hor,C}$
Palermo (PA)	5 034	1 121	1 446	166	3 830
Rome (RM)	5 789	1 643	1 084	143	4 004
Turin (TO)	6 604	2 648	809	84	3 511
Belluno (BL)	7 395	3 841	410	38	3 037

HDD = heating degree-days [°C·d], CDD = cooling degree-days [°C·d], $H_{sol,gl,hor,C,}$ = global solar irradiation on a horizontal surface in the cooling period [MJ·m^{-2}]

Table 69 Main geometric characteristics of the building and of the analysed units

Building unit code	Storey	Building unit	V_g [m^3]	V_n [m^3]	A_f [m^2]	A_{env} [m^2]	A_w [m^2]	A_{env}/V_g [m^{-1}]	WWR [-]
BU0A	0	A	255	205	76	187	11.1	0.73	0.15
BU0B		B	184	153	57	108	8.7	0.58	0.29
BU0C		C	389	320	118	246	18.0	0.63	0.18
BU1A	1-2	A	285	230	85	116	11.1	0.41	0.14
BU1B		B	184	153	57	46	8.7	0.25	0.29
BU1C		C	389	320	118	116	18.0	0.30	0.18
BU3A	3	A	285	230	85	201	11.1	0.71	0.14
BU3B		B	184	153	57	108	8.7	0.58	0.29
BU3C		C	389	320	118	246	18.0	0.63	0.18
Building			3 401	2 788	1 033	1 653	151	0.49	0.18

V_g = gross conditioned volume, V_n = net conditioned volume, A_f = net conditioned floor area, A_{env} = envelope area, A_w = windows area, WWR = windows-to-wall ratio.

The sensitivity analysis determines how six values of levels of thermal insulation, from highly (level no. 6) to scarcely insulated (level no. 1), affect the energy needs under a given set of assumptions summarized below:

- each global thermal insulation level of the building envelope is a combination of thermal transmittances of the opaque and transparent envelope components (the thermal properties of all the envelope components are shown in Table 70);
- the thermal transmittance of every component includes the effect of thermal bridges;
- every residential unit corresponds to a building thermal zone;
- the same thermal transmittance is assumed for each opaque component (walls, roof and ground floor) and the thermal insulating material is placed always on the exterior side;
- the areal thermal mass is about 270 kg·m^{-2} for the external walls and the ground floor, and 400 kg·m^{-2} for the roof.
- for each insulation level, the thermal transmittance of windows varies accordingly, while the total solar energy transmittance of glazing at normal

incidence is kept constant ($g_{gl,n}$=0.67). This choice was made to keep all free thermal heat gains constant for all levels of thermal insulation;

- the ventilation flow rate was determined according to UNI/TS 11300-1 (UNI, 2014) [161].
- hourly profiles of the internal heat gains and mean values of internal heat gains are calculated according to UNI/TS 11300-1 [161] and are respectively 5.31 W·m^{-2} for BU0A; 4.99 W·m^{-2} for BU1A and BU2A; 5.97 W·m^{-2} for BU0B, BU1B, and, BU2B; 3.82 W·m^{-2} for BU0C, BU1C, BU2C;
- a solar shading (τ=0.15; ρ=0.70) is supposed to be placed on the external side of all windows (except for those located to the north). The activation is considered in function when the mean hourly value of global solar irradiance exceeds 300 W·m^{-2};
- the external opaque surfaces of the fabric of a building are intermediate coloured (solar absorption coefficient equal to 0.60);
- the set-point temperature was fixed at 20°C and 26°C for heating and cooling, respectively.

Table 70 Thermal properties of the building envelope components

Insulation	External walls			Flat roof			Ground floor			Windows
level	U	κ_i	$\lvert Y_{ie}\rvert$	U	κ_i	$\lvert Y_{ie}\rvert$	U	κ_i	$\lvert Y_{ie}\rvert$	U
1	0.10	48.9	0.009	0.10	64.8	0.006	0.10	56.6	0.015	1.00
2	0.20	49.3	0.031	0.20	65.1	0.021	0.20	56.9	0.049	1.50
3	0.30	49.6	0.053	0.30	65.3	0.034	0.30	56.7	0.081	2.00
4	0.40	50.0	0.076	0.40	65.5	0.048	0.40	56.6	0.115	2.50
5	0.50	50.4	0.104	0.50	65.7	0.064	0.50	56.5	0.151	3.00
6	0.60	50.9	0.138	0.60	66.0	0.081	0.60	56.5	0.191	3.50

U = thermal transmittance [W·m^{-2}K^{-1}], κ_i = internal areal effective heat capacity [kJ·m^{-2}K^{-1}], Y_{ie} = periodic thermal transmittance [W·m^{-2}K^{-1}]

Four characteristic climatic datasets corresponding to various locations (Udine, Turin, Rome, and Palermo) were considered. The test reference years were derived from the CTI database (CTI, 2017) [252]. As specified by the Italian regulations (DPR 412/1993 [159] and UNI/TS 11300-1 [235]), a continuous thermal system operation is considered during the heating and cooling seasons.

3.2.4 Results and Discussion

The results of the sensitivity analysis are reported in the charts (Fig. 14., Fig. 15, Fig. 16, Fig. 17, Fig. 18, Fig. 19, Fig. 20, Fig. 21, Fig. 22, Fig. 23).

This first part of the study does not investigate the primary energy, since it focuses on the effects of thermal insulation on the improvement of energy performance of the building envelope. The charts report in abscissa the level of thermal insulation and on the ordinate the building energy performance express in terms of annual sensible energy need for space heating (in orange) and for space cooling (in blue) respectively normalised on the useful floor area.

- The charts show that as the level of thermal insulation increases, in general the heating energy need decreases; however, at the same time, the cooling energy need increases slightly. In any case, heating energy savings are more significant than the cooling energy savings. This trend is not the same for all building units and locations. The global situation is summarized in for Belluno with increasing thermal insulation, for all building units and for the whole building there are a reduction of $EP_{\mathrm{H,nd}}$ and an increasing of $EP_{\mathrm{C,nd}}$;

- for Turin with increasing thermal insulation, for all building units and for the whole building occurs a reduction of $EP_{\mathrm{H,nd}}$ and an increasing of $EP_{\mathrm{C,nd}}$ for all building units except for those of the last floor;
- for Rome the situation is the same as the previous point with a reduction of $EP_{\mathrm{C,nd}}$ also for BU1A;
- for Palermo with an increase of thermal insulation, for all building units and for the whole building, occurs a reduction of $EP_{\mathrm{H,nd}}$ and of $EP_{\mathrm{C,nd}}$ for all building units except for those of the first floor.

Table 71:

- for Belluno with increasing thermal insulation, for all building units and for the whole building there are a reduction of $EP_{\mathrm{H,nd}}$ and an increasing of $EP_{\mathrm{C,nd}}$;
- for Turin with increasing thermal insulation, for all building units and for the whole building occurs a reduction of $EP_{\mathrm{H,nd}}$ and an increasing of $EP_{\mathrm{C,nd}}$ for all building units except for those of the last floor;
- for Rome the situation is the same as the previous point with a reduction of $EP_{\mathrm{C,nd}}$ also for BU1A;
- for Palermo with an increase of thermal insulation, for all building units and for the whole building, occurs a reduction of $EP_{\mathrm{H,nd}}$ and of $EP_{\mathrm{C,nd}}$ for all building units except for those of the first floor.

Table 71 Effect of thermal insulation on $EP_{\mathrm{H/C,nd}}$ for building units and analysed locations.

		Belluno		Torino		Roma		Palermo	
		$EP_{\mathrm{H,nd}}$	$EP_{\mathrm{C,nd}}$	$EP_{\mathrm{H,nd}}$	$EP_{\mathrm{C,nd}}$	$EP_{\mathrm{H,nd}}$	$EP_{\mathrm{C,nd}}$	$EP_{\mathrm{H,nd}}$	$EP_{\mathrm{C,nd}}$
0	BU0A	↘	↗	↘	↗	↘	↗	↘	↗
	BU0B	↘	↗	↘	↗	↘	↗	↘	↗
	BU0C	↘	↗	↘	↗	↘	↗	↘	↗
1-2	BU1A	↘	↗	↘	↗	↘	↘	↘	↘
	BU1B	↘	↗	↘	↗	↘	↗	↘	↗↘
	BU1C	↘	↗	↘	↗	↘	↗	↘	↘
3	BU3A	↘	↗	↘	↘	↘	↘	↘	↘
	BU3B	↘	↗	↘	↘	↘	↘	↘	↘
	BU3C	↘	↗	↘	↘	↘	↘	↘	↘
Whole building		↘	↗	↘	↗	↘	↗	↘	↗

↗ Increase of energy need
↘ Decrease of energy needs

From Fig. 14 that is referred on the whole building, it is evident that with the same geometry and thermal insulation the energy performance of the case studies are very different between climatic zones. In Palermo the energy needs for heating vary from 0 kWh·m^{-2} (level 6) to about 8 kWh·m^{-2} (level 1), in Rome from 0 kWh·m^{-2} (level 6) to 19 kWh·m^{-2} (level 1) and in Turin from 6.5 kWh·m^{-2} (level 6) to about 45 kWh· m^{-2} (level 1). It is therefore evident that there is a greater effect of thermal insulation in places with colder climates.

As for the $EP_{C,nd}$ in Palermo, they range from 29 kWh·m^{-2} (level no 6) to 33 kWh·m^{-2} (level no 1), in Rome from 26 kWh m^{-2} (level no 6) to 27 kWh m^{-2} (level no 1), and in Turin from 22 kWh·m^{-2} (level no 6) to 19 kWh·m^{-2} (level no 1).

The trend in Turin and Belluno is different than in the other two locations. Charts show that the various analysed building units have a different thermal behaviour from that of the whole building.

In Palermo the effect of thermal insulation on the heating energy need is visible to a greater extent on ground floor units (for BU0C *EP* variable from 0 for level no 6 to 21.9 kWh·m^{-2} for level no 1). As far as the summer performance is concerned, the main effects of the thermal insulation are on the building units on the last floor which are characterized by an attic towards the outside (for BU3B $EP_{C,nd}$ variable from 38.7 kWh·m^{-2} for level no 1 to 56.2 kWh·m^{-2} for level no 6).

In terms of global performance, the most energy-consuming units are those on the top floor, which for the level no. 1 (less insulated) can reach energy needs of about 60 kWh·m^{-2}, while for intermediate ones for the same level they have a need of about 30 kWh·m^{-2} and the building in the complex of 42 kWh·m^{-2}.

For Rome, the general energy behaviour of the building is the same as for Palermo. As for Turin, the effect of thermal insulation on thermal performance is visible above all in the winter season, while it is less noticeable in the summer.

Also for Turin, at the global performance level the most energy-consuming units are those on the top floor, which for level no. 1 (less insulated) can reach requirements of about 110 kWh·m^{-2}, not very far from those on the ground floor characterized for the same level from an EP_{gl} of about 90 kWh·m^{-2}, while for those intermediate for the same level they have a requirement of about 60 kWh·m^{-2} and the building in the complex of 77 kWh·m^{-2}.

For all the building units on the ground floor, the thermal insulation has a negative effect on the cooling energy needs.

Concerning peak power, as expected, it is evident that there is a greater winter peak power in the cold localities and a greater summer peak power in the warm places. The summer and winter peak powers, for all locations, increase as the thermal insulation decrease.

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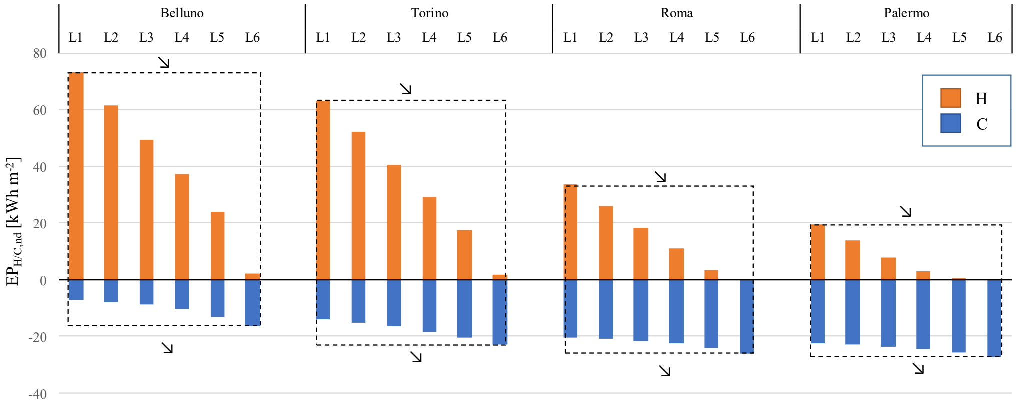


Fig. 14 Whole building. Results of the analysed configurations for localities and level of thermal insulation: EP_{nd} for cooling and heating

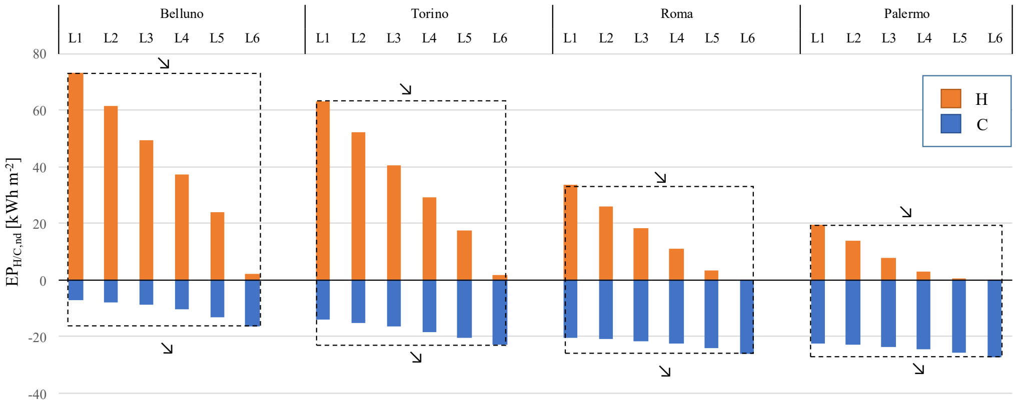


Fig. 15 BU0A. Results of the analysed configurations for localities and level of thermal insulation: EP_{nd} for cooling and heating

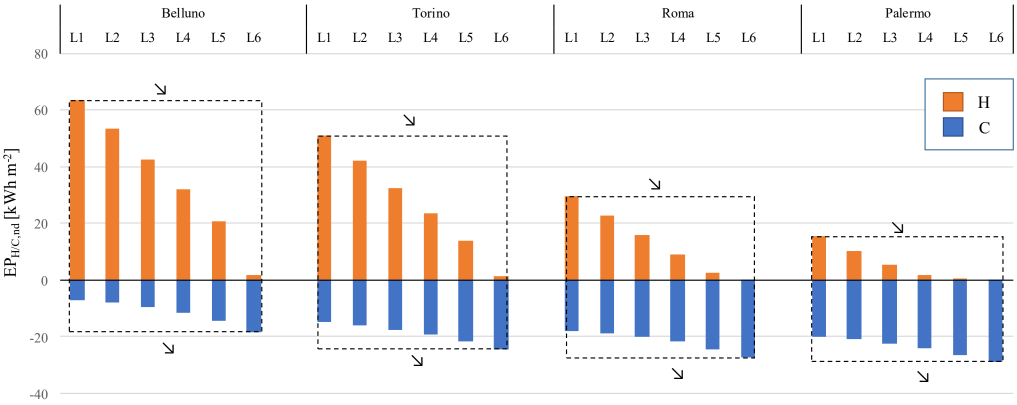


Fig. 16 BU0B. Results of the analysed configurations for localities and level of thermal insulation: EP_{nd} for cooling and heating

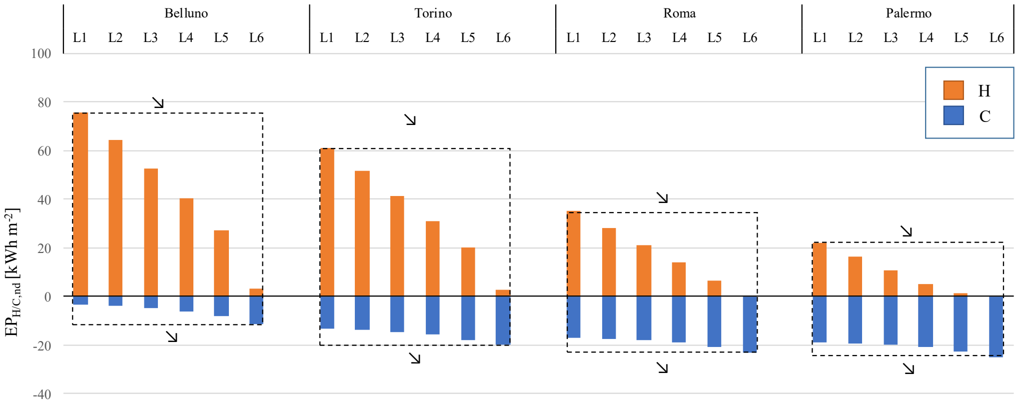


Fig. 17 BU0C. Results of the analysed configurations for localities and level of thermal insulation: *EP*nd for cooling and heating

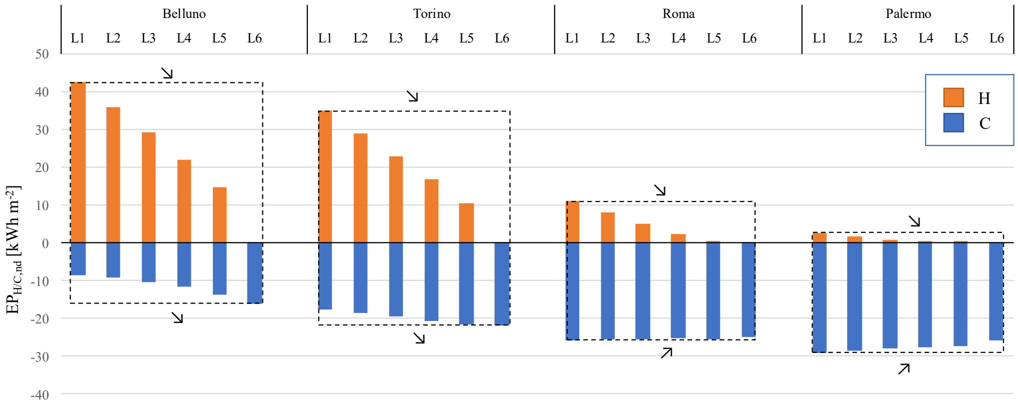


Fig. 18 BU1A. Results of the analysed configurations for localities and level of thermal insulation: *EP*nd for cooling and heating

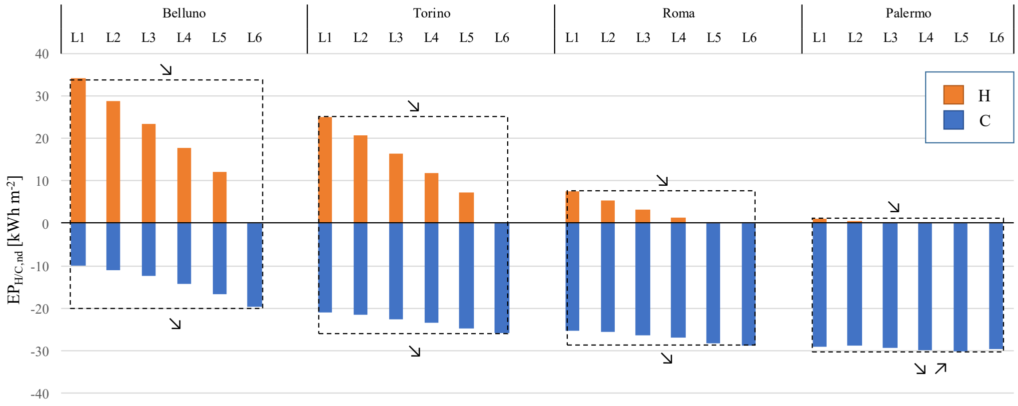


Fig. 19 BU1B. Results of the analysed configurations for localities and level of thermal insulation: *EP*nd for cooling and heating

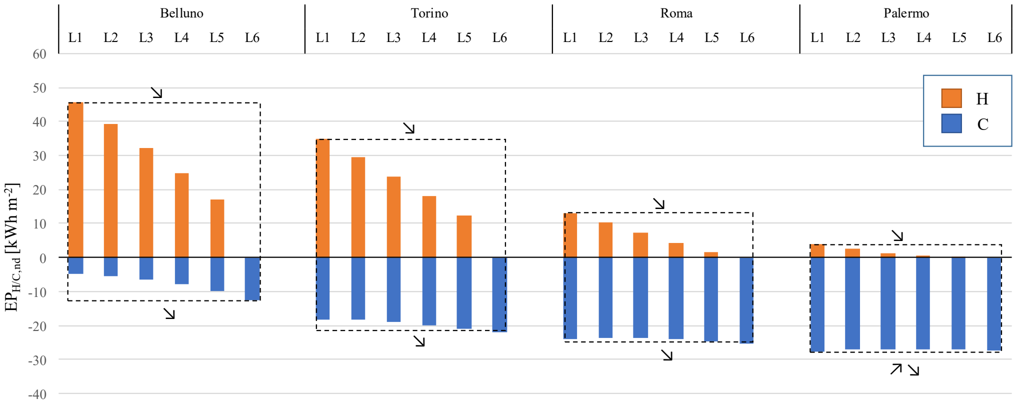


Fig. 20 BU1C. Results of the analysed configurations for localities and level of thermal insulation: *EP*$_{\mathrm{nd}}$ for cooling and heating

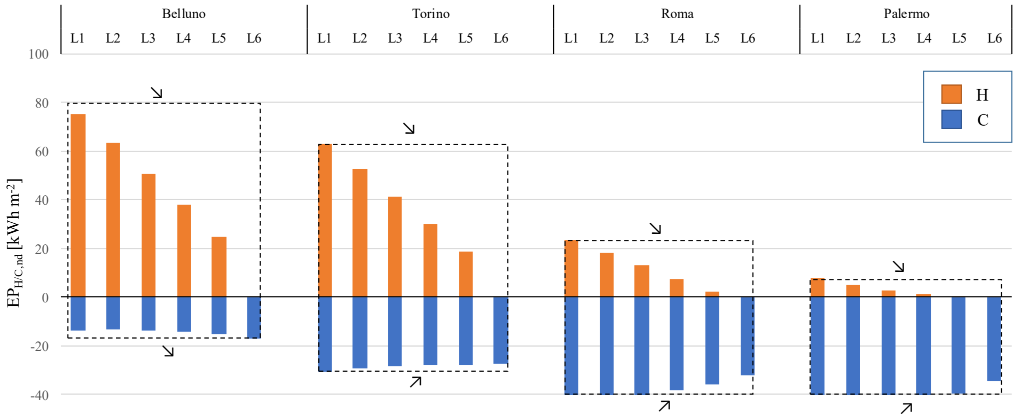


Fig. 21 BU4A. Results of the analysed configurations for localities and level of thermal insulation : *EP*$_{\mathrm{nd}}$ for cooling and heating

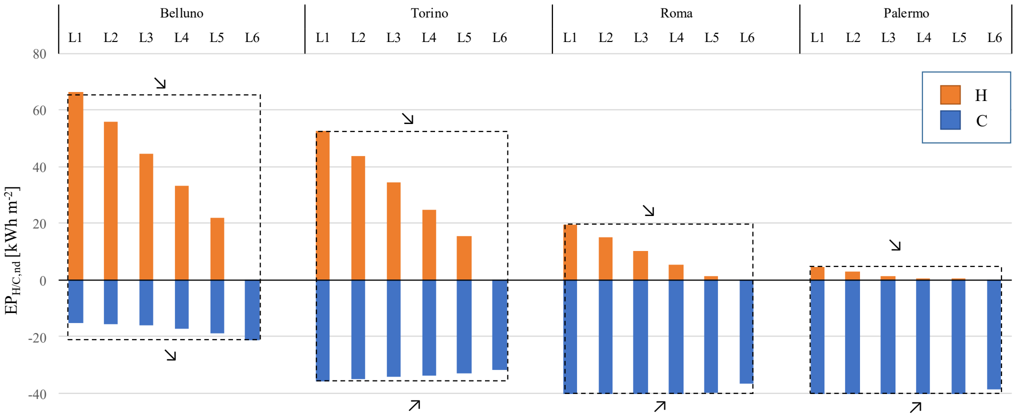


Fig. 22 BU4B. Results of the analysed configurations for localities and level of thermal insulation : *EP*$_{\mathrm{nd}}$ for cooling and heating

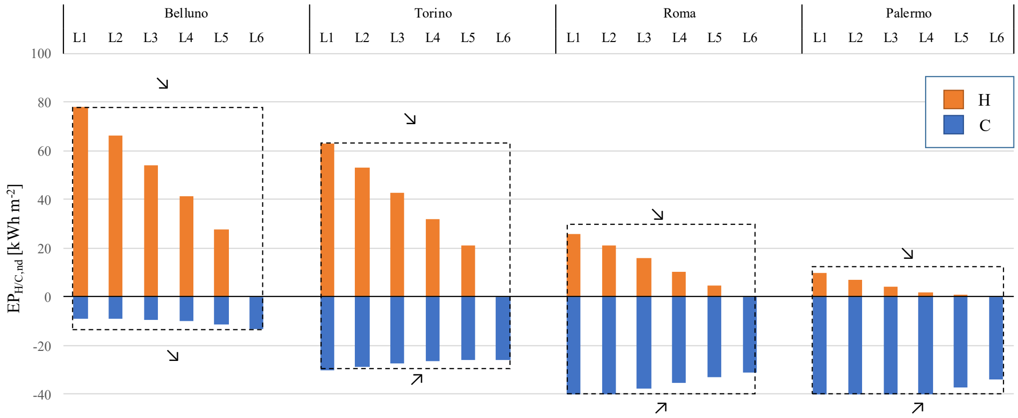


Fig. 23 BU4C. Results of the analysed configurations for localities and level of thermal insulation : EP_{nd} for cooling and heating

For each location, Fig. 24 (left) shows cooling energy performance vs. heating energy performance of the whole building for the different insulation levels.

For each location, Fig. 24 (right) shows cooling peak power vs. heating peak power for the same thermal insulation levels. Fig. 25 (Belluno), Fig. 26 (Turin), Fig. 27 (Rome), Fig. 28 (Palermo) show the same outcomes both for the whole building and for each building unit.

In addition, each figure displays the annual overall primary energy vs. the annual energy needs for heating and cooling. The dotted grey lines represent the *Iso*-EP_{gl} lines, as described in paragraph 1.4.

In the construction of the graphs the values of the notional reference building were used. The following values have been assumed: (a) for the heating, the non-renewable primary energy conversion factor for natural gas equal to 1.05; the mean seasonal efficiency of the heating utilisation subsystems (i.e. heat emission, control and distribution, equal to 0.81), and is the mean seasonal efficiency of the heating generation subsystem $\eta_{H,g}$ equal to 0.95, (b) for the cooling, the non-renewable primary energy conversion factor for natural electricity equal to 1.95; the mean seasonal efficiency of the cooling utilisation subsystems (i.e. heat emission, control and distribution, equal to 0.81), and is the mean seasonal efficiency of the cooling generation subsystem $\eta_{C,g}$ equal to 2.50.

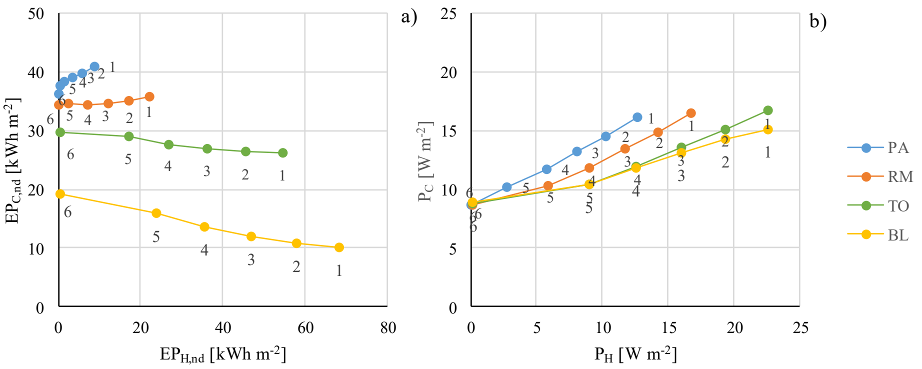


Fig. 24 Net energy need (EP_{nd}) and peak power (P) for heating (H) vs. cooling (C) for the whole building and for six insulation levels.

Examining the whole building (Fig. 25), the sensitivity of the $EP_{H,nd}$ to the thermal insulation level is higher in the locality with higher HDD, like Udine and Turin, and usually it is more sensitive than the $EP_{\mathrm{C,nd}}$. In any case, in Turin and Udine a reduction of heating energy need by progressively reducing the thermal transmittance corresponds to an increase of $EP_{\mathrm{C,nd}}$.

Differences in the energy behaviour between the building units are evident, above all in Rome (Fig. 27) and Palermo (Fig. 28). *In Palermo, where the CDD are higher, the influence of thermal insulation is more evident in summer than in winter and an opposite effect is revealed between the units at ground floor and those at the highest floor.* Specifically, by reducing the U-value of the building envelope*, at ground floor the reduction of heating corresponds to an increase of the energy need for cooling, while at the highest floor the reduction of cooling is higher than the reduction of the energy need for heating.*

The energy behaviour variation between building units is less evident moving from Palermo to Udine, even if the hyper-insulation of the ground floor units always determines a higher energy need for cooling regardless of the climatic zone. For instance, considering a medium thermal insulation level (level no. 2) in Turin, the difference between the cooling energy needs of the ground floor and the third floor units is greater by 68% than the difference between the respective heating needs. In Palermo, switching from thermal insulation level no. 1 to no. 6, the cooling need is reduced by 31% for BU3B and increases by 32% for BU0C. *This is due to a greater value of the solar-air temperature on the upper units, where a high level of thermal insulation has a favourable effect. On the other hand, the hyper-insulation of the ground floor does not allow the discharge of the accumulated heat, thus leading to an increase of the cooling energy need. For intermediate floors above all in Palermo, the sensitivity to the insulation level is negligible, due to a very low shape factor.*

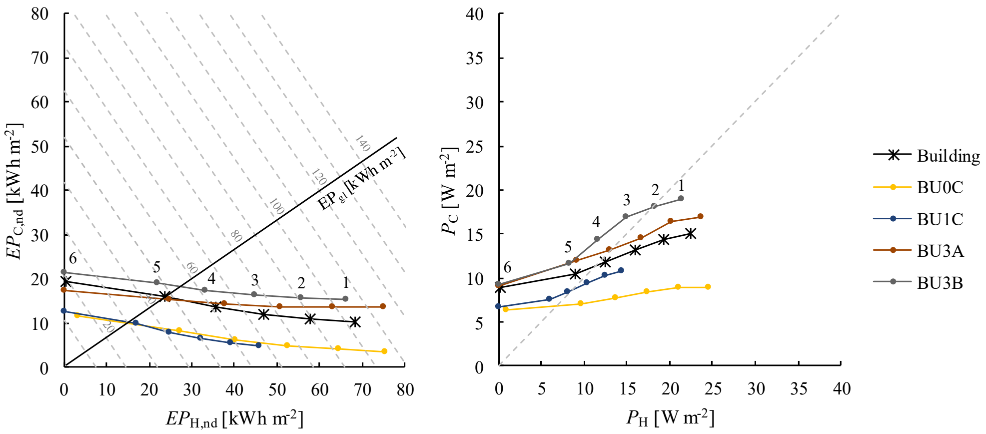


Fig. 25 Belluno. Net energy need (EP_{nd}) for heating vs. cooling, and overall primary energy for the whole building and for different building units, for six thermal insulation levels.

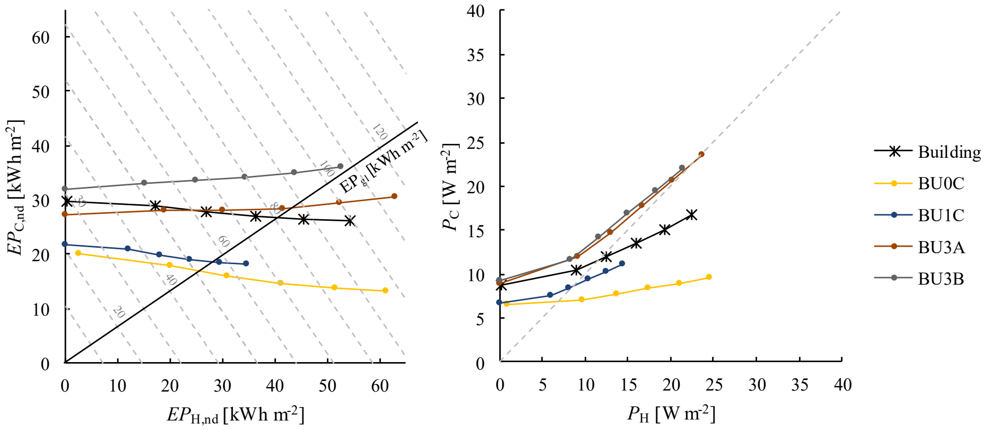


Fig. 26 Turin. Net energy need (EP_{nd}) for heating vs. cooling, and overall primary energy for the whole building and for different building units, for six thermal insulation levels.

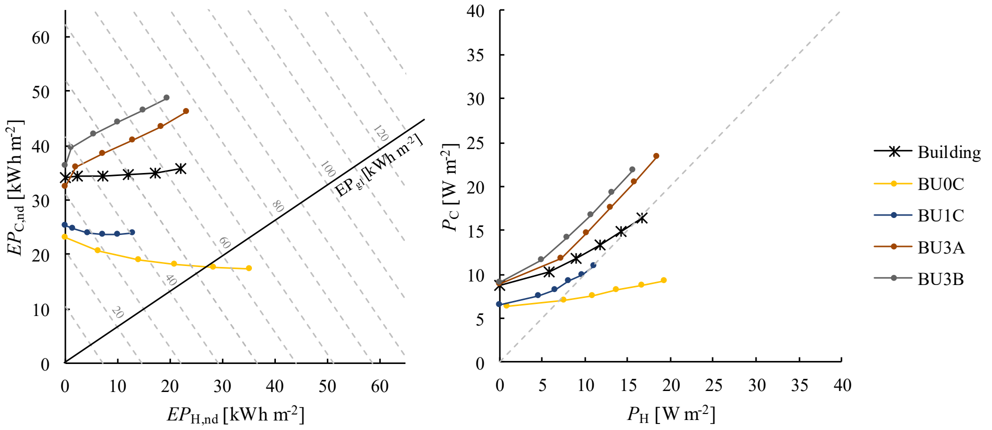


Fig. 27 Rome. Net energy need (EP_{nd}) for heating vs. cooling, and overall primary energy for the whole building and for different building units, for six thermal insulation levels.

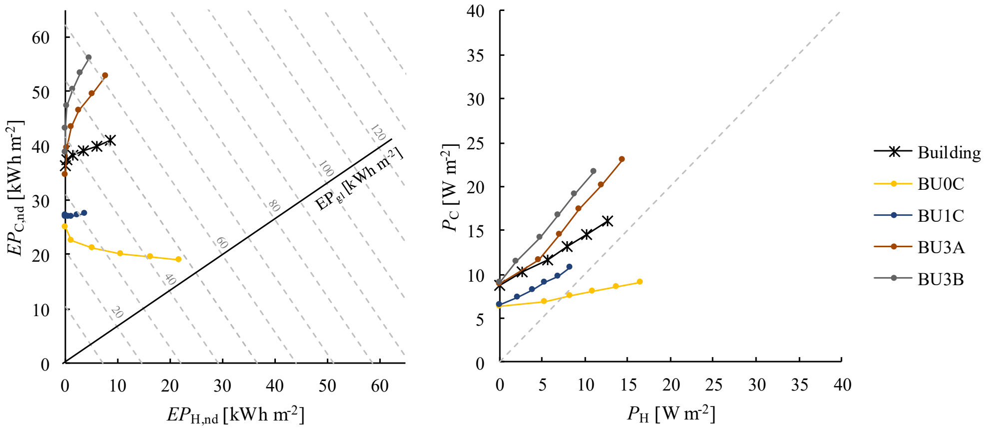


Fig. 28 Palermo. Net energy need (EP_{nd}) for heating vs. cooling, and overall primary energy for the whole building and for different building units, for six thermal insulation levels.

The high differences of the energy need between building units at different storeys are also evident in the overall primary energy (EP_{gl}), so that the same EP_{gl} can be achieved by insulating the units differently. For instance, in Palermo, BU3B and BU0C have the same EP_{gl} with $U = 0.10$ W·m^{-2}K^{-1} in the former case and $U = 0.40 \div 0.50$ W·m^{-2}K^{-1} in the latter case.

Due to the imbalances between annual energy needs for heating and cooling and in the ground floor units, it would be possible to identify limit U-values below which EP_{gl} *tends to increase. An example is BU0C in Palermo; by switching from level no.5 to level no.6, the same* EP_{gl} *is obtained (24 kWh·m*$^{-2}$*). Level no.2 would consist in a contain U-value for this unit.*

The U-value decrease generally causes the decrease both of P_{H} and P_{C}. A higher P_{H} than P_{C} occurs in Udine and Turin rather than in Palermo, where in addition the P_{C} is more sensitive to the thermal insulation level.

To improve the energy design of buildings, the findings of the work pointed out that, where possible, it would be desirable to differentiate the envelope requirements for each building unit in function of the geometrical properties, storey location and exposure. In such a way, the imbalances between energy needs for heating and cooling on the building energy performance due to the hyper-insulation of the envelope can be controlled and the overall EP minimised.

The analysis will be widened by investigating more use categories, glazing properties and shading positions, and assessing the primary energy through detailed models of the technical building systems, in order to take into account, the temporal variability of system efficiencies.

3.3 Transparent Envelope

In improving the EP of buildings, windows play a significant role as they largely influence the energy need. According to Schnieders (2009) [81], in the design of passive house solar control (with shading elements or different window solutions), wall to window ratio and the reduction of internal heat loads (such as lighting, equipment, etc.) are the most critical aspects to examine.

During the winter season, windows represent the weak element of the design for the relative heat exchanges for transmission, on the other they represent a vehicle for the solar heat gains. In the summer season the situation is reversed because solar heat gains have only a negative role and they contribute to the risk of overheating.

According to Santamouris et al. (2005) [82], the passive solar systems and solar protections, such as exterior high solar reflectance surfaces, thermal insulation, solar shading devices, and solar chimneys decrease the cooling energy needs in a building. Especially in climates characterized by warm and humid summers with cold or mild winters.

Bellia et al. (2011) [83] analyse the effect of solar protection devices (louvers and overhangs) on the energy performance of an office building. The simulation has been carried out by using *EnergyPlus* assuming three Italian climates.

The use of solar protection devices leads to energy saving only for the cooling energy need, while it leads to an increase of energy needs for both heating and lighting. According to the authors, the global annual energy savings (considering the service of heating, cooling, and lighting) can be between 8% for Milan and 20% for Palermo, while the energy savings related only to the cooling energy need are between 26% and 29%. The authors have noticed that building height does not influence the energy saving connected to solar protection devices. The dependence of the percentage energy savings on the number of building floors can be considered negligible.

The case study has been considered for two different conditions of thermal insulation. For Palermo the considered solar protection devices allow a 14% energy savings for the uninsulated building and a 24% savings for the well-insulated building. For Milan, the global energy savings are 3% for the uninsulated building and 16% for the insulated building. In the latter case, the use of solar shadings is negligible. According to Bellia et al. (2011), highly glazed buildings require more energy but the use of solar protection devices can reduce the cooling energy needs.

Feng et al. [67] have shown that the windows orientation have a strong effect on the building energy needs. The greatest solar heat gains are obtained by positioning the windows in the following order East (West) > South > North

Poirazis et al. [68] have calculated the EP of some office buildings with a 30%≤WWR≤100%, for different windows property, solar shading devices and main orientations in cold area of Göteborg. In the results was outlined that office buildings with the smallest WWR show the greater energy-saving.

Pernigotto et al. [69] have investigated the influence on the heating and cooling energy needs of different pattern of glazing systems, window size, main orientation and internal heat gains. In the energy simulations of a highly insulated residential building, they have considered localities with different weather conditions (Paris, Milan, Nice and Rome). For all analysed localities, the energy need for heating always decreases with the addition of glazing surfaces for all the exposure different from the North. According to the research, the solar shadings devices on the South oriented configurations help to reduce the cooling energy need to the levels of the East and West exposure. On the contrary, the heating energy need is only marginally influenced by overhangs. The variation of heating peak loads in relation to WWR is very limited. On the contrary, except for North exposure, with the increasing of WWR the cooling peak loads amplify. The thermal transmittance is a relevant parameter in heating and cooling conditions both for energy needs and peak loads. The transmittance of solar radiation, instead, has more influence on heating and cooling energy needs and for summer peak loads.

Tsikaloudaki et al. (2015) [70] *have compared the window energy performance of office and residential buildings, to identify its impact on the overall energy performance of Mediterranean buildings. The study concerned several window typologies with varying properties (combinations of* U-value *and g-value) configurations (frame and window fractions, orientations) and intended use (office and residential). They have observed that windows with low U-value are not always as efficient in cooling dominating climates.*

Ochoa et al. [72] have determined the suitability of combined optimization criteria on window sizing procedures for standardized offices located in temperate *climates with low energy needs and high visual comforts. They have determined that the complexity of the design lies in jointly considering several comfort measures and criteria as acoustics, energy performance, thermal and lighting comfort. It has shown that optimizing window size for one objective can hinder attaining additional ones; for example, windows optimized exclusively for visual comfort produce large energy consumption patterns.*

Ma et al.[73] have determined relationships in thermally autonomous buildings between maximum WWR and the ambient temperature amplitudes with different envelope thermal resistances. In the study, it has been demonstrated the utility of process assumption-based design alongside heat balance design as the tool for achieving real building energy saving.

Goia [74] has searched for the optimal WWR in different European climates in relation to an office building characterized by best-available technologies for building envelope components and installations. The optimal WWR was obtained considering the minimum sum of the energy use for heating, cooling, and lighting. According to Goia, an optimal WWR can be found in a relatively narrow range ($0.30 \leq \text{WWR} \leq 0.45$). Only south-oriented facades in very cold or very warm climates require WWR values outside this range.

For existing office buildings, Harmatia and Magyar (2015) [75] have investigated the preferable window to wall ratio (WWR) and window geometry (WG) in function of indoor daylight quality and heating and cooling energy performance. According to the authors, WWR and WG can be determined from the daylight dispersion and daylight factor to offer performable results for improvement of indoor environmental quality. In the research, the WWR was decreased from 50% to 30% and 25% per single office wall area depending on the orientation, and by application of adequate glazing type. With these implementations, the case study concluded that the heating energy demand could be reduced by 83%.

In the work of Chiesa et al. (2018) [256] in order to improve the cooling energy performance of some case studies, passive solutions have been examined. A part of the research has analysed the implications on the energy performance of solar shading devices with motorized operating mechanism linked to solar radiation sensors. The research has shown that increasing the value of radiation control of solar shading (value of solar irradiance) increase also the cooling energy need. The activation valour that show the best cooling energy performance is 120 $W \cdot m^{-2}$. This activation valour corresponds to the highest value of sunlit hours (10 hours).

3.3.1 Parametric Analysis: Transparent Envelope

This paragraph investigates the role of the transparent building envelope in achieving the NZEB target and in particular the impact of different orientations of WWR on the *EP* of buildings in three Italian climatic zones. To this purpose the *EP* of a case study with different envelope features (i.e. level of thermal insulation, windows properties, shading devices, WWR) was assessed. The *EP* was calculated taking into account the thermophysical characteristics of the notional reference building (NRB) as defined by the Italian MD 26/06/2015 [143].

For new buildings and in the refurbishing of the existing buildings stock, the MD does not provide maximum values for WWR. Besides the verification of the EP through the NRB, additional parameters related to the thermal quality of the building envelope, as the mean overall heat transfer coefficient by thermal transmission (H'$_T$) and the summer solar effective collecting area of the building ($A_{sol,sum}/A_f$), are specified.

3.3.2 Energy Characteristics of Windows

For the same locations as in the previous paragraph, the relations between the optimal window-to-wall ratio (WWR) and *EP* in NZEB residential buildings are examined. The energetic characteristics of the transparent envelope -specifically *U*-value and solar transmittance is critical to provide comfort and lower cooling energy need. This service is becoming a key factor for evaluating the energy performance of NZEB in Italy. The relationship between solar transmittance reduction of the transparent building envelope and the cooling energy need, can be calculated in numerical terms. $EP_{H,nd}$ and $EP_{C,nd}$ are investigated, while the energy needs for lighting are neglected as envisaged for the residential buildings by the MD. The overall energy performance in terms of non-renewable primary is also assessed with a simplified method.

Tsikaloudaki et al. [70] have established that the influence of the transparent envelope in defining cooling loads is maximized when their g_{gln} is high and their *U*-value is low.

As visible in Fig. 29, Fig. 30, Fig. 31, Fig. 32 with the reinforcement of the characteristics of the building opaque envelope, the influence of the fenestration is becoming always more important especially in the definition of cooling energy needs. The objective of this part of thesis is compare the energy performance of some type of window glass (shown in Table 72). The types analysed have similar performances. The values shown in the table derive from a national Recommendation (UNI, 2016) [71]. The case study analysed refers to the level of thermal insulation n.3 (intermediate).

Table 72 Energy and optical characteristics of some solution of windows [71].

	Glazing		Energetic characteristics		Optical characteristics	
	Inner layer	Outer layer	g_{gln}	U_g	τ_v	ρ_v
S1	Without coating	Low-emission	62	1.10	79	13
S2	Selective 70/40	Without coating	43	1.10	72	10
S3	Selective 40/22	Without coating	23	1.10	40	20
S4	Selective 70/35	Without coating	38	1.00	71	16
S5	Selective 60/28	Without coating	28	1.00	40	20

S= Solution

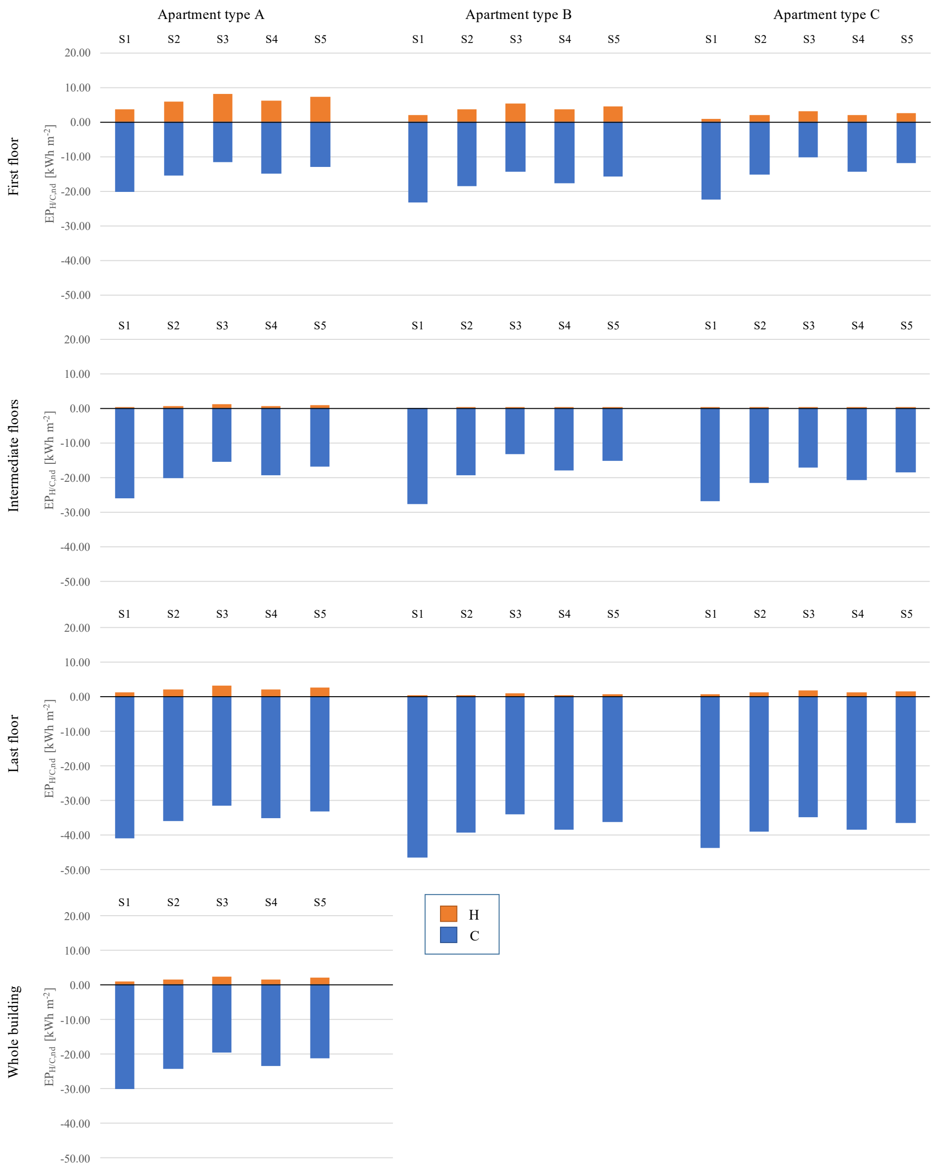


Fig. 29 Palermo – Variation of the energetic characteristics of glazing of the windows for the level of thermal insulation L.3.

The solar heat gains are directly related to the window solar properties; the glass is integral part in designing of NZEB sustainability. When the solar transmittance is low, the solar heat gains and cooling energy need are low. In fact, for all the localities analysed the minor cooling energy need are for the S3 solution (g_{gln} equal to 23%). At the same time, the higher heating energy need occur for the same solution. From the graphs it is also evident that it is necessary to differentiate the thermal properties of the windows based on the position of the building unit inside the whole building. It would be wrong to use windows with the same properties in all apartments. The ground floor building units are characterized by more pronounced heating energy needs compared to the intermediate floors and the top floors.

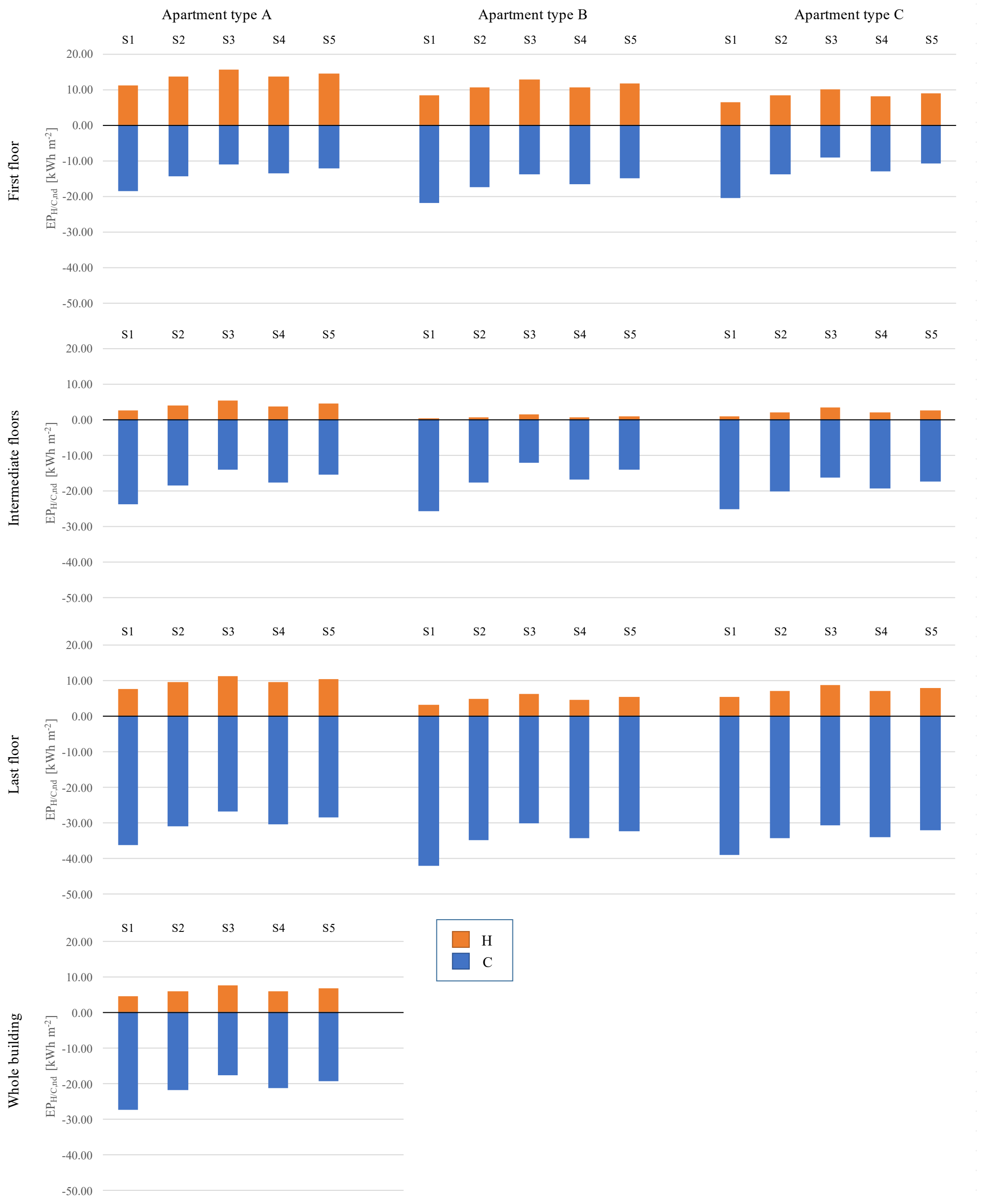


Fig. 30 Rome – Variation of the energetic characteristics of glazing of the windows for the level of thermal insulation L.3.

The cooling energy needs vary according to the position of the building unit, even if in a less evident way than the heating energy needs. The impact of shading devices is also significant, with the aim of generalizing the results however in this study the same shading device have been considered ($g_{\text{gl+sh}} = 0.35$, τ=0.15, ρ=0.70, internal side of the window). For better energy performance, windows with as high visible light transmittance and with as low *g*-value as possible should be used (unfortunately, the S3 solution despite having a low g_{gln}, is characterized by a low τ_{v}, probably therefore leads to higher lighting consumption). As expected, for the cooling service the EP of windows in warm climates (Palermo and Rome) is influenced significantly by their thermos-physical properties. For Belluno the use of a glass solution rather than another is more appreciable in the definition of heating energy need while cooling ones varies little.

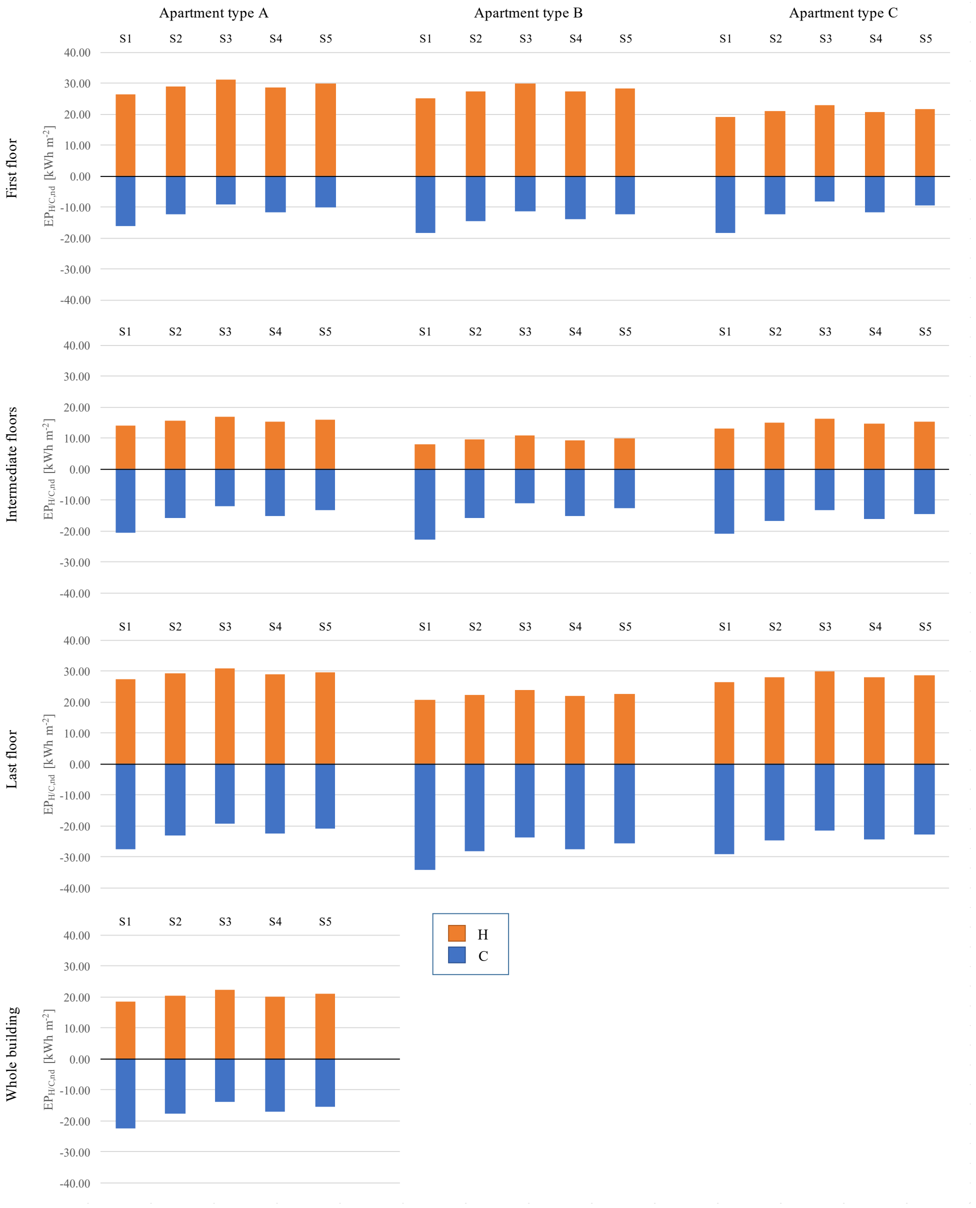


Fig. 31 Turin – Variation of the energetic characteristics of glazing of the windows for the level of thermal insulation L.3.

Table 73 shows the overall thermal performance for each solution examined by type of building unit and location. The solution that allows to reach the lowest global requirement is highlighted in red. A, B, and C represent the type of building unit. The second column represents the floor of the apartment. It is evident how it is not possible to generalize or find a common rule for locality and residential unit.

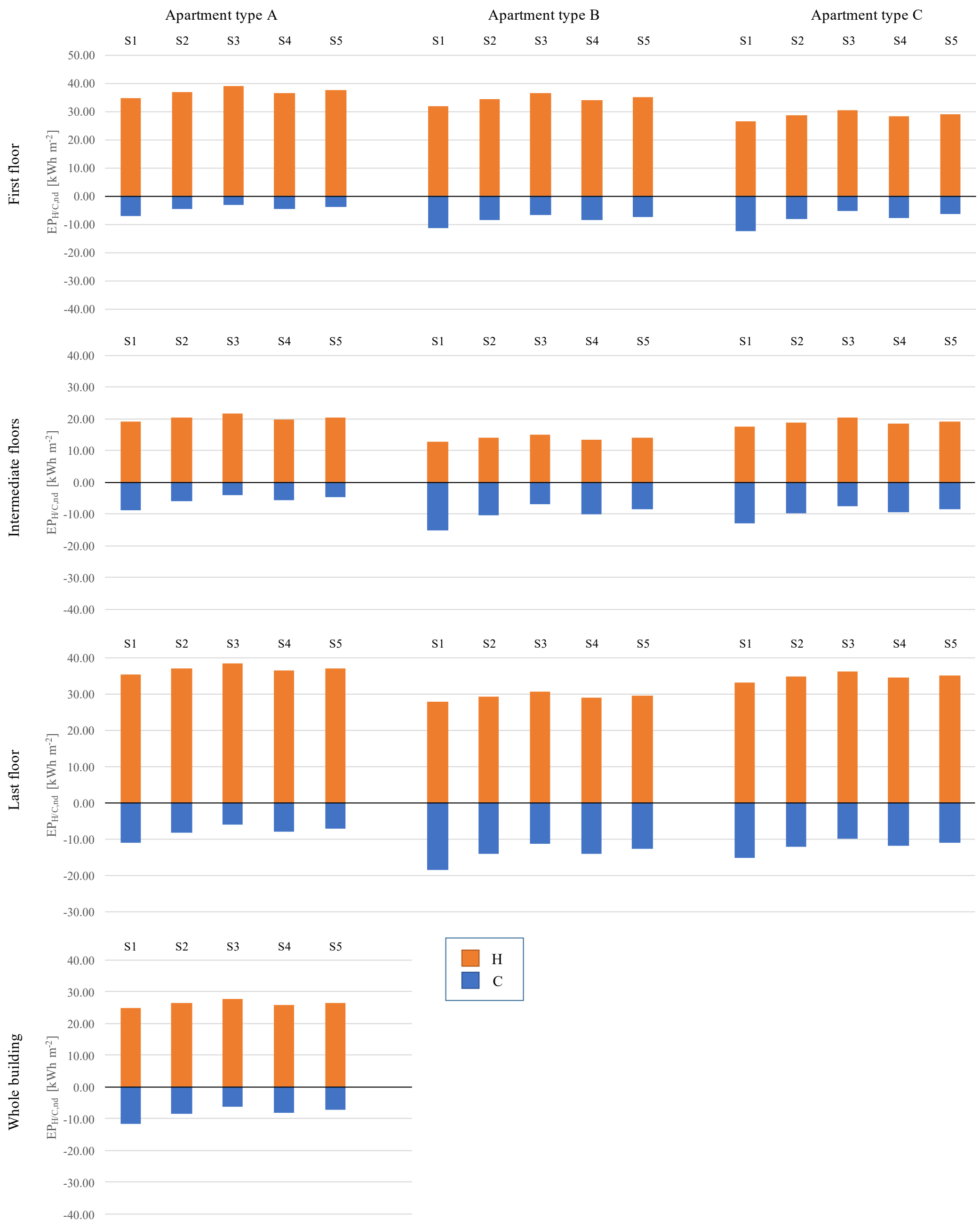


Fig. 32 Belluno – Variation of the energetic characteristics of glazing of the windows for the level of thermal insulation L.3.

Table 74 shows instead the solution characterized by the best energy performance at building level. The solution S1 is the best only in the case of Belluno for apartment A on the ground floor. The S2 solution is never the best choice. The solution S3 shows good energy performance in the following cases: Apartment type A (Rome and Palermo), Apartment B (Turin, Rome and Palermo) while it is always the best solution for apartment C (Rome and Palermo). It is evident that, in the choosing of the best solution it plays a fundamental role both the main orientation of the building unit and the extension of the dispersing surface. We also have to consider that all the technological solutions have very close values.

Table 73 Best solution in terms of EP_{gl} by type of building unit and location

		A					B					C				
		S1	**S2**	**S3**	**S4**	**S5**	**S1**	**S2**	**S3**	**S4**	**S5**	**S1**	**S2**	**S3**	**S4**	**S5**
BL	1	54.13	54.86	55.96	54.14	54.67	54.60	55.09	56.07	54.45	54.93	48.05	46.85	46.59	45.93	45.78
	2/3	34.61	33.62	33.28	32.65	32.46	32.27	29.02	27.19	28.02	27.08	36.37	35.19	34.76	34.46	34.22
	4	58.74	58.31	58.29	57.40	57.39	55.69	53.74	52.78	52.81	52.37	59.72	59.19	59.15	58.47	58.45
TO	1	51.51	51.10	51.43	50.34	50.46	51.91	51.39	51.62	50.62	50.70	43.72	40.60	39.00	39.50	38.71
	2/3	38.70	36.33	34.70	35.33	34.49	32.83	28.28	25.31	27.08	25.68	38.17	36.42	35.16	35.58	34.95
	4	63.93	62.05	60.94	61.21	60.59	61.13	57.57	55.37	56.61	55.72	63.85	62.22	61.27	61.58	61.08
RM	1	33.31	32.26	32.00	31.69	31.53	32.66	31.25	30.67	30.58	30.27	28.53	24.68	22.33	23.71	22.60
	2/3	26.30	22.94	20.84	22.14	21.11	25.09	18.13	13.65	17.08	14.91	25.65	22.24	20.10	21.45	20.42
	4	45.23	42.88	41.41	42.31	41.57	44.88	40.21	37.27	39.39	38.31	44.95	42.88	41.42	42.41	41.71
PA	1	24.62	23.08	22.42	22.55	22.20	25.38	22.63	21.23	21.99	21.22	22.92	17.29	14.10	16.33	14.80
	2/3	25.51	20.20	16.48	19.39	17.46	26.58	18.57	12.73	17.42	14.63	26.04	21.02	17.13	20.19	18.21
	4	41.19	37.40	34.68	36.84	35.50	45.24	38.54	33.87	37.71	35.81	43.14	39.23	36.26	38.69	37.24

Considering instead the overall characteristics of the building, the situation shown in Table 74 suggests the S5 solution for Belluno (U_{g}=1.00 $\mathrm{Wm^{-2}K^{-1}}$, g_{gln}=0.28), S1 for Turin (U_{g}=1.10 $\mathrm{Wm^{-2}K^{-1}}$, g_{gln}=0.62) and the S3 solution for Rome and Palermo (U_{g}=1.10 $\mathrm{Wm^{-2}K^{-1}}$, g_{gln}=0.23).

Table 74 Best solution in terms of EP_{gl} for type of building and location

	S1	**S2**	**S3**	**S4**	**S5**
BL	45.17	44.22	43.96	43.37	43.22
TO	41.19	45.01	43.73	44.12	43.47
RM	32.56	29.31	27.30	28.57	27.61
PA	30.27	25.55	22.22	24.79	23.15

3.3.3 WWR design

This part discusses about the WWR that, in the design of NZEBs, should be adopted to minimize at the same time both $EP_{H,nd}$ *and* $EP_{C,nd}$.

The case study is a single room of a residential apartment. The reference room is of rectangular plan, 4.5 m wide and 4.5 m long, with a story height of 3.0 m. The aim of the WWR optimization is to minimize the overall building energy need. The sensitivity analysis took into account ten levels of WWR, from the lowest (level no. 1) equal to 10% to the highest (level no. 10) equal to 100%. All opaque building components of the reference room have been regarded as adiabatic, with the exception of the front wall, which was regarded as thermally insulated according to the thermal characteristics of the notional reference building as described by the MD 26/06/2015. The insulation layer is placed on the exterior side of the wall. Table 75 summarises the properties of the building envelope.

The impact of shading devices on the energy performance has been examined through two fixed types of solar shadings (a) $g_{gl+sh} = 0.15$ *(*τ*=0.20,* ρ*=0.70, external side of the window) and (b)* g_{gl+sh}*=0.35 (*τ*=0.15,* ρ*=0.70, internal side of the window). The characteristics of solar protection devices combined with glazing have been determined according to standard* EN ISO 52022-1 [76].

The analysis was carried out in reference to a reference *room with a single orientation (only one wall facing outwards) because the comfort conditions can change considerably for each environment in relation to the incident solar irradiation.* The case study is located in three Italian localities: Turin (TO, climatic zone E), Rome (RM, climatic zone D) and Agrigento (AG, climatic zone B). The weather data were derived from the new national Typical Meteorological Year of the Italian Thermotechnical Committee (CTI) [252]. Summary climatic data are given in Table 75.

Table 75. Climatic data of the considered locations (left) and properties of the building envelope (right).

Loc.	HDD	Solar irradiation					Wall				Window	
		S	E	N	W	Hor.	U	M_s	$\lvert Y_{ie} \rvert$	κ_i	U	$g_{gl,n}$
	[°C·d]	[kWh m^{-2}]					[W·m^{-2}K^{-1}]	[kg·m^{-2}]	[W·m^{-2}K^{-1}]	[kJ·m^{-2} K^{-1}]	[W·m^{-2}K^{-1}]	[-]
TO	2617	930	1030	505	559	1354	0.26	260	0.04	49.5	1.4	0.67
RM	1415	1057	867	547	828	1603	0.29	259	0.05	49.6	1.8	0.67
AG	729	1177	929	576	889	1762	0.43	258	0.09	50.1	3	0.75

Hourly profiles of the internal heat gains and the ventilation flow rate were determined according to national specification UNI/TS 11300-1 [235] *for residential buildings. The overall sensible internal heat gain, obtained as the mean value of the weekly profile, has a value of 5.30 W·m*$^{-2}$ *(for a residential apartment of 75 m*^{2}*). As specified by the Italian legislation, continuous operating schedules were assumed during the heating and cooling seasons. The set-point temperature was fixed at 20 °C and 26 °C for heating and cooling, respectively. The solar shading devices are considered in function when the hourly value of solar irradiance exceeds 300 W·m*$^{-2}$*.*

The software Design Builder (version 5.4.0.014), based on EnergyPlus (version 8.9.0 released on 31/03/2018), was used to run dynamic simulations and define the energy need of the case studies. The views of the case studies and the main geometric features are shown in Table 76.

The overall energy performance was evaluated in terms of non-renewable primary energy, using equation (5). *The technical building system were characterised in compliance with* MD 26/06/2015 [143], *considering the mean seasonal efficiency of the heating/cooling utilisation subsystems (i.e. heat emission, control and distribution)* $\eta_{H/C,u}$ *equal to 0.81, and the mean seasonal efficiencies of the generation subsystem for heating* $\eta_{H,g} = 0.95$ *and for cooling* $\eta_{C,g} = 2.50$ (Section 1.4). *Specifically, gas condensing boiler and electric chiller were assumed as reference generators for heating and cooling, respectively. Two types of energy carrier were considered in the current analysis: natural gas and electricity with non-renewable primary energy conversion factors* $f_{p,nren}$ *equal to 1.05 and 1.95, respectively, according to MD* [143] (Table 7).

The verification of the two parameters prescribed by the Italian legislation is shown in Table 76 *and in* Table 77. *The compliant WWR configurations are shown in green. To calculate the summer solar effective collecting area of the building (*$A_{sol,sum}/A_f$*), the solar irradiance of main orientation was determined according to* EN ISO 52010-1 [246]. *Table 77 highlights that, using building elements having the same characteristics as the notional reference building, it is possible to increase WWR up to 40% in Turin, 30% in Rome, and 10% in Agrigento.*

Table 76. Main geometric features of reference room and mean overall heat transfer coefficient by thermal transmission H’$_T$ [W·m^{-2}K^{-1}].

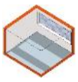
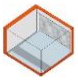
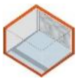
WWR	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
										
TO	0.37	0.49	0.60	0.72	0.83	0.94	1.06	1.17	1.29	1.40
RM	0.44	0.59	0.74	0.89	1.05	1.20	1.35	1.50	1.65	1.80
AG	0.69	0.94	1.20	1.46	1.72	1.97	2.23	2.49	2.74	3.00

Table 77 shows that with configurations of total solar energy transmittance of the transparent part of the element in presence of a shading device of $g_{\mathrm{gl+sh}}$ *= 0.15 is always possible to realize more glazing area.*

Table 77. Summer solar effective collecting area ($A_{\mathrm{sol,sum/Af}}$) of different configurations.

WWR	South						East						North			West					
	TO		RM		AG		TO		RM		AG		TO	RM	AG	TO		RM		AG	
[%]	0.15	0.35	0.15	0.35	0.15	0.35	0.15	0.35	0.15	0.35	0.15	0.35	0.67	0.67	0.75	0.15	0.35	0.15	0.35	0.15	0.35
10%	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0	0.01	0.01	0.02	0.01	0.01
20%	0.01	0.03	0.01	0.03	0.01	0.03	0.02	0.04	0.02	0.04	0.01	0.03	0.04	0.04	0.04	0.01	0.02	0.01	0.03	0.01	0.03
30%	0.02	0.05	0.02	0.05	0.02	0.04	0.03	0.07	0.02	0.06	0.02	0.05	0.07	0.06	0.06	0.02	0.04	0.02	0.05	0.02	0.04
40%	0.03	0.06	0.03	0.07	0.02	0.05	0.04	0.09	0.03	0.07	0.03	0.06	0.09	0.08	0.08	0.02	0.05	0.03	0.07	0.03	0.06
50%	0.03	0.08	0.04	0.09	0.03	0.07	0.05	0.12	0.04	0.09	0.04	0.08	0.11	0.1	0.1	0.03	0.06	0.04	0.09	0.03	0.07
60%	0.04	0.1	0.05	0.1	0.04	0.08	0.06	0.14	0.05	0.12	0.04	0.1	0.14	0.13	0.13	0.03	0.07	0.05	0.11	0.04	0.09
70%	0.05	0.11	0.05	0.12	0.04	0.1	0.07	0.17	0.06	0.14	0.05	0.12	0.16	0.15	0.15	0.04	0.09	0.06	0.13	0.05	0.11
80%	0.06	0.13	0.06	0.14	0.05	0.12	0.08	0.2	0.07	0.16	0.06	0.14	0.19	0.17	0.17	0.04	0.1	0.06	0.15	0.05	0.12
90%	0.06	0.15	0.07	0.16	0.06	0.13	0.1	0.22	0.08	0.18	0.07	0.15	0.21	0.2	0.2	0.05	0.12	0.07	0.17	0.06	0.14
100%	0.07	0.17	0.08	0.18	0.06	0.15	0.11	0.25	0.09	0.2	0.07	0.17	0.24	0.22	0.22	0.06	0.13	0.08	0.19	0.07	0.16

In general, the configuration of WWR for g_{gl+sh}*=0.35 which allows to satisfy the requirements of MD is between 10% and 20% of WWR. In accordance with the provisions of the MD the solar shading devices are not installed on the windows at North. The energy performance of 70 configurations of the case study was calculated for three Italian locations characterized by different climatic conditions (for a total number of 210 simulations). The configurations concern the progressive increase of WWR, the use of two different types of solar shading with different energy performance characteristics and different orientations of the reference room, representing the case study.*

The trends of heating and cooling energy performance for configurations of glazing and shading device having the same g_{gl+sh} *-value are shown in Fig. 33.*

For all the case studies and for all the locations, with the only exception of Turin for the northern front (configuration WWR of 10%), the energy need for cooling is higher than the one for heating.

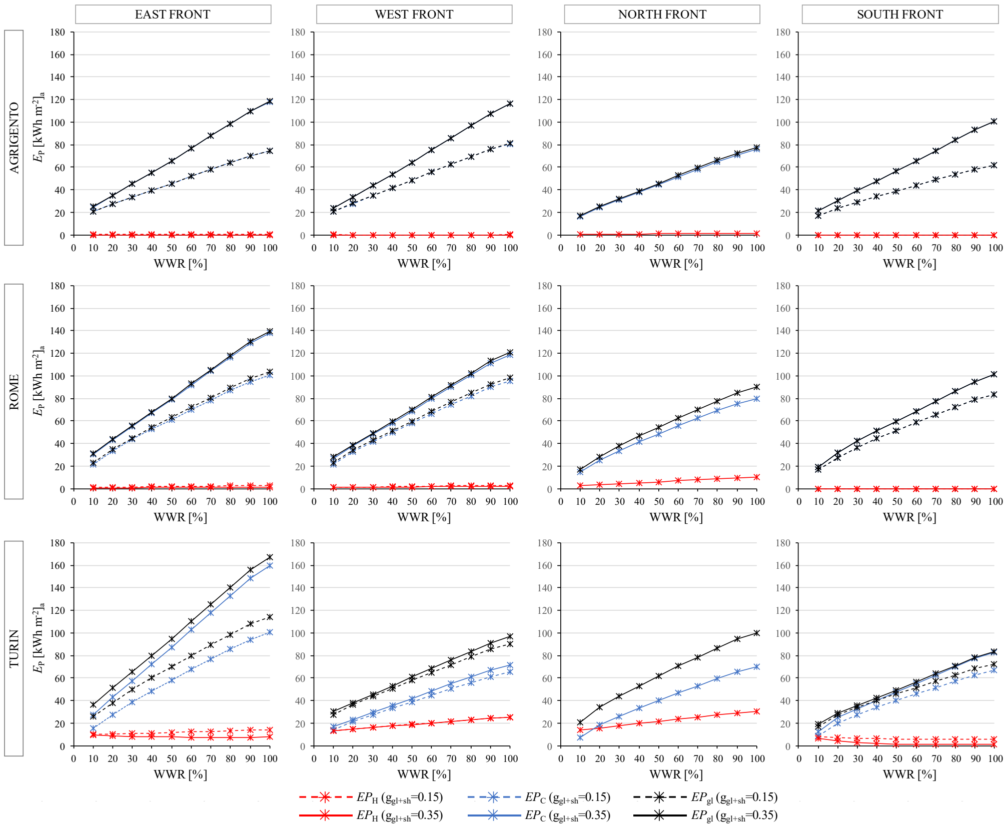


Fig. 33. Cooling, heating and global energy performance of the analysed configurations.

The results show that window-to-wall ratio and energy needs are directly related. For example, for Turin and for configurations of glazing and shading device with $g_{gl+sh} = 0.35$*, differences of total energy needs of 357% for the East front, 222% for the South front, 385% for the North front, and 340% for the West front occur increasing WWR from 10% to 100%. These percentages significantly increase for the locations of central and southern Italy where the energy needs for heating are nearly zero while the energy needs for cooling have a significant weight.*

For all the analyzed locations, the effect of WWR on the east front is very pronounced, followed by that on the west.

The use of a high performance shading device has a positive effect on the energy need for cooling. In general, for any WWR configuration the use of best performing shading device decreases the energy needs for cooling: for Agrigento, for all orientations, the energy benefits increase for large glazing surfaces; for Turin the best energy benefits are for WWR between 10 and 20%; in conclusion at Rome in the East and West front the trend is similar to that for Turin while at South is similar to Agrigento.

The best performing shading device ($g_{gl+sh} = 0.15$) *has a greater impact on the energy performance of buildings in the following order East > South > West.*

In Turin the reference room on east and north fronts shows higher values of EP_{gl}*. By contrast, the reference room acts differently on the fronts West and South* *where instead the* EP_{gl} *referred to Turin has lower values compared to other locations.*

Fig. 34 shows results related to peak power. For all case studies, and for the different examined WWR configurations, the results indicate that the increase of the energy performance of shading device has a twofold and opposite effect. On the one hand, there is a substantial reduction of the cooling demand of the reference room and on the other a slight increase of the energy need for heating. In general, for all localities and orientations (with exception of the north front) the use of large windows increases both the heating and the cooling peak loads.

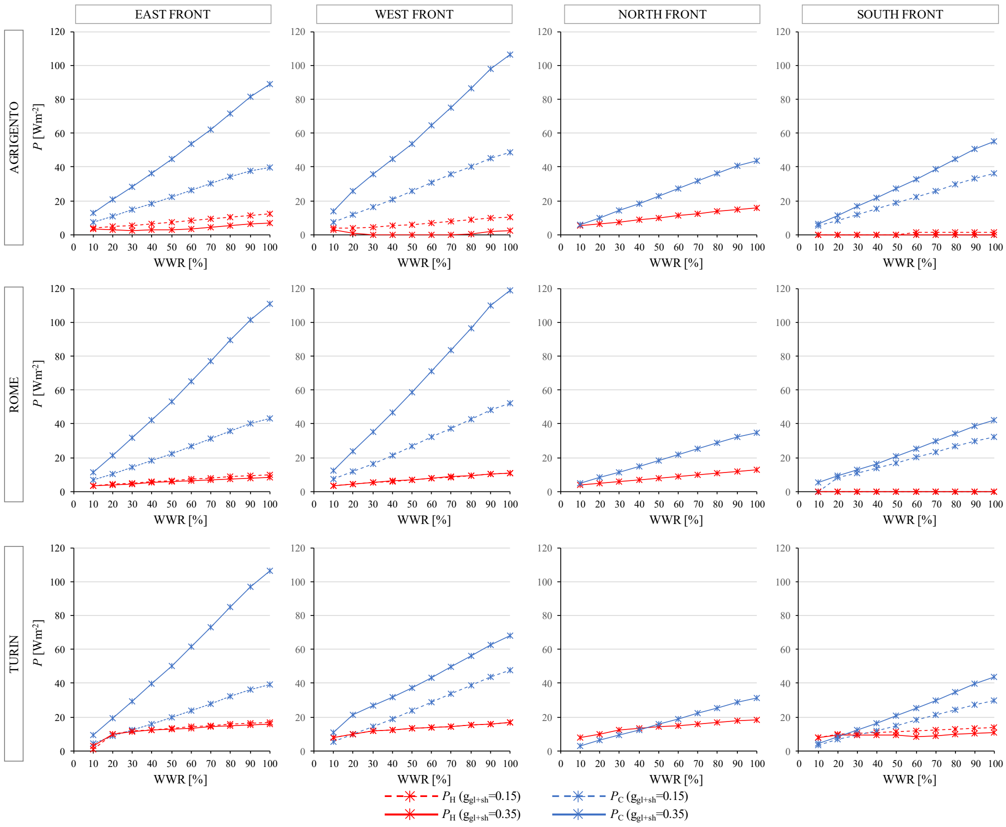


Fig. 34. Cooling and heating peak power of the analysed configurations.

In order to achieve the NZEB target it is not a good design practice to increase the WWR ratio. Moreover, the orientation of the windows has a significant impact on the energy performance of the building.

For a single reference room with only one external wall a WWR range from 0 to 100% was tested to investigate its effect on the energy need. The results show some common trends for all the considered climates.

In general, for all localities and orientations, the use of large windows increases both the heating and cooling energy need and the peak power. For all orientations and localities, the WWR with minimum EP_{gl} *is always equal to 10%. The weakest link of the NZEBs design concerns the cooling energy performance. It is always a good practice to use a high-performance shading device to reduce the overall energy demand despite it negatively effects on the heating energy behavior* *of the building (which as seen, however, has a low percentage incidence). Therefore, in the design of NZEBs, it is important to consider the orientation fronts of glazed surfaces, the solar and thermal properties of windows and the shading devices properties in addition also to the reduction of internal heat loads (such as lighting, equipment, etc). Future studies will examine further configurations of the reference room with expanded thermal envelope also including ground floor or roof. Other glazing properties will also be considered. The lighting service that is strongly dependent on the characteristics of glass and solar shading will also be taken into consideration. Considering the solar contributions for each orientation it will be investigated the method of reaching the optimum configuration combining all four sides of a building.*

3.4 Cost Optimal Application

The energy optimization of a building during the refurbishment or design stage can be defined as the exploration of the set of design solutions on the building envelope, on the building technical systems and RES (renewable energy sources), whose combination provides the minimum of the objective function. In this analysis the objective function is related to the energy performance of building.

The classic legislative framework is reported in the cost-optimal methodology [64] that defines a "*comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements*".

Y. Al-Saeed and Abdullahi Ahmed (2018) [31] have investigated on the potential of achieving a NZEB in African regions (MENA). They have developed and proposed a unified code for NZEB with the aim of evaluating the current design standards and how these can be improved to achieve higher building EP and, consequently cost savings. They have developed several design scenarios to evaluate the energy performance. The best solution has been obtained increasing the air change to 1.2 ACH, an HVAC with a highly-efficient HP, building envelope with thermal transmittance of 0.17 (wall), 0.11 (roof), high efficiency lighting (2.32 $W \cdot m^{-2}$), and PV. Using these technologies, the EP for residential buildings falls within the range of 229 (Jordan) to 285 $kWh \cdot m^{-2}$ a (United Arab Emirates).

Rodrigues et al. (2018) [32] have analysed the implications of lowering the building envelope thermal transmittance. From the study results that when the thermal transmittance decreases the EP variation amplitude (difference between max. and min. energy need) is reduced, therefore the geometry of the building loses importance. Differently, in warm climates, low thermal transmittance tends to increase the energy need and also rise the EP variation therefore, the geometric variables recover importance. The Authors have found for each climate zone, a theoretical thermal transmittance for which the geometry effect becomes less significant (building shape and window designs).

In the South of Europe, the climate is characterized by dry warm/hot summers and mild winters (Lisbon, Toledo, and Porto). According the study, in this context the thermal transmittance increases the cooling energy need and become the major influencer factor. Differently, in location where the climate is characterized by humid mild/cold winters and hot/warm summers this effect is not visible.

In location with cold/severe winter and warm/cool summer climates the cooling energy need is almost neglect able. Concerning the building indexes:

- the shape coefficient does not have correlation for any of the thermal transmittances and in any of the locations;
- buildings with low compactness coefficient have generally low energy need, however in EU southern countries, for very low thermal transmittances, the coefficient inverts its influence presenting very weak positive correlation (compactness slightly increase energy needs);

for all locations, WWR show moderate to strong negative correlations on energy needs for higher thermal transmittances, that tend to de-crease with decreasing thermal transmittances. For high thermal transmittances, the glazing areas improve the EP by reducing the heating needs.

D’Agostino et al. (2017) [56] have realized a tool for the provision of a harmonized NZEBs database of good practices at EU level that provides a reference guideline in case of retrofit of residential and non-residential NZEBs. Existing building retrofit towards NZEBs requires an appropriate combination of efficient technologies, systems, renewables and envelope solutions depending on location, legislation and market conditions.

Different levels of renovation can be distinguished depending on the type of intervention. The *EP* can be improved by a single measure, such as a new heating system or roof insulation or with combinations of more packages of efficiency measures. According to the European Parliament, the deep renovation is a refurbishment that reduces both delivered and final energy consumption of buildings by at least 80% respect the initial level.

The design process of NZEBs involves an integrative approach looking to (a) reduce energy needs for heating and cooling by optimizing the building envelope with replacement or upgrade of all building elements and eventually integrating passive heating and cooling techniques; (b) improve the energy efficiency of technical building systems (heating, ventilation and air conditioning - HVAC, lighting, etc.) (c) installation of renewable energy sources (RES).

A NZEB is more economically feasible if more emphasis is given on increasing roof and wall insulation, while PV systems seem to be an attractive investment for the building’s renewable energy provider [19].

Zangheri et al. (2018) [78] have applicate the cost-optimal methodology for identifying proper retrofit measures to reach cost optimal levels and NZEB levels. The application has considered set of passive and active renovation options for various building categories (residential and non-residential) of 60s–70s in different climatic conditions. They looking at the results determined that the cost-optimal levels imply an average reduction of 66% in primary energy and of 27% in global costs respect to the starting levels. In the Central-North Europe, the NZEB levels result economically more advantageous than the starting levels. Some results demonstrate that the improvement of the building envelopes allows avoid the installation or substitution of an active cooling system. In addiction for some case studies, as the apartment blocks in Spain, the NZEB benchmarks have a lower investment cost of the cost-optimal ones.

However, in spite of the fact they also have lower energy running costs, the global costs are slightly higher than the cost-optimal retrofit solution in fact the retrofit solutions have lower lifespan (e.g., fan coils) compared to more expensive alternatives (e.g., radiant floor).

In Italy, the MD 26/06/2018 [143] set the minimum requirements for NZEB (new and existing buildings) but specific requirement for cultural heritage buildings are completely missing. Lucchi et al. (2017) [79] have studied the application of cost optimality methodology for internal insulation systems of historic buildings.

They have noticed that there aren’t examples of historic reference building and shared information. In their research, they have definite a methodology and a procedure for evaluate the economic benefit. To study exclusively the internal insulation systems, the authors don’t have considered other technologies and HVAC systems. The results have demonstrated that both organic and inorganic insulations have a good behavior.

Buso et al. (2017) [80] have applicate the cost-optimality to an Italian Reference Hotel undergoing major renovations. For each of proposed retrofit solution, they have considered also comfort aspects. The considered retrofit options are not able to meet the legal requirements but in any case, anyway results provide encouraging perspectives. Among the negative factors that prevent the effective exploitation of RES there are that (a) the case-study is an energy-intensive building, (b) it’s located in a densely-built context. Nonetheless, the implementation of retrofit options allows the compliance with NZEB primary energy requirements. The authors have pointed out that the retrofit options with better economic performances shown worse comfort values. Therefore, the study suggests that for hotels, where guests’ comfort is a priority, economic and financial convenience should not be the only leading parameter to evaluate retrofit options.

Montana and Severino (2018) [62] have provided a general overview on existing optimization algorithms, and methodologies to use for the refurbishment of existing buildings for the conversion into low-energy buildings or nearly zero-energy buildings. The cost optimality-solution may be subject to contrasting technical restrictions, environmental aspects and objectives. Moreover, designers frequently have to evaluate different solutions and perform many BES in order to find the configuration that showing the best energy performance and to correctly design the energy from renewable sources produced on-site that will cover these building energy needs.

Table 78 Typology of optimization problem [62]

Acronym	Typology of optimization problem	Property
SOOP	Single-Objective	The objective function (a) has one global minimum; (b) has one best solution (or none).
MOOP	Multi-Objective	MOOP finds a vector of decision variables (the constraints can be conflicting). Objective functions are represented by an optimized vector function. There is a group of different solutions that can be considered equally optimal. MOOP, to find a single solution, implemented two stages: optimization and decision-making.
	MOOP a priori [63]	– minimization of a weighted sum of objective functions; – analysis of a single-objective optimization; and search of one optimal solution.
	MOOP a posteriori [63]	– methods oriented to identify the whole Pareto front; – diversified solutions are obtained for facilitate the process of decision-making.

The mathematical algorithms can be classified as:

- “exact” or “deterministic” or “heuristic” methods.
- "single-point" or "population-based".

A category of MOOP, DM, PB, is known as “evolutionary algorithms” [65]. This category is represented by “genetic algorithms”. These techniques are employed in the design of a low energy buildings; they can handle non-linear problems with discontinuities and many local minima, they do not require to calculate the objective function’s gradients but are based on results improvement through the fitness function to assess the improvement of solutions.

Table 79 Methods of optimization problem [62]

Acronym	Methods	Property
EM	Exact	– based on mathematical operations (involve derivatives); – the objective function is expressed in a continuous and differentiable analytical form.
DM	Deterministic or heuristic	– based on criteria derived from the experience of the analyst; – the objective function not require continuity and differentiability; – the convergence criterion derived by a fitness function (deriving from the objective function).
SP	Single-point	– consider the perturbation of decision variables one by one;
PB	Population-based	– each iteration considered multiple sets of values of decision variables.

Fokaides and Padopoulos (2014) [66] have conducted a study on cost-optimal thermal insulation thickness for the various building elements. The windows haven't considered in the research because the investigated methodology concerns conduction-oriented heat transfer. The optimal thermal insulation thickness depends by the match between the optimal economic results and the max EP achievable. The research shows that the minimum requirements of thermal insulation thickness are significantly higher respect the values of the proposed model.

3.4.1 Applications

The study presents some results of the on-going European Project, RePublic_ZEB, on the refurbishment of the public building stock towards nearly Zero Energy Building (NZEB) [11]. *The work is focused on the application of the NZEB requirements to two existing public buildings representative of the 1960s in Northern Italy. Many packages of energy efficiency measures that comply with NZEB requirements are identified and evaluated. The aim is to promote energy efficient but also cost-effective solutions for the Italian building stock refurbishment. The results are presented in terms of "package of measures", energy consumption, global costs, actualized pay-back period and* CO_2 *emission.*

The Commission Delegated Regulation No. 244/2012 (European Commission, 2012) [241] *requires the evaluation of the cost optimal level both at a macroeconomic and at a financial level. Concerning the financial level calculation, the methodology is based on the overall costs, considering the initial investment, the sum of the annual costs for each year (energy, maintenance, operation and any additional costs), the extraordinary replacement of systems and components, the final value, and the costs of disposal, as appropriate. All costs are actualized to the starting year. In the macroeconomic approach, the costs corresponding to the* CO_2 *emissions are also considered.*

For the RePublic_ZEB purposes, the financial perspective calculation is applied, without considering subsidies. The financing framework methodology is based on the net present value (global costs, GC) calculation, carried out according to standard EN 15459:2018 (European Committee for Standardization, 2018) [242], *which provides a method for considering the economic aspects related to the application of heating systems and other technical systems that affect the energy consumption of the building.*

In the RePublic_ZEB *context, a tool to calculate the optimal levels of minimum energy performance requirements towards NZEB was developed, which is in accordance with* [241] *and the accompanying Guidelines* (European Commission, 2012) [64]. *The tool is based on the Italian cost optimal methodology framework, but it was modified in such a way as to consider the partners' assumptions. The energy cost optimization procedure is based on a sequential search-optimization technique [243]. The method considers, for each energy efficiency measure, a discrete number of options (e.g. different levels of thermal insulation), described by relevant performance parameters (e.g. thermal transmittance) and by specific* *costs. Different packages of energy efficiency measures are applied and compared: each package is a set of energy efficiency options, one for each measure. Among all the considered packages of measures, the optimization process allows to identify those characterized by the lowest global cost within the calculation period. In this point is analysed an office and a school chosen among the Italian case studies of the RePublic_ZEB project. Both are real buildings placed in Turin (2617 HDD), representative of the 1960s public building stock. The main characteristics are reported in Table 80 and Table 81 .*

Table 80 Geometrical and construction data of office and school reference buildings.

Geometrical data			Construction data		
	Office building	School		Office building	School
V_g	20638	39760	U_{op}	0.68	2.07
$A_{f,n}$	4521	8598	U_w	2.87	4.08
A_{env}/V_g	0.23	0.32	$g_{gl,n}$	0.75	0.75
A_w	628	2436	U_f	0.94	1.32
No. floors	7(+2)	3(+1)	U_r	1.69	1.43

Table 81 Technical building systems of office and school reference buildings.

System data (description and mean seasonal efficiency)			
Office building		School	
Radiators and fan-coils	($\eta_{H,e} = 0.87$)	Radiators and fan-coils	($\eta_{H,e} = 0.91$)
Room and climatic temperature control	($\eta_{H,ctr} = 0.86$)	Climatic temperature control	($\eta_{H,ctr} = 0.83$)
Central distribution, horizontal pipes	($\eta_{H,d} = 0.96$)	Central distribution, horizontal pipes	($\eta_{H,d} = 0.90$)
2 natural gas generators	($\eta_{H,gn} = 0.87$)	3 natural gas generators	($\eta_{H,gn} = 0.77$)
Electrical storage water heater	($\eta_{W,gn} = 0.80$)	Natural gas generator	($\eta_{W,gn} = 0.86$)
Indoor units split systems	($\eta_{C,e} = 0.97$)	No cooling system	-

In the retrofit process of the buildings a whole renovation is considered; the energy efficiency measures (EEMs) concern both the fabric and the technical systems (Table 82). *The EEMs from 1 to 6 consider the envelope (e.g. exterior insulation, windows replacement, solar shading devices); the EEMs from 7 to 11 involve the technical systems for space heating/cooling and/or DHW (e.g. replacement of the heat generator) and take into account technologies like condensing boiler, biomass generator, district heating, air-to-air and air-to-water heat pumps. The EEMs 12 and 13 concern the energy production from renewables (i.e. solar collectors and PV panels), while EEM 14 the heat recovery ventilation system. Finally, an advanced control for space heating (EEM 15) and the lighting system replacement are considered (EEM 16 and 17).*

There are up to five energy efficiency options (EEOs) for each EEM, representing different levels of performance. For each EEO the specific cost is estimated. Table 82 summarizes the EEOs thermal parameters values and the referred costs for the considered reference buildings. The costs exclude 23% VAT but include extra-costs for lathing and technical systems adjustment.

Table 82 Energy efficiency measures, related options and costs.

No.	EEM	Parameter	Building office EEO 1	2	3	4	5	School EEO 1	2	3	4	5
1	External wall thermal insulation	U_{op}	0.27	0.23	0.21			0.26	0.24	0.20		
		C/A	44.21	46.55	48.95			48.95	53.75	74.85		
2	Wall vs unconditioned spaces	$U_{op,u}$	0.3	0.25	0.21	0.19		0.29	0.28	0.25	0.24	
		C/A	31.13	32.39	42.4	44.92		29.85	34.85	31.13	37.35	
3	Roof/last floor thermal insulation	U_r	0.24	0.21	0.19			0.25	0.23	0.22	0.20	
		C/A	39.28	44.01	49.13			46.03	39.28	52.69	44.01	
4	Ground/first floor thermal insulation	U_f										
		C/A										
5	Window thermal insulation	U_w	1.49	1.35	1.16	0.91		1.40	1.16	0.92	0.86	
		C/A	387.3	308	300.2	399.6		140.7	163.7	189.2	200.7	
6	Solar shading system	τ_s	0.40	0.35				0.40				
		C/A	113	95				113				
7	Chiller	EER	5.00	6.00								
		C	66934	75880								
8	Generator for heating and appropriate emission system	$\eta_{gn,Pn,H}$ or COP	1.10	0.88	3.70							
		C	51050	30276	206818							
9	Generator for DHW	$\eta_{gn,Pn,W}$ or COP	2.60									
		C	15082									
10	Combined generator for heating, DHW, and appropriate emission system	$\eta_{gn,Pn,H+W}$ or COP	1.10	0.88	3.90			1.10	0.90	0.88	4.30	
		C	59296	30276	215059			59296	133054	30276	264522	
11	Heat pump for heating, DHW, cooling, and appropriate emission system	COP	4.30									
		EER	3.10									
		C	215059									
12	Thermal solar system	A_{coll}						10	16	5	18	
		C						6920	10188	6789	20362	
13	PV system	W_p	27	47	70	85		20	40	60	150	
		C	12221	26607	45401	82452		19835	54667	121682	225000	
14	Heat recovery ventilation system	η_{ve}	0.70					0.7				
		C	30740					35511				
15	Heating control system	η_{ctr}	0.995					0.995				
		C	31526					43726				
16	Lighting system	PN	10.85	10.85	6.09	6.09	6.09	7.91	7.91	4.34	4.34	4.34
17	Lighting control system	F_D	1	(0.9)	1	0.9	0.9	1	(0.9)	1	0.9	0.9
		(F_C)	(0.9)	(0.9)	(0.9)	(1.0)	(0.9)	(0.9)	(0.9)	(0.9)	(1.0)	(0.9)
		C	19794	31236	68712	68712	80154	26715	39175	120143	120143	132603

The electricity from PV panels is considered as a reduction of the monthly electrical energy demand; the exported electrical energy is not considered.

The following assumptions are used for the GC calculation:

- *period of 30 years;*
- *3% real interest rate; electricity and natural gas costs from the National Authority for Electricity and Natural Gas (AEEG);*
- *biomass cost from market surveys;*
- *energy trend scenarios developed with the PRIMES model according to* Commission staff working document (European Commission, 2014) [244];
- *annual maintenance costs variable from 0% to 4% of the investment cost depending on the technology;*
- *technical lifespan of building elements fixed at 20 years, of systems variable from 15 to 20 years.*

3.4.2 Results

Concerning the optimal retrofit of the office building (Table 83), the following measures are considered: the opaque components thermal insulation, the PV panels and the heat recovery ventilation system installation, the heating system control and lighting system replacements. The proposed NZEB solutions increase the thermal insulation and add the movable shading system. Moreover, in order to achieve the RER goal, different technical building systems have been considered: centralized heat pump for heating, cooling and DHW (NZEB1); centralized heat pump for heating and DHW (NZEB2); heat recovery ventilation and centralized heat pump (NZEB3). In all the solutions, the climatic plus ambient heating control system and the PV panels have been considered, while the lighting system has been equipped with T5 lamps and daylight control. The results in

Table 84 *show that the optimal retrofit of the school considers the following EEMs: all the envelope components thermal insulation; the generator replacement with district heating; the PV panels and the heat recovery ventilation system installation; the lamps and lighting control replacement. In order to achieve the NZEB goal, the proposed solutions reduce the energy need by adding a higher thermal insulation and a movable shading system. Moreover, different technical systems have been considered: biomass boiler (NZEB1); centralized heat pump for heating and DHW, and PV panels (NZEB2 and 3). In all the NZEB solutions, the climatic plus ambient heating control, the heat recovery ventilation, and the lighting system (lamps and control) have been renovated.*

Table 83 Office Building. Cost-optimal and NZEB packages of measures

No.	Energy Efficiency Measure EEM	Parameter	Before refurbishment	Cost optimal	NZEB1	NZEB2	NZEB3
1	External wall thermal insulation	U_{op}	0.94	0.23	0.27	0.27	0.21
2	Wall vs. unconditioned thermal insulation	$U_{op,u}$	1.72	0.25	0.25	0.25	0.21
3	Roof/last floor thermal insulation	U_r	1.69	0.24	0.24	0.24	0.19
4	Ground/first floor thermal insulation	U_f	0.96				
5	Window thermal insulation	U_w	2.87		1.49	1.49	
6	Solar shading system	τ_s			0.40	0.40	0.35
7	Chiller	EER	3				
8	Generator for heating and appropriate emission system	$\eta_{gn,Pn,H}$ or COP	0.87				
9	Generator for DHW	$\eta_{gn,Pn,W}$ or COP	0.8				
10	Combined generator for heating and DHW, and appropriate emission system	$\eta_{gn,Pn,H+W}$ or COP				3.9	3.9
11	Heat pump for heating, DHW and cooling,	COP			4.3		
	and appropriate emission system	EER			3.1		
12	Thermal solar system	A_{coll}					
13	PV system	W_p		70	70	85	70
14	Heat recovery ventilation system	η_{ve}		0.7			0.7
15	Heating control system	η_{ctr}	0.86	0.995	0.995	0.995	0.995
16	Lighting system	PN	12	10.85	10.85	10.85	10.85
17	Lighting control system	F_D	1.0	0.9	0.9	0.9	0.9
		(F_C)	(1.0)	(0.9)	(0.9)	(0.9)	(0.9)

Table 84 School. Cost-optimal and NZEB packages of measures

No.	Energy Efficiency Measure EEM	Parameter	Before refurbishment	Cost optimal	NZEB1	NZEB2	NZEB3
1	External wall thermal insulation	U_{op}	2.10	0.26	0.26	0.26	0.26
2	Wall vs unconditioned thermal insulation	$U_{op,u}$	0.85	0.25	0.28	0.28	0.29
3	Roof/last floor thermal insulation	U_r	1.43	0.23	0.23	0.23	0.23
4	Ground/first floor thermal insulation	U_f	1.32				
5	Window thermal insulation	U_w	4.10	1.40	1.16	1.16	0.92
6	Solar shading system	τ_s			0.40	0.40	
7	Chiller	EER					
8	Generator for heating and appropriate emission system	$\eta_{gn,Pn,H}$ or COP	0.91				
9	Generator for DHW	$\eta_{gn,Pn,W}$ or COP	0.86				
10	Combined generator for heating and DHW, and appropriate emission system	$\eta_{gn,Pn,H+W}$ or COP		0.88	0.9	4.3	4.3
11	Heat pump for heating, DHW and cooling, and appropriate emission system	COP EER					
12	Thermal solar system	A_{coll}					
13	PV system	W_p		150		150	150
14	Heat recovery ventilation system	η_{ve}		0.7	0.7	0.7	0.7
15	Heating control system	η_{ctr}	0.83	0.995	0.995	0.995	0.995
16	Lighting system	PN	9.00	7.91	4.34	4.34	4.34
17	Lighting control system	F_D	1.0	0.9	0.9	0.9	0.9
		(F_C)	(1.0)	(0.9)	(0.9)	(0.9)	(0.9)

In Fig. 35 all the solutions are shown, for the office (a) and the school (b) respectively. As regards the office, the NZEB solution that records the lowest ΔGC is the No. 3, that is characterized by a 110 €·m^{-2} global cost lower than the current state of the reference building, and a total energy performance of 88 kWh·m^{-2}, of which only 44 kWh·m^{-2} are non-renewable. As for the school, the NZEB solution that records the lowest ΔGC is the No. 3, that is similar to the cost optimal solution in terms of costs and EP; it is characterized by a 620 €·m^{-2} global cost lower than the reference building in its current state, and a total energy performance of 112 kWh·m^{-2}, of which 53 kWh·m^{-2} are non-renewable.

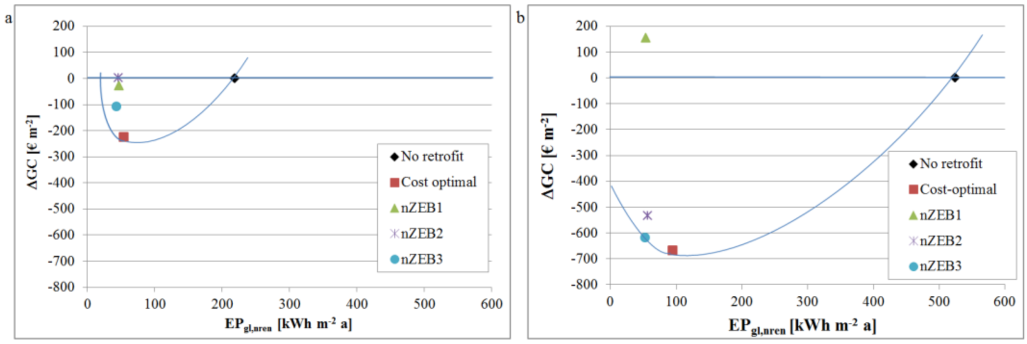


Fig. 35 ΔGC and referred $EP_{gl,nren}$: current state of the building, cost-optimal, NZEB. Office (a); school (b).

The PBP_{act} associated to each case is shown in Fig. 37 *for the office (a) and the school (b), while Fig.3 shows the CO_2 emission. The PBP_{act} referred to all the solutions is lower than 30 years, namely the duration of the calculation time, except* *for the NZEB1 solution of the school.* Fig. 37 *puts in evidence the deep reduction of the* CO_2 *emission.*

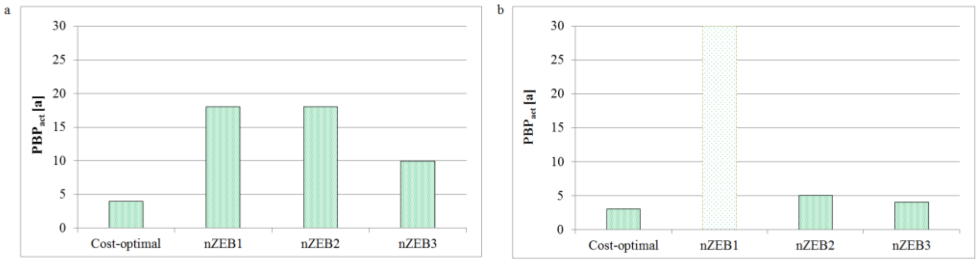


Fig. 36 Office (a); school (b). PBP_{act}: cost optimal and NZEBs solutions.

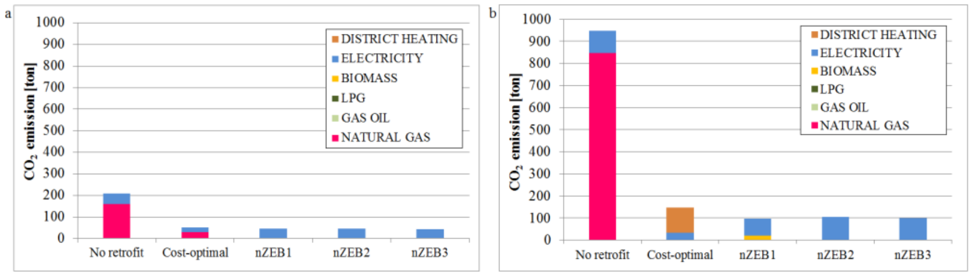


Fig. 37 Office (a); school (b). CO_2 emission: current state of the building, cost optimal, NZEBs.

The work has presented *some results of the ongoing EU project RePublic_ZEB on the refurbishment of the public building stock towards the nearly zero-energy target.* The chapter has shown *the approach and the common methodology adopted in the project for the assessment of retrofit measures suitable to reach NZEBs. This approach is implemented into a tool available to all the partners, as to investigate cost-effective as well as high EP retrofit solutions. The results of the application of the tool to two Italian reference buildings show that it is feasible to achieve the NZEB target. For both the considered reference buildings, the* EP_{nren} *associated to the NZEB solutions is lower than 100 kWh* m^{-2}*, while the retrofit cost effectiveness increases for buildings characterized by a very low energy performance at the current state, as the considered school: in similar cases the estimated global cost can reach values of about 600 €* m^{-2} *lower than the building before the retrofit. Low values of the* PBP_{act} *strengthen the cost effectiveness of the retrofit, however the calculation considers a continuous use of the building over the heating season. Finally, the heat pump combined with the PV system prevails among the EEMs: this technical solution seems to be the most cost-effective, energy performant, and suitable to reach the RER Italian requirements.*

3.5 Conclusions

This part of the activity was extremely stimulating and exciting as it allowed me to get to the heart of the energy design of buildings. I have had the opportunity to deepen and resolve some critical issues present in the commonly used EP calculation methodologies.

Up to now the design of nearly zero-energy buildings was a target, from 2021 it will be a legal obligation. The research has examined the design approach and the energy performance results of NZEBs realized in locations with cold and warm in Mediterranean area. There are still too many shadows and taboos on NZEBs and it seems that designers are not yet adequately prepared to sufficiently respond to the demands of the EPBD directive. Furthermore, the legislative and regulatory framework still have some points to solve and investigate further. This part of the activity therefore sought to identify and respond to these questions.

The effect of thermal insulation is more visible in the limitation of energy need for heating. The thermal insulation, in contrast, if it is not associated to other design strategies (thermal mass of the building in combination with nocturnal ventilation) could have little influence on cooling energy need. The most effective design solution that shows positive effects on cooling energy performance is the use of shading devices (or external double skins, glazing solar films). Furthermore, the use of thermal insulation in cold and hot locations leads to very different results on energy performance. As seen in bibliography ([256],[54]), also aspects like the positioning of the thermal mass layers and the use of natural cooling ventilation by means of the passive techniques shown important effects on the limitation of the energy need of buildings. In this work the standard conditions of buildings use and traditional design techniques was considered. This research does not address the air flow control and the ventilation regarding fenestration (free cooling, wind-driven, stack-driven, and combined airflow rates through a building, wind tower, stack, solar chimney, air plenum, etc.). Other design techniques are therefore related to the improvement of Energy Performance by passive cooling with increased ventilation and night cooling. For all the building units on the ground floor, the thermal insulation has a negative effect on the cooling energy needs.

With the increase in thermal insulation of the building envelope, there is also a greater cooling peak power. With regard to the transparent envelope it has been noted that its influence is maximized when their g_{gln}-value is high and their U-value is low. The analysis has shown that it is preferable not use the same types of windows for all the building units, but it is necessary to differentiate the thermal properties of the windows based on the position of the unit inside the building. For example, the ground floor building units are characterized by more pronounced heating energy needs compared to the intermediate floors and the top floors. Therefore, the management of dispersions / thermal heat gains can be carried out by carefully choosing the energy properties of the transparent building envelope.

As for the windows-to-wall-ratio it has been seen that the cooling energy performance is directly proportional to this parameter. The only way to limit the thermal energy needs is to keep this ratio to a minimum. It should be noted, however, that lighting energy needs were not considered in the analysis. Considering this energy service could overturn results considerations.

The last part of the chapter has presented some results of the ongoing EU project RePublic_ZEB. In this part of the research the cost-optimal methodology was applied for identifying proper retrofit measures to reach cost optimal levels and

NZEB levels. The analysis shown (with calculation with quasi-steady method) that today the conversion of buildings in NZEB is not economically convenient since the return time of the invested capital is too long. This studies allowed me to publish various researches and articles. Some references are reported Below.

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Chapter 5

4 Best choice of climatic data

To quantify the energy needs and the peak power of nearly zero-energy buildings it is required to know the behavior of the building under the effect of realistic drivers in order to avoid over-dimensioning of technical building systems, comfort conditions, and to generate extra costs by failing to meet the energy saving goals and the targets of the EPBD. For this reason, the users of BES should avoid using single year because this can't represent the typical long-term weather patterns and can vary significantly from year to year.

Most of the methods available in scientific literature have the objective to select single months from a multi-year database preserving a statistical correspondence of the final TMY respect to historical data series.

The reliability of BES depends directly by quality and detail of the building model and by the uncertainties linked to adequate weather datasets. One of the crucial factors for successful BES is creation of TMYs able to represent in a single year the long-term typical weather condition.

The reliability of the climatic data is of considerable importance in the EP calculation of nearly-zero energy building and passive building in which all the design choices aimed at obtaining the expected benefits must be correctly calibrated. Another open question concerns the conservation over time of energy performance. To this end, a field of research in recent times concerns precisely the future predictions of energy consumption in which the climatic references represent the starting point for any future impact assessment and energy forecast.

This chapter provide an overall view to the interaction between several typologies of building and climate. In the introduction, it then describes the emerging body of knowledge in this specific field giving an overview of the main researches.

In this research, according to the EN ISO 15927-4 [112] the Finkelstein-Schafer statistical method [108] was applied to analyses the hourly measured weather data related to several localities of north (Turin and Udine) and south Italy (Agrigento, Palermo, and Ragusa) of a long period and select representative typical meteorological months. The cumulative distribution function (CDF) for each year was compared with the CDF for the long-term composite of all the years in the period for four major weather indices including dry-bulb air temperature, relative humidity, solar irradiance and wind speed.

4.1 Introduction

While in the past detailed simulation was used almost exclusively for complex buildings, due to the regulatory and legislative changes underway, an increasingly intensive use of this method is expected in the near future.
Climate data can influence the building energy performance in several ways according to building typology (shape of fabric, WWR, etc.), and the building services available (lighting, heating, cooling, etc.).
The thermal energy balance of buildings depends on different terms related to the climate. The air temperature drives the heat transmission through the envelope and the sensible part of the ventilation enthalpy flow. The pressure difference caused by stack (chimney, or ΔT-induced) and the wind speed affect the air infiltrations. Also solar gains play a significant role in the energy balance of a building. The windows transmit, reflect, and absorb a given wavelength range of the solar radiation, according to the glazing characteristics, while the opaque envelope absorbs a part of the solar radiation depending on colour of outer surface. Temperature and wind speed have impact on the convective surface heat transfer of the building envelope. The apparent sky temperature and the atmospheric radiation influence the radiative surface heat transfer coefficients. Lastly, the outdoor moisture content influences the latent part of the ventilation enthalpy flow.

The influence of climatic data on the energy sensible needs for heating and cooling of the Italian NZEBs was examined by Murano, Corrado, and Dirutigliano (2016*)* [88]. They have highlighted the variation in the energy performance of buildings for all Italian provincial capitals using different climate data files. The variations were brought to light using both the semi-stationary calculation methods and the detailed methods (EnergyPlus). In this work, only the heating and cooling energy needs were examined.

Climate data are also used to support and direct the decisions of public authorities. Several researches had been conducted on the impact of climate change on building energy use world widely. Hong, Chang, and Lin (2013) [99] have analysed impact of weather on peak electricity demand and energy needs with the 30-year actual meteorological year (AMY) for typical office buildings (large, medium, and small size). Through BES has been possible to define that the TMYs are not always representative of the energy needs over a long period with greater impact in colder than warmer climates, in addition the simulated energy savings and peak demand reduction can be significantly underestimated or overestimated (i.e. the peak demands of buildings can under-estimate of 32.4%, and over-estimate of 21.0%). Weather impact on peak demand reduction and HVAC source energy savings are large with greater impact on the peak demand reduction than HVAC source energy savings. However, as evidenced by Alley et al. (2003) [218] and Karl et al. (2003) [220], most all climate modelling ignores predict feedback processes, for example, increases in methane emissions from melting permafrost. Therefore, uncertainties in reference data may distort the policies based on the energy demand of buildings

(Hopfe et al. 2009) [100]. In response to this question various studies have been carried out to predict the future energy needs and thermal comfort in office building.

Pieter de Wilde and David Coley (2012) [6] have dedicated a special issue of the Journal Building and Environment on implications of a changing climate for buildings. This issue represents one of the main challenges that humankind will facing in the 21th century, as it will have direct consequences on environment, human health, economy and consequently on the aspects correlated to whole society.

Guan (2009) [221] has individuated two approaches to obtaining TMYs for future predictions: the first based on historical data, and the other based on fundamental physical models. Another approach used by Gaterell and McEvoy (2005) [222] concerns the replacement of measured data with those of other geographical locations to mimic changed conditions. Instead Eames et al. (2011) highlights the need to take into account the local geographic conditions.

Therefore, the need to make predictions for weather variation scenarios is becoming increasingly important. For the Netherlands, Hopfe et al. (2009) [100] have carried out new climate files for different future weather scenarios defining several typology of climate adjustments. The study has shown that (a) energy needs and peak power are strongly related to the uncertainty in climate change scenarios, (b) the annual heating energy need is decreasing, whilst the cooling energy need is increasing. The same happen for the under-heating hours and overheating hours, (c) different (uncertain) climate scenarios can have an important role in design decision making.

In the same year, other authors have done similar research related to the uncertainty of Weather File Data. Struck et al. (2009) [101] has evaluated, through the application of uncertainty and sensitivity analysis techniques, the representativeness of TMYs in the forecast of building energy needs. The study, based on office buildings, has underlined the potential of projected multi-year Weather File Data based on several scenarios in the definition of future energy needs.

Shen (2016) [102] has deepened the topic of climate prediction using a “morphing” methodology which allows to obtain robust meteorological weather data without access historical data.

This data can be used by dynamic simulation software (TRNSYS, Energy Plus) to predict future energy needs of residential building in the United States. The outcome of research has indicated that in future the difference of heating energy need of residential buildings located in cold and hot areas will be less (39% more cooling and 15% less heating in the hottest year, and 14% more heating and 64% less cooling in the coldest year), while during cooling seasons there will occur peak electricity power growth. The author then has highlighted the importance of energy need analysis based on TMYs especially for buildings with limited energy supply and storage.

BES software use Weather File Data in the form of data sets of hourly values, which are determined starting from archives of historic years much longer than a year in duration. Typically, at least 30 years of raw data measurements are required. Starting from a larger database generally affords smaller differences between months of TMY and long-term monthly characteristics.

Archives of historic years have to satisfy the guidelines of Word Meteorological Organization (WMO) which provides climatological standard and procedures for analysing climate data for climate change purposes as well as for other applications. The guidelines take into account the updating of the industry and therefore the evolution of the characteristics of the instrumentation for detection. It identifies in particular three ranges of relevant periods of climatic data: 1900÷1930, 1931÷1960,1961÷1990, and 1991÷2020.

In scientific literature, the most commonly used archives are the TMY (Typical Meteorological Year) and the TRY (Test Reference Year). These two archives are similar but the TMY represents an evolution of the TRY methodology. In the first versions of TRY datasets, for example, there was no information on solar irradiance estimated starting from cloudiness index. The methodologies available in literature differ according to type and number of weather variables used in the procedure, the type of statistics employed and the use of weighting coefficients of variables diversified for climatic parameters. In both cases, the main requirements are true frequencies, true sequences and true correlations between different climatic variables. The Weather File Data used by EnergyPlus software contain the following hourly data: dry-bulb temperature, dew point temperature, relative humidity, atmospheric pressure, wind speed, wind direction, total sky cover, opaque sky cover, precipitable water, aerosol optical depth, radiation values (Direct/Diffuse), and illuminance values. The Weather File Data used in BES have to be consistent with the typical long-term distribution data.

The files provided by Energy Plus have generally EPW format (Energy Plus Weather Format) and are based on improved solar models, and more closely match the long-term average weather conditions. The software Energy Plus uses the weather data sets provided by White Box Technologies and immediately ready for the use. These data sets are based on recordings from weather stations going back up to 25 years and archived as the Integrated Surface Hourly Database by the (US) National Centre for Environmental Information (NCEI). The transition from TMY2 to TMY3 files has resulted in complete weather files with solar irradiance, daylight illuminance, and precipitation, in addition to the standard parameters of air-temperature, humidity, pressure, wind speed and direction, etc. For the Italy are available 65 TMYs.

Table 85 Principal TMY available in scientific bibliography and acronyms

TMY2	Typical Meteorological Year 2
TMY3	Typical Meteorological Year 3
WYEC2	Weather Year for Energy Calculations 2

The TMY can be used to estimate the operating costs for heating and cooling for the design of new buildings or for the renovations of existing buildings and, as indicated by Directive 2010/31/EU, for the determination of cost-optimal balance between the investments involved and the energy costs saved throughout the lifecycle of the building. Reliable and realistic Weather File Data are needed to make the estimates of energy performance of buildings in the medium and long-term as reliable as possible.

In fact, as evidenced by Magrini et. al (2018) [223] the results related to costs/energy benefits analysis are heavily affected by climatic conditions and therefore from weather Data used in the BES. For a residential apartment in a multi-family dwelling and three locations (Bolzano, Trento, and Perugia), they have compared EP and global costs calculated using conventional weather data set taken from UNI 10349 (1994), UNI 10349-1 (2016) [130], and real weather data of the last 20 years. To highlight the effect of the weather data on the calculations, the study has focused in particular on the influence of the monthly mean data of dry-bulb temperature and solar irradiance on the building envelope performance. From the results analysis, authors have concluded that there is need of (a) indications by the EC on a regularly reference weather data updating (b) the introduction of a tolerance range of results to take into account the climate change.

The TMY can also be used for different applications, including energy and environmental analyses and to estimate the productivity of installations powered by renewable sources (for instance solar thermal, photovoltaic panels, heat pumps, etc.). Argiriou et al. (1999) [103] summarized the different methodologies used for the generation of TMYs available in the literature. Various methods for deriving TMY provide results that can be significantly different. In the study, the authors developed the Sandia National Laboratories method (Hall et al. 1978) [181], the Danish method, and the Festa–Ratto method.

Kalamees and Kurnitski (2006) [184] have elaborated Estonian TRYs for energy calculation. In the study has been used the methodology of EN ISO 15927-4 for six stations. The authors have identified the smoothing between the parameter values of different months of the TRY (sixteen hours for month) among the problematic aspects because these doesn’t represent physical data.

Zang et al. (2012)[185] *proposed a modified method to generate TRY based on the Sandia National Laboratories method and on a simplified method introduced by Pissimanis et al. (1988)* [106] *based on the root mean square difference (RMSD). The Sandia National Laboratories methodology (Wilcox and Marion 2008)* [107] *involves the application of Finkelstein-Schafer statistic (F_S) (Finkelstein and Schafer 1971)* [108] *of ten climate parameters (max, min, mean dry-bulb air temperature; max, min, mean dew point temperature; max e min wind velocity; global and direct irradiance). For each climatic parameter considered, the Finkelstein-Schafer statistic is a measure of the closeness of two cumulative distribution functions concerning the considered month, the first one (F) relating to a specific year and the second one (Φ) regarding long-term data.*

$$F_S(p,y,m)=\sum_{i=1}^{n}\left|F(p,y,m,i)-\Phi(p,m,i)\right| \tag{9}$$

The procedure uses weighting coefficients that multiply the Finkelstein-Schafer statistic of parameters so as to select the candidate months that have the lowest weighted sum. The TMY made for United States by the National Solar Radiation Data Base for 1020 locations was created using procedures similar to those developed by Sandia National Laboratories (Wilcox and Marion 2008) [107]. *Modifications were made to optimize the weighting of the indices, to provide preferential selection for months with measured solar irradiance data, and to account for missing data.* The weighting coefficients are shown in Table 86.

Table 86 Weighting values for FS statistics used in Sandia Method and NSRDB TMY3 method

Index		Sandia Method (TMY2)		NSRDB TMY (TMY3)	
Dry bulb temperature	Max	4.2%	16.7%	5.0%	20.0%
	Min	4.2%		5.0%	
	Mean	8.3%		10.0%	
Dew point temperature	Max	4.2%	16.7%	5.0%	20.0%
	Min	4.2%		5.0%	
	Mean	8.3%		10.0%	
Wind velocity	Max	8.3%	16.7%	5.0%	10.0%
	Mean	8.3%		5.0%	
Solar irradiance	Global	50.0%	50.0%	25.0%	50.0%
	Direct	-		25.0%	
Total	-	**100%**		**100%**	

From TMY 2 to TMY3 an index for direct normal solar irradiance was added. According to Wilcox and Marion (2008) [107], With this update, the annual direct radiation values for the 20 stations were within 4% (95% confidence) of the 30-year annual average. Using weighting coefficients for global horizontal and direct irradiance indices has halved the differences to 2%.

Taylor et al. (2014) [109] *examined how the external climate can influence the overheating risk inside dwellings by looking at a large range of building types and potential retrofit measures under different UK climate scenarios.*

Arima, Ooka, and Kikumoto (2017)[110] propose a new type of climate data TDWY (Typical and Design Weather Year) based on the Finkelstein-Schafer statistic that can be used both as a typical weather year and as design weather data. Sughwan et al. (2016) [111], applying EN ISO 15927-4 (European Committee for Standardization 2005), generated TMYs of the major 18 meteorological locations in South Korea. The analysis has some limitations; for example, the internal heat and moisture loads in the modelling of the case studies were neglected. Pernigotto et al. (2014) [113] have investigated two possible modifications of the EN ISO 15927-4 procedure aimed at improving the representativeness of TMY, by introducing weighting coefficients for the different climate parameters. According to Pernigotto et al. (2014) [113], using separate TRYs for the heating and cooling needs *assessment provides good performance in terms of the representativeness of the energy results with respect to long-term averages. For this reason, weighting* *the different climatic parameters ensured more reliable results. However, there were no correlations between the lengths of the multi-year series and the optimum weighting coefficients. Rahman and Dewsbury (2007)* [114] *on the contrary suggested avoiding the use of weighting coefficients. Hensen (1999)* [115] *and Kershaw, Eames, and Coley (2010)* [116] *proposed variables weighting coefficients according to the characteristics of the building.*

In 2004 Poland processed new TMYs in accordance to EN ISO 15927-4. It has used 61 weather stations with data observed in the period among 1971 and 2000. The purpose of this work was the introduction of obligatory energy performance certification for buildings.

Grudzińska and Jakusika (2016) [117] *noted that the results of simulations, with TMYs, shown that the cooling demand in summer was significantly underestimated respect to that calculated with long-term climatic data. They recommended updating the calculation methodology. Sorrentino et al. (2012)* [119], *for the city of Palermo, Italy, compared different TRY construction methods. In the calculation of the energy performance of building the analysis carried out with a dynamic model shown that the TRY prepared in accordance with the approach of Hall et al. (1978)*[181] *is more reliable than the Dogniaux and Sneyers approach (1977)* [120] *and the EN ISO 15927-4 method. Chan (2011) developed a set of TRYs based on climate change and analysed their impact on an office building and a residential apartment with EnergyPlus. The research indicated that there is a substantial impact of climate data on the performance of air-conditioning systems. Bhandari, Shrestha, and New (2012)* [122]*compared TRY with data collected from a weather station inaccessible to the service providers and estimated the impact of discrepancy in various climate parameters as well as heating/cooling loads.*

In 2016 the Italian Thermotechnical Committee (CTI) processed the new versions of national Typical Meteorological Year for 110 locations in Italy, to be used for a detailed energy performance simulation of the ([125],[126],[127],[128],[129]). *The selection of representative months was carried out according to EN ISO 15927-4, only considering the outdoor temperature and the global solar irradiance on the horizontal plane without any weighting coefficient (Italian Organisation for Standardisation 2016).*

In March 2019 are available for the Italy new 238 TMYs on the site: Climate.OneBuilding.Org. [124]. The name of these Typical Meteorological Years is TMYx. The generation of files consider at least 5 years but usually they are created starting from 15 years.

Huld et al. (2018) [137] *have presented a method to generate TMY data sets based on satellite derived solar radiation data and other meteorological parameters obtained from reanalysis products. In the validation process, TMYs generated with the ground station data have been compared with reanalysis data. To validate the method for the generation of TMYs, the authors have made calculations of building energy performance using EnergyPlus. The study has shown that the generated data sets using a long time series perform better than the*

TMY data generated from station with relative standard deviations remaining below 6% for heating calculations. Although the EN ISO 15927-4 [112] *standardized methodology is recognized as reference for the creation of TMY, ongoing research (Pernigotto et al. 2014* [113]*; Hensen 1999* [115]*; Kershaw, Eames, and Coley 2010* [116]*; Grudzińska and Jakusik 2016* [117]*) show that its application without adjustments can lead to reference years that underestimate or overestimate the energy-related needs.*
This research investigates the reliability of the TMY determined according to EN ISO 15927-4 [112] *in the energy need assessment for heating, cooling, humidification, and de-humidification. This study proposes the implementation of the procedure of EN ISO 15927-4 for TMY elaboration, consisting in the introduction of weighting coefficients for different climatic variables. The study aims at detecting the best representative data set for different types of buildings, focussing on the fabric, while recognising that the performance of technical building systems (passive and active systems) are also affected by climatic variables. The introduction of the weighting coefficient in the* standardized methodology [112] *can be used either to compensate a dataset of unsatisfactory climate data quality (i.e. high presence of gaps, length of the historical series less than 10 years), or to increase the representativeness of the TMY by taking into account the influence of the individual climate variables on specific energy services correctly. In this work, this second case is explored.*

Several examples of TMY optimisation are reported for the cities of Agrigento, Palermo, Ragusa, Turin and Udine from a fifteen-year archive of meteorological records. In this work several TMYs representative of long-term energy performance are suggested.

4.2 Theory

Before applying the methodology for the calculation of the TMY it is necessary to apply the following steps:

1. Collection of the historical data series;
2. For each parameter, calculation of the higher resolution hourly averages;
3. Translation of the time axis to the Italian local time zone according to the solar time (UTC + 1). The control is carried out by identifying the time of the maximum of global solar radiation on a horizontal plane that must occur between 12 and 13 hours local due to the geographical configuration of Italy;
4. For each parameter, data analysis with elimination of outliers and invalid data with possible linear detrending;
5. For each parameter, verify the percentage of valid data. if, for each parameter, the month has a percentage of invalid data, greater than 10% (72 hours) is discarded from processing;

6. For each month and for each parameter, missing data with amplitude of less than 6 hours are allowed. If, for these parameters, the month has data gaps greater than six hours, it is discarded from processing;
7. In the case of missing data, linear interpolation is performed for the dry-bulb air temperature parameter, wind speed and relative humidity;
8. In the case of missing data, for the parameter global solar irradiation on a horizontal plane, the theoretical calculation of the missing values is carried out.

(*) To fill gaps between 6 and 24 hours in length, for not discarding the whole month the procedure derive data from adjacent days (average value of the day before and after the missing value).

4.3 Methodology for the Construction of the TMY

In the standardized methodology, EN ISO 15927-4 [112]*, dry-bulb air temperature, global solar irradiance and relative humidity (or alternatively air absolute humidity, water vapour pressure or dew point temperature) are taken as the primary parameters (p) for selecting the "best" months to form the reference year, with wind speed as a secondary parameter. As highlighted by Nielsen et al. (2017)* [118] *the use of Finkelstein-Schafer statistic was a robust selection methodology because the function did not rely on probability of distributions of climate values. The procedure of EN ISO 15927-4* [112] *includes the following steps.*

a) *From at least 10 years of hourly values of p, calculate the daily means.*
b) *For each calendar month (m), calculate the cumulative distribution function of the daily means over all years in the data set, Φ(p,m,i), by sorting all the values in increasing order and then using the following equation, where K(i) is the rank order of the value of the daily means within that calendar month in the whole data set.*

$$\Phi(p,m,i) = \frac{K\left(\bar{p}_{\mathrm{i}}\right)}{N+1} \tag{10}$$

c) *For each year (y) of the data set, calculate the cumulative distribution function of the daily means within each calendar month, F(p,y,m,i), by sorting all the values for that month and that year in increasing order and then using* Equation (11), *where J(i) is the rank order of the value of the daily means within that month and that year*

$$\mathrm{F}(p,y,m,i) = \frac{J\left(\bar{p}_{\mathrm{i}}\right)}{n+1} \tag{11}$$

d) *For each calendar month, calculate the Finkelstein-Schafer statistic, $F_S(p,y,m)$, for each year of the data set using* Equation (9)
e) *For each parameter and for each calendar month, rank the individual months from the multiyear record in order of increasing size of $F_S(p,y,m)$ using* Equation (12)*, where $L(F_S)$ is the rank order of the yearly value of the $F_S(p,y,m)$*

$$R(p,y,m)=\frac{L(F_\mathrm{S})}{n_\mathrm{y}+1} \tag{12}$$

f) *For each calendar month and for each year, add the separate ranks (R) for the three climate parameters.*

$$R_\mathrm{tot}(y,m)=R\left(T,y,m\right)+R\left(I,y,m\right)+R\left(RH,y,m\right) \tag{13}$$

g) *For each calendar month, for the three months with the lowest total ranking $R_{tot}(y,m)$, calculate the deviation of the monthly mean wind speed from the corresponding multi-year calendar-month mean. The month with the lowest deviation in wind speed is selected as the "best" month to be included in the reference year.*

h) *For each selected calendar months, adjust the hourly values in the selected month to provide a smooth transition when the different months were linked to form the TMY.*

4.4 Improvement of Representativeness of TMY

In this work the methodology of EN ISO 15927-4 is applied with some variations in the selection procedure; in particular, the implemented method operates changes on point f), while point g) is neglected.

There are two reasons for neglecting the wind speed: the first one is that its effect on the energy performance of buildings is little; the other one is that the focus of this work is to investigate the effect of air temperature, global solar irradiance and air relative humidity on the selection of the "best" month.

Three different weighting coefficients (α, β, γ) are applied to the ranks of the climate variables, air temperature, global solar irradiance and air relative humidity respectively.

$$R_\mathrm{tot}(y,m)=\alpha\cdot R\left(T,y,m\right)+\beta\cdot R\left(I,y,m\right)+\gamma\cdot R\left(RH,y,m\right) \tag{14}$$

In the proposed procedure, the month with the lowest R_{tot} is considered as the "best" month regardless the monthly mean wind speed and it is included in the reference year.

This study aims at verifying if these weighting coefficients should be diversified in function of building characteristics (window-to-wall ratio, thermal insulation, solar shading device) or of energy services analysed. The introduction of weighting coefficients aims to make TMYs more representative of long term time data and, therefore, more reliable for energy performance estimates.

Weighting coefficients express the relevance of different climatic parameters to the energy performance of building. The use of the weights associated with Finkelstein-Schafer statistic (1971) expresses this concept.

sixty six combinations *of weighting coefficients were chosen to generate different TMYs as represented in* Fig. 38. *The ternary plot is used to represent the weighting coefficients of the three climatic variables.*

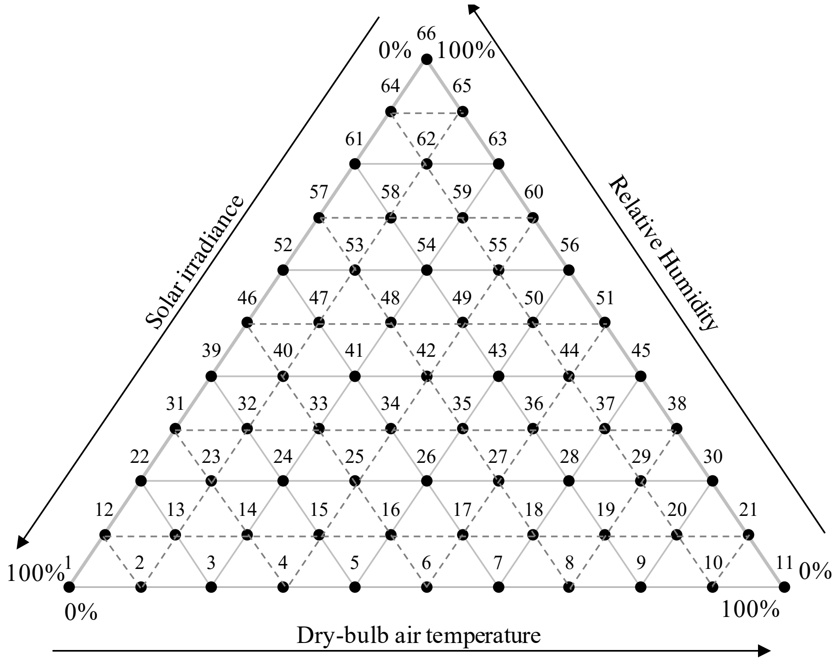


Fig. 38 Ternary plot of the weighting coefficients configurations for TMYs selection

Table 87 Weighting coefficients configurations for TMYs selection

	Weighting coefficients				Weighting coefficients				Weighting coefficients		
Configuration	*T*	*I*	*RH*	Configuration	*T*	*I*	*RH*	Configuration	*T*	*I*	*RH*
C1	0.00	1.00	0.00	C23	0.10	0.70	0.20	C45	0.60	0.00	0.40
C2	0.10	0.90	0.00	C24	0.20	0.60	0.20	C46	0.00	0.50	0.50
C3	0.20	0.80	0.00	C25	0.30	0.50	0.20	C47	0.10	0.40	0.50
C4	0.30	0.70	0.00	C26	0.40	0.40	0.20	C48	0.20	0.30	0.50
C5	0.40	0.60	0.00	C27	0.50	0.30	0.20	C49	0.30	0.20	0.50
C6	0.50	0.50	0.00	C28	0.60	0.20	0.20	C50	0.40	0.10	0.50
C7	0.60	0.40	0.00	C29	0.70	0.10	0.20	C51	0.50	0.00	0.50
C8	0.70	0.30	0.00	C30	0.80	0.00	0.20	C52	0.00	0.40	0.60
C9	0.80	0.20	0.00	C31	0.00	0.70	0.30	C53	0.10	0.30	0.60
C10	0.90	0.10	0.00	C32	0.10	0.60	0.30	C54	0.20	0.20	0.60
C11	1.00	0.00	0.00	C33	0.20	0.50	0.30	C55	0.30	0.10	0.60
C12	0.00	0.90	0.10	C34	0.30	0.40	0.30	C56	0.40	0.00	0.60
C13	0.10	0.80	0.10	C35	0.40	0.30	0.30	C57	0.00	0.30	0.70
C14	0.20	0.70	0.10	C36	0.50	0.20	0.30	C58	0.10	0.20	0.70
C15	0.30	0.60	0.10	C37	0.60	0.10	0.30	C59	0.20	0.10	0.70
C16	0.40	0.50	0.10	C38	0.70	0.00	0.30	C60	0.30	0.00	0.70
C17	0.50	0.40	0.10	C39	0.00	0.60	0.40	C61	0.00	0.20	0.80
C18	0.60	0.30	0.10	C40	0.10	0.50	0.40	C62	0.10	0.10	0.80
C19	0.70	0.20	0.10	C41	0.20	0.40	0.40	C63	0.20	0.00	0.80
C20	0.80	0.10	0.10	C42	0.30	0.30	0.40	C64	0.00	0.10	0.90
C21	0.90	0.00	0.10	C43	0.40	0.20	0.40	C65	0.10	0.00	0.90
C22	0.00	0.80	0.20	C44	0.50	0.10	0.40	C66	0.00	0.00	1.00

4.5 Calculation

4.5.1 Weather Data Set

The climatic hourly data that have been used in this work was provided from the Regional Agency for the Protection of the Environment (ARPA Piedmont) for Turin (2002÷2016), by the Regional Agency for the Protection of the Environment (ARPA Friuli Venezia Giulia) for Udine (1996÷2018), while for Agrigento, Palermo and Ragusa (2002÷2018) from the Geographic Information System for agriculture (SIAS Sicily). The geographical coordinates of the weather stations used are shown in the Table 88.

Table 88 Geographical coordinates of the stations used for the construction of TMYs.

	Station	Longitude °	Longitude '	Longitude "	Latitude °	Latitude '	Latitude "	Elevation m	HDD[1] °C	Climate Zone[1]
AG	Agrigento Mandrascava	13	38	9	37	14	16	40	729	B
PA	Palermo	13	19	40	38	7	52	50	751	B
RG	Ragusa - Cilone	14	40	35	36	57	14	650	1.324	C
TO	Bauducchi	7	42	35	44	57	40	226	2.617	E
UD	Udine	13	6	50	46	1	27	80	2.323	E

Source data used in simulations included hourly values of the following measured parameters: UTC, dry-bulb air temperature, air relative humidity, wind velocity and total solar irradiance on a horizontal plane. The diffuse solar irradiance on a horizontal surface is calculated according to Boland and Ridley (2008) [219]*, and UNI 10349-1 (2016)*[130].

The solar irradiance on a normal plane, as requested in the Energy plus EPW files, has been obtained dividing the direct solar irradiance on a horizontal plane by the cosine of the Zenith angle. This formula provides critical results when dawn occurs near the time found in the climate file. This causes an increase in the direct solar irradiance beyond the limits of acceptability. So, to put a higher limit on this solar irradiance, a clear sky model was used by calculating the integral Rayleigh optical thickness and using Linke turbidity index ([132],[133],[134],[135],[136]).

The procedure adopted is shown below. The formula for calculating solar radiance on an inclined plane is the following:

$$I_{\mathrm{b}\vartheta} = I_{\mathrm{bh}} \cdot \frac{\cos\vartheta}{\cos\vartheta_z} \tag{15}$$

In which:

- I_{bh} is the solar irradiance on a horizontal plane;
- ϑ is the angle of incidence of the inclined plane;
- ϑ_z is the zenithally angle.
- α is solar elevation
- $\cos\vartheta_z = sen\alpha$

For time instants near sunrise and sunset the ϑ_z value is close to 90 degrees and therefore the $\cos\vartheta_z$ is close to zero.

Since this value is a denominator in the formula, although the denominator $I_{\mathrm{bh}} \cdot \cos\vartheta$ may be small, the final value could tend $I_{\mathrm{b}\vartheta}$ to infinity. To overcome this drawback, the following steps have been applied:

$$I_{\mathrm{b}\vartheta} = I_{\mathrm{bh}} \cdot \frac{\cos\vartheta}{\cos\vartheta_z} = I_{\mathrm{bn}} \cdot \cos\vartheta \tag{16}$$

Where $I_{\mathrm{bn}} = DNI = \dfrac{I_{\mathrm{bh}}}{\cos\vartheta_Z}$

$$I_{\mathrm{bn}} = I_{\mathrm{on}} \cdot K_{\mathrm{bn}} \tag{17}$$

Where I_{on} is the solar irradiance at the top of the atmosphere and K_{bn} is the transmission coefficient for the DNI. The highest value of K_{bn} occurs under clear skies, so the following theoretical equations exist:

$$K_{\mathrm{bn,clear}} = \exp\left(-m \cdot \delta_R \cdot T_L\right) \tag{18}$$

where the term $e^{-m\delta_R T_L}$ expresses the attenuation of the DNI that occurs in clear sky conditions

The influence of the path length of the direct radiation in the atmosphere is formalized in the term m – function of $\cos\vartheta_z$ (Air Mass). The scattering caused by the presence of gases is coded in the *factor of Rayleigh* $\bar{\delta}_R$, mediated on all wavelengths of the incident solar radiation and of which expressions are available as a function of air mass m .

T_L is called *Linke turbidity factor* and is related to the presence of water vapour and aerosols.

In ideal conditions of clear sky and water vapour and absent aerosols (clean dry air) is $T_L = 1$; instead in real conditions these two components are always present in variable quantities and induce a greater attenuation compared to the dry and clean case, for which T_L is greater than 1; in any case this term varies little both in terms of time and space and reference tables of monthly average values have been produced for different locations. Experimental data of the Linke turbidity factor for two Italian localities (Rome and Rende) have been obtained by Cucumo et al [138]

The direct transmission coefficient for clear sky conditions is always generally significantly smaller than 0.90.

In all other cloudy conditions, i.e. with different degrees of cloud cover: $K_{\mathrm{bn}} \le K_{\mathrm{bn,clear}}$

$$I_{\mathrm{bn}} = \begin{cases} \dfrac{I_{\mathrm{bh}}}{\cos\vartheta_Z} \text{ if } \dfrac{I_{\mathrm{bh}}}{\cos\vartheta_Z} \le I_{\mathrm{on}} \cdot e^{-n \cdot \delta_R \cdot T_L} \\ I_{\mathrm{on}} \cdot e^{-n \cdot \delta_R \cdot T_L} \end{cases} \tag{19}$$

The T_L coefficient can be assumed to be equal to 1 (extreme limit) or another value which is more convenient and realistic ($T_L = 1.50$ or $T_L = 2.00$) can be selected. After these operations $I_{\mathrm{b}\vartheta}$ can be determined as $I_{\mathrm{b}\vartheta} = I_{\mathrm{bn}} \cdot \cos\vartheta$

In this search $T_\mathrm{L} = 2$ was used.
Generally, the collected data are of good quality, as there are not too many gaps or invalid records. The parameters fall within the acceptability thresholds. For each year available and for each parameter, the percentage of invalid climatic data (including missing data) and the hourly extreme values are presented in Table 89 (Agrigento), Table 90 (Ragusa), Table 91 (Palermo), Table 92 (Turin), and Table 93 (Udine).

EN ISO 15927-4 does not provide instructions on the interpolation of invalid climate data. Many different interpolation methods exist. Eguía Oller et al. (2017) [140] *investigated the performance of several interpolation techniques in reproducing on-site climate data for building thermal simulations. In this study, periods with missing data of maximum five consecutive hours, are filled by linear interpolation between the last hour before the gap to the first hour after the gap.*

Table 89 Agrigento. Weather data set

	a) Percentage of invalid data				b) Extreme hourly values					
Year	**T_h [°C]**	**I_h [W m^{-2}]**	**RH_h [%]**	**WS_h [m s^{-1}]**	**T_h [°C]**		**I_h [W m^{-2}]**	**RH_h [%]**		**WS_h [m s^{-1}]**
					Min	Max	Max	Min	Max	Max
2002	24.28%	34.17%	24.28%	24.28%	7.7	37.7	908	13	100	9.4
2003	0.00%	0.05%	0.00%	0.00%	1.9	36.4	919	13	100	9.5
2004	0.00%	0.03%	0.00%	0.00%	0.3	35.1	961	13	100	10.1
2005	0.00%	0.88%	0.86%	0.86%	1.3	35.8	961	16	100	7.1
2006	0.05%	0.37%	0.05%	0.05%	0.0	35.9	967	13	100	21.6
2007	0.00%	0.37%	8.08%	0.00%	1.6	37.2	967	16	99	19.6
2008	0.20%	0.01%	0.00%	0.00%	-1.1	32.6	956	15	100	25.7
2009	0.21%	0.02%	0.00%	0.06%	1.5	36.8	961	20	100	24.8
2010	3.52%	2.91%	22.01%	6.02%	1.7	34.5	956	18	100	20.8
2011	0.13%	0.03%	0.00%	0.00%	2.5	35.6	961	19	93	26.3
2012	0.02%	0.05%	0.00%	0.00%	2.3	38.4	953	14	92	19.7
2013	0.50%	0.30%	0.50%	10.73%	2.6	36.4	1008	11	100	16.8
2014	0.01%	0.02%	0.01%	4.50%	0.8	31.3	1036	27	100	13.9
2015	0.00%	0.01%	0.00%	0.00%	3.4	33.5	1061	26	100	14.0
2016	0.00%	0.00%	0.00%	0.00%	2.6	34.9	1075	18	100	14.3
2017	0.00%	4.03%	0.00%	0.00%	0.9	36.5	1022	18	100	15.9

Table 90 Ragusa. Weather data set

	a) Percentage of invalid data				b) Extreme hourly values					
Year	**T_h [°C]**	**I_h [W m^{-2}]**	**RH_h [%]**	**WS_h [m s^{-1}]**	**T_h [°C]**		**I_h [W m^{-2}]**	**RH_h [%]**		**WS_h [m s^{-1}]**
					Min	Max	Max	Min	Max	Max
2002	9.4%	0.0%	9.9%	25.7%	-2.0	37.6	994	11	100	11.7
2003	7.5%	0.0%	0.4%	0.4%	0.0	36.7	1011	13	100	11.0
2004	1.2%	0.0%	1.2%	0.0%	-1.8	33.5	1025	14	100	12.0
2005	0.0%	0.0%	0.0%	0.0%	-1.0	35.1	1025	13	100	12.3
2006	0.0%	0.0%	1.3%	0.0%	-3.0	37.9	1047	11	100	12.1
2007	0.0%	0.0%	0.0%	0.0%	0.2	36.6	1008	10	100	11.5
2008	7.5%	0.0%	2.0%	2.0%	-2.4	34.1	992	13	100	12.0
2009	14.5%	10.3%	5.8%	22.6%	0.0	37.9	1008	12	100	16.7
2010	0.1%	4.9%	19.2%	0.0%	-0.7	35.0	1028	7	100	15.6
2011	8.0%	1.6%	11.0%	0.1%	-0.4	33.8	1064	16	100	21.6
2012	0.9%	0.0%	0.1%	0.0%	-0.9	38.0	1033	10	100	20.9
2013	0.9%	0.0%	2.1%	0.0%	-0.8	33.7	1036	11	100	22.3
2014	0.0%	0.0%	3.0%	35.7%	-3.8	32.9	1064	7	100	16.8
2015	0.0%	0.0%	0.0%	2.8%	-2.9	33.6	1039	10	100	14.9
2016	0.0%	0.0%	0.0%	0.4%	-1.9	33.7	1056	11	100	20.3
2017	0.0%	0.1%	0.0%	6.6%	-3.8	36.6	1042	8	100	18.0

Table 91 Palermo. Weather data set

	a) Percentage of invalid data				b) Extreme hourly values					
	T_h	I_h	RH_h	WS_h	T_h		I_h	RH_h		WS_h
Year	[°C]	[W m^{-2}]	[%]	[m s^{-1}]	[°C]		[W m^{-2}]	[%]		[m s^{-1}]
					Min	Max	Max	Min	Max	Max
2002	0.0%	0.0%	0.4%	0.0%	1.1	40.0	1006	13	100	4.6
2003	0.0%	0.0%	0.7%	0.0%	3.4	38.3	961	14	100	4.2
2004	0.0%	0.0%	0.2%	0.0%	2.8	35.0	981	18	100	4.9
2005	0.0%	0.1%	0.6%	0.0%	2.4	36.2	967	14	100	4.5
2006	0.0%	0.0%	0.5%	0.0%	2.2	37.5	967	16	100	4.0
2007	0.0%	0.0%	3.3%	0.2%	3.9	44.0	986	12	100	4.6
2008	0.0%	0.0%	33.3%	0.0%	2.9	38.7	972	11	97	8.5
2009	0.7%	0.1%	0.0%	0.0%	1.6	36.3	989	18	98	7.4
2010	3.5%	3.5%	3.5%	3.5%	3.8	36.6	1022	19	97	6.6
2011	0.0%	0.0%	0.0%	0.0%	3.2	36.0	1042	15	95	9.3
2012	0.0%	0.0%	0.0%	0.0%	3.6	38.2	989	9	91	8.7
2013	0.1%	0.1%	0.1%	0.3%	4.7	36.1	1042	12	90	6.9
2014	0.0%	0.0%	0.0%	0.0%	1.4	37.9	944	10	91	7.4
2015	0.0%	0.0%	0.0%	0.0%	3.0	36.8	1039	11	98	7.1
2016	0.0%	0.0%	0.0%	0.1%	5.4	41.6	1036	10	100	7.6
2017	0.0%	0.0%	0.0%	0.0%	2.0	40.4	983	12	100	8.4

Table 92 Turin. Weather data set

	a) Percentage of invalid data				b) Extreme hourly values					
	T_h	I_h	RH_h	WS_h	T_h		I_h	RH_h		WS_h
Year	[°C]	[W m^{-2}]	[%]	[m s^{-1}]	[°C]		[W m^{-2}]	[%]		[m s^{-1}]
					Min	Max	Max	Min	Max	Max
2002	0.00%	0.00%	0.00%	48.36%	-10.8	33.2	943	8	100	7.5
2003	1.27%	1.18%	1.52%	1.40%	-6.9	38.1	939	6	99	10.1
2004	0.00%	0.00%	0.00%	0.00%	-6.8	35.0	962	0	99	12.7
2005	0.00%	0.00%	0.00%	0.02%	-9.0	34.3	1028	12	99	11.7
2006	0.00%	0.00%	0.00%	0.00%	-8.0	35.7	992	8	100	10.3
2007	0.00%	0.00%	0.00%	0.00%	-7.0	34.5	953	11	100	11.0
2008	0.00%	0.00%	0.00%	0.10%	-8.0	33.2	942	5	100	13.8
2009	0.03%	0.03%	0.03%	0.03%	-11.7	34.3	978	11	100	12.4
2010	0.00%	0.01%	0.02%	0.01%	-9.1	35.2	963	15	100	10.7
2011	0.00%	0.00%	0.00%	0.00%	-6.9	36.5	996	15	100	9.9
2012	0.31%	0.31%	0.31%	0.31%	-20.3	36.3	965	13	100	10.2
2013	0.00%	0.00%	0.00%	0.00%	-10.2	35.5	974	19	100	8.9
2014	0.00%	0.00%	0.00%	0.00%	-4.85	34.2	1020	1	100	11.7
2015	0.00%	0.00%	0.00%	0.00%	-4.75	37.7	1069	14	100	11.2
2016	0.00%	0.00%	0.00%	0.00%	-8.05	35.2	1045	10	100	9.5

Table 93 Udine. Weather data set

	a) Percentage of invalid data				b) Extreme hourly values					
Year	**T_h** **[°C]**	**I_h** **[W m^{-2}]**	**RH_h** **[%]**	**WS_h** **[m s^{-1}]**	**T_h** **[°C]**		**I_h** **[W m^{-2}]**	**RH_h** **[%]**		**WS_h** **[m s^{-1}]**
					Min	Max	Max	Min	Max	Max
1996	0.46%	0.49%	0.48%	0.98%	-8.6	34.4	945	11	99	11.3
1997	0.21%	0.21%	0.19%	0.21%	-4.4	32.5	970	9	99	12.0
1998	0.15%	0.16%	0.18%	0.17%	-5.8	35.0	996	10	99	10.1
1999	0.57%	0.87%	0.81%	1.14%	-7.3	31.2	1013	10	99	11.4
2000	0.01%	0.02%	0.01%	0.02%	-9.6	33.8	1018	16	99	10.8
2001	0.37%	0.84%	0.37%	0.46%	-6.8	33.5	973	14	100	10.2
2002	0.17%	0.17%	0.17%	0.39%	-9.5	34.9	936	10	99	11.6
2003	0.13%	0.06%	0.10%	0.07%	-7.9	37.4	896	9	98	10.5
2004	0.00%	0.00%	0.00%	0.05%	-6.0	34.4	951	9	99	11.1
2005	0.02%	0.02%	0.02%	0.03%	-8.7	34.9	964	8	99	9.2
2006	0.01%	0.02%	0.01%	0.01%	-8.3	38.1	973	7	99	9.6
2007	0.00%	0.01%	0.00%	2.18%	-4.1	35.7	949	9	99	9.5
2008	0.05%	0.05%	0.05%	0.61%	-5.5	33.7	1007	10	99	10.1
2009	0.13%	0.01%	0.03%	0.00%	-10.6	35.2	960	9	99	9.3
2010	0.00%	0.00%	0.01%	0.08%	-9.7	36.3	1001	9	99	12.1
2011	0.41%	0.42%	0.41%	0.43%	-6.4	36.7	1075	9	99	12.8
2012	0.00%	0.00%	0.00%	0.35%	-6.9	36.7	946	9	99	10.9
2013	0.00%	0.01%	0.00%	0.02%	-4.4	37.0	942	22	99	10.2
2014	1.06%	0.00%	1.54%	0.00%	-6.1	35.0	968	16	99	13.0
2015	0.01%	0.00%	0.00%	0.79%	-4.0	38.7	973	11	99	12.3
2016	0.02%	0.00%	0.01%	0.47%	-6.4	34.6	971	11	99	9.7
2017	0.88%	0.35%	1.42%	1.11%	-10.4	36.5	983	9	100	11.4
2018*	0.43%	0.02%	0.45%	0.43%	-7.5	31.3	977	9	100	9.6

* Weather data-set until June 30th

Subsequently, it is necessary to apply the Finkelstein-Schafer statistic according to EN ISO 15927-4 [112].

Regarding the parameters related to air humidity, the EN ISO 15927-4 procedure allows the alternative use of the following parameters: relative humidity, absolute humidity, water vapour pressure or dew point temperature. The alternative choose of the various humidity parameters can lead to different results in term of Finkelstein-Schafer statistic. In this study the relative humidity was used as primary parameter, future research will examine the variation of the composition of TMY according to the other *RH* alternative parameters.

Although all the climate parameters are related to each other, any Finkelstein-Schafer statistic of each parameter could have different distribution for the same calendar real months. This aspect is visible in Fig. 39*, which highlights* that for Turin the relative humidity *is often the climatic parameter with the highest* F_S*, especially in the winter months* (The graphs of the other locations are shown in the appendix). *This means that the TMY will be less accurate for that parameter. For each climatic parameter and month of considered period, the Finkelstein-Schafer statistic permits to assign a rank (with reference to c) step in par. 2.1). For each calendar month and for each year, the separate ranks applying weighing coefficients according to Eq. 6 are summed. The selected month of TMY will be the one with the lowest total rank.*

Fig. 39 Turin. Finkelstein-Schafer statistic of climate variables.

The selected months are merged to form the TMY. The procedure requires the first eight hours of each month and the last eight hours of the previous month to be interpolated, for ensuring a smooth transition. In this study a linear interpolation is used.

4.5.2 Case studies

The case studies are three buildings:

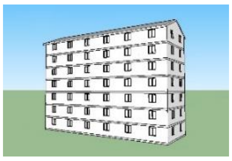
- a two-story residential single-family house;
- an apartment block with 24 apartments;
- an office building.

The work is focused on the calculation of the net energy needs for space heating, space cooling, humidification, de-humidification the technical building systems were not modelled. Since the other building energy services (e. g. ventilation, domestic hot water, lighting) are not included in this research.

The building model, the main geometric features, and pictures of the models are shown in Table 94.

In order to guarantee the representativeness of the result, the proposed method was applied to a typical building taken by the TABULA European project (Ballarini, Corgnati, and Corrado 2014 [141]).

Table 94 Geometric features of case studies

	Single Family House (SFH)		Apartment block (AB)		Office building (OB)	
Geometric data						
Case study	SFH.I.W SFH.NI.W	SFH.I.w SFH.NI.w	AB.I.W AB.NI.W	AB.I.w AB.NI.w	OB.I.SH OB.NI.SH	OB.I.sh OB.NI.sh
A_{f} [m^2]	158		2 125		1 519	
V_{g} [m^3]	576		8 199		6 100	
V [m^3]	414		5 738		4 101	
$A_{\mathrm{e}}/V_{\mathrm{g}}$ [m^{-1}]	0.74		0.40		0.35	
A_{w} [m^2]	71.5	24.2	407.25	549.92	434	
$A_{\mathrm{w}}/A_{\mathrm{f}}$ [-]	0.452	0.153	0.192	0.258	0.286	
WWR [-]	0.304	0.103	0.348	0.249	0.203	

The work considers different kinds of building envelope, including a low thermal insulation solution, as shown in TABULA [141] for a building constructed in 1946-1976, and a highly insulated solution, as indicated in the Italian Inter-Ministerial Decree 26/06/2015 [143]. In this last case, as shown in Table 95 two different building envelope configurations have been tested.

Every case study hasn’t adjacent buildings or external obstructions of any kind. As regards the transparent envelope two variants of window-to-wall ratio (WWR) were analysed. All configurations are characterized by a movable solar shading device.

Table 95 Thermo-physical characteristics of the case studies

Envelope element	Parameter	Highly insulated building	Poorly insulated building
Wall	U [W m^{-2} K^{-1}]	0.25	1.19
	κ_i [kJ m^{-2} K^{-1}]	87.5	94.2
Roof	U [W m^{-2} K^{-1}]	0.80	1.54
	κ_i [kJ m^{-2} K^{-1}]	121.8	149.0
Last Floor	U [W m^{-2} K^{-1}]	0.31	1.08
	κ_i [kJ m^{-2} K^{-1}]	105.3	149.0
Ground Floor	U [W m^{-2} K^{-1}]	0.47	1.74
	κ_i [kJ m^{-2} K^{-1}]	103.6	174.8
Windows	U [W m^{-2} K^{-1}]	1.40	3.20
	g_{gl} [-]	0.67	0.75
	g_{gl+sh} [-]	0.35	0.35

The characterization of the occupancy patterns and the operation schedules of appliances and lighting is diversified on the base of building typology.

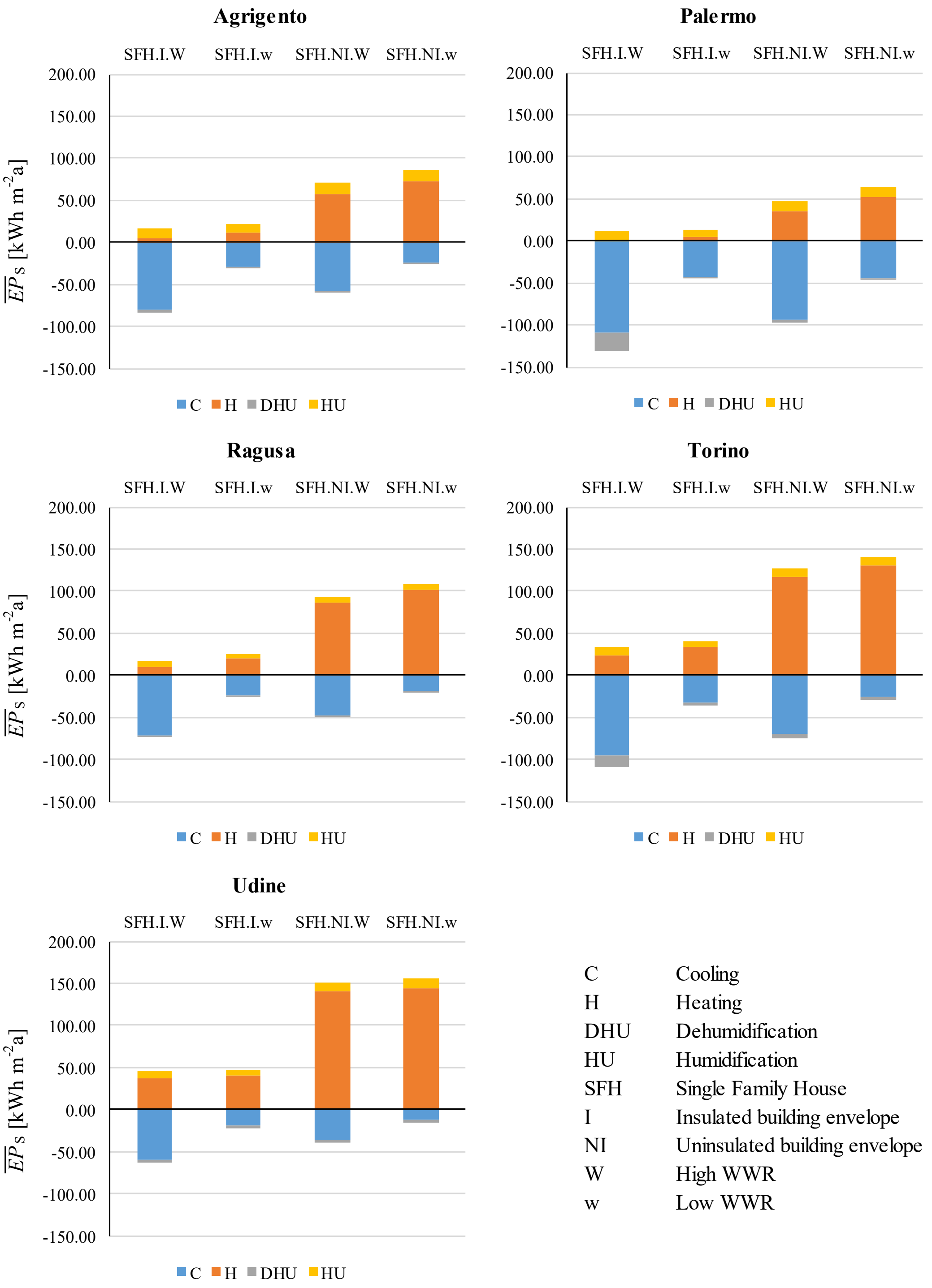
The global sensible internal heat gain, obtained as the mean value of the weekly profile, has a value reported in Table 96 while the global moisture flow has a value of 250 $g \cdot h^{-1}$.

Table 96 Global sensible internal heat gain

	Single Family House	Apartment block	Office building
Sensible thermal loads [$W \cdot m^{-2}$]	2.85	5.25	6.00
Latent thermal loads [$g \cdot h^{-1} \cdot m^{-2}$]	1.56	3.33	6.00
Ventilation flow rate [$vol \cdot h^{-1}$]	0.30	0.30	8.00

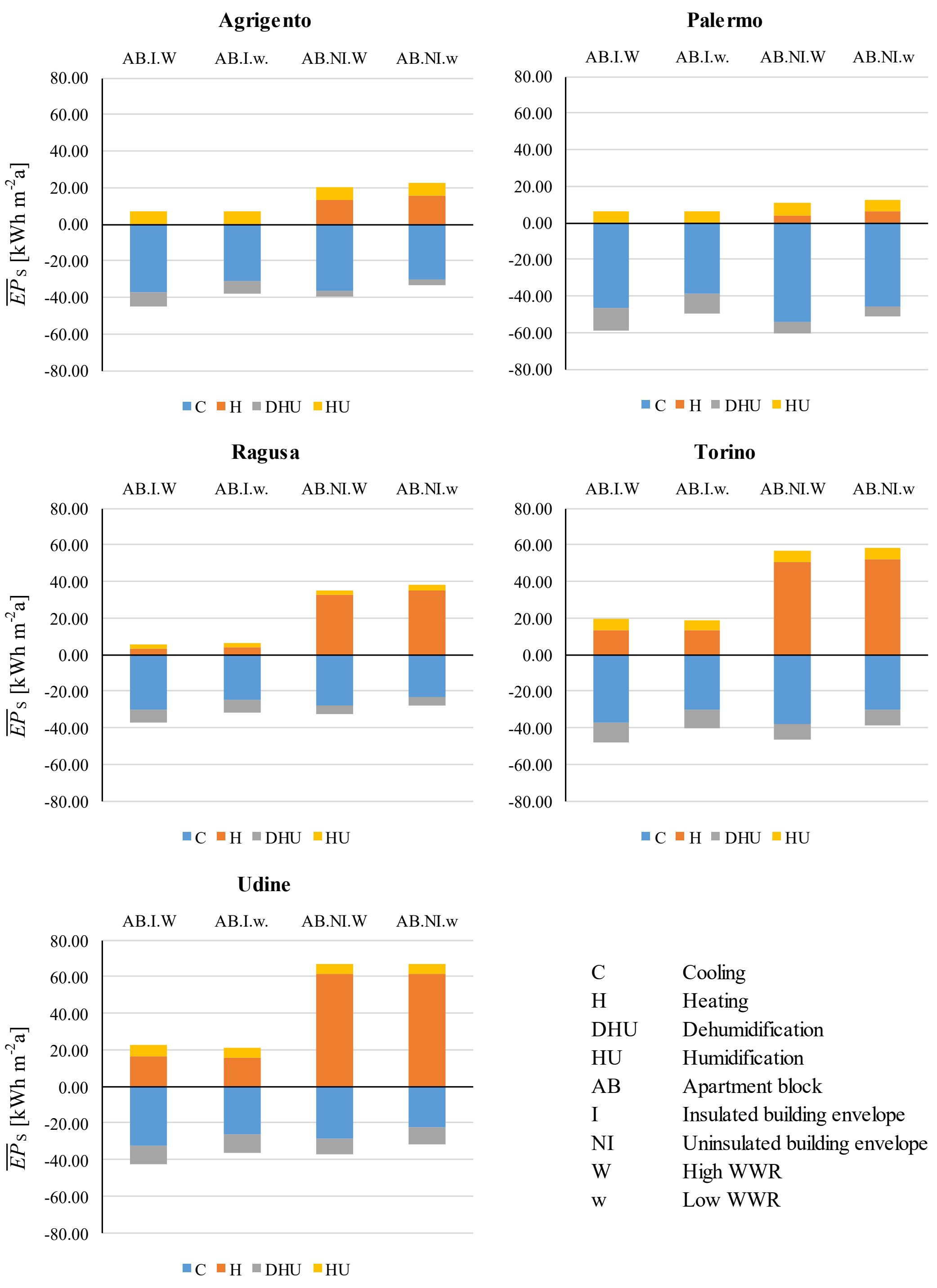
(*) Average value

The case studies have been modelled considering internal heat and moisture loads and natural ventilation. The following assumptions were considered: heating and cooling temperature set-points are 20 °C and 26 °C respectively, air relative humidity set-point for humidification and de-humidification is equal to 50%, in accordance with the prescriptions of national specification UNI/TS 11300-1(Italian Organisation for Standardisation, 2014 [235]) for residential buildings. Continuous operating schedules during the conditioning period are assumed, as indicated by the Italian regulations. Fig. 40, Fig. 41, and Fig. 42 show the long-term average *EP* split by energy service for the different case studies. The thermal energy need for space cooling (EP_C) is significantly dependent on WWR, EP_{DHU} has similar values regardless thermal insulation level, and EP_{HU} is generally negligible. The heating energy need, for all case studies, strongly depends by the degree of thermal insulation and the climatic characteristics of the location.



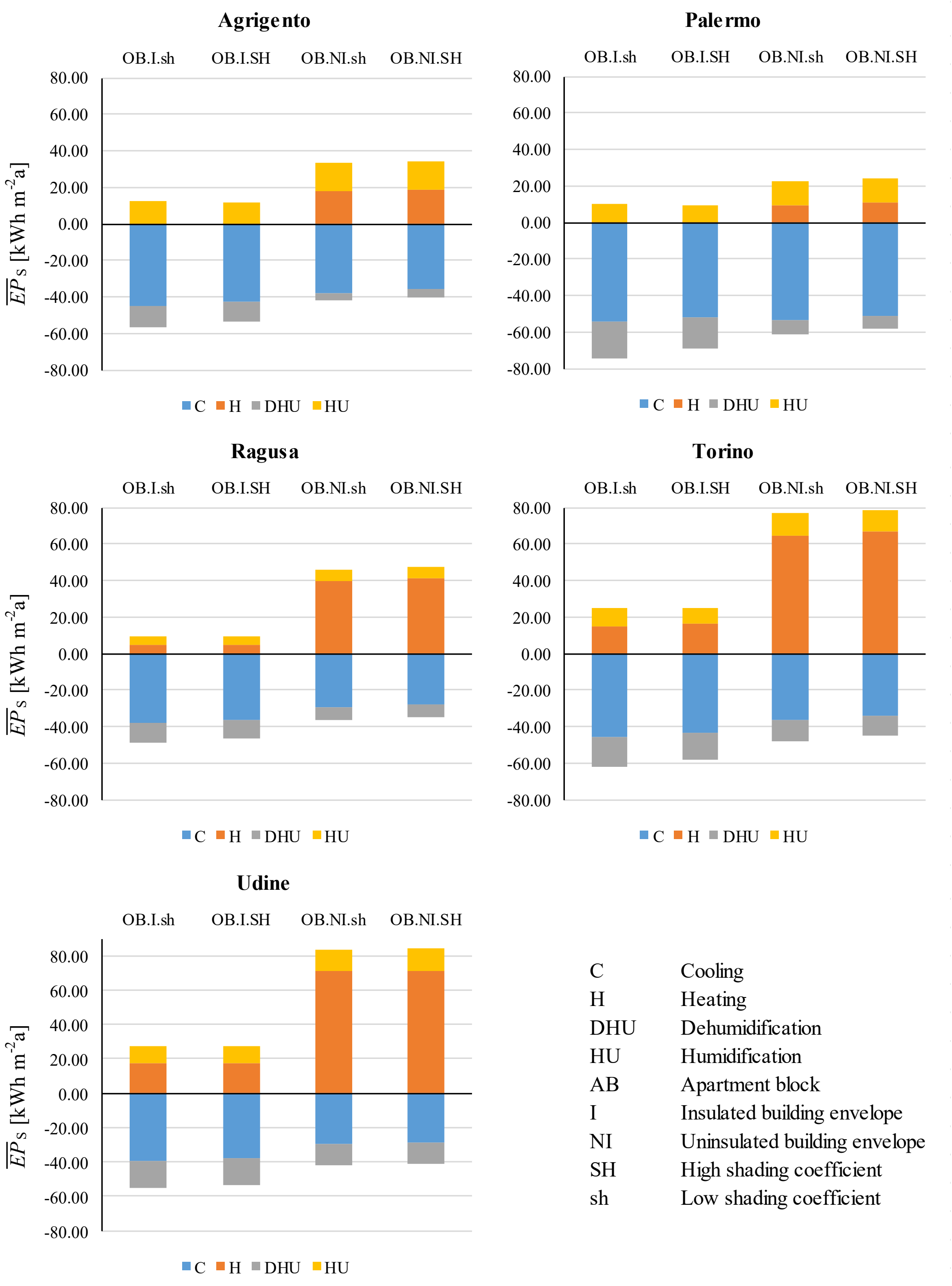
C	Cooling
H	Heating
DHU	Dehumidification
HU	Humidification
SFH	Single Family House
I	Insulated building envelope
NI	Uninsulated building envelope
W	High WWR
w	Low WWR

Fig. 40 Single Family House. Long-term average *EP* split by energy service



C	Cooling
H	Heating
DHU	Dehumidification
HU	Humidification
AB	Apartment block
I	Insulated building envelope
NI	Uninsulated building envelope
W	High WWR
w	Low WWR

Fig. 41 Apartment block. Long-term average *EP* split by energy service



C	Cooling
H	Heating
DHU	Dehumidification
HU	Humidification
AB	Apartment block
I	Insulated building envelope
NI	Uninsulated building envelope
SH	High shading coefficient
sh	Low shading coefficient

Fig. 42 Office building. Long-term average *EP* split by energy service

Regarding the climatic conditions, different locations have been chosen, characterized by different climatic conditions. The main climatic characteristics are shown in Table 97.

Table 97 Climatic characteristics of the selected locations.

Station		HDD[1]	Climate Zone[1]	HDD_{20}[2]	CDD_{26}[2]	x_H[2]	x_C[2]	TSR_H	TSR_C
		°C		°C	°C	g/kg·d	g/kg·d	MJ/y	MJ/y
AG	Agrigento Mandrascava	729	B	1186	79	128	260	2200	4031
PA	Palermo	751	B	1121	166	196	226	1879	3830
RG	Ragusa - Cilone	1.324	C	1875	75	332	68	2000	4058
TO	Bauducchi	2.617	E	2648	84	492	144	1331	3511
UD	Udine	2.323	E	2384	74	496	229	1242	3441

[1] According to DPR 412/1993 [159]
[2] According to UNI 10349-3 [131]
TSR Total solar radiation

Agrigento and Palermo climate are classified as warm and temperate. Summers are very long, hot and dry due to the domination of subtropical high pressure system, while winters experience moderate temperatures and changeable, rainy weather due to the polar front. The rain falls mostly in the winter, with relatively little rain in the summer. According to Köppen and Geiger, this climate is classified as Csa (Hot-summer Mediterranean climate).

In Ragusa the climate is warm and temperate. The rain in Ragusa falls mostly in the winter, with relatively little rain in the summer. According to Köppen and Geiger, this climate is classified as Csa (Hot-summer Mediterranean climate).

In Turin the climate is moderately continental, with cold and wet winters, and hot and sultry summers. Therefore, Turin is located in the humid subtropical climate zone according to Köppen’s classification.

Udine is characterized by equable climates with few extremes of temperature and ample precipitation in all months. Temperatures in the winter tend to be mild, while summer temperatures are moderate. Precipitation is abundant year round with spring and fall being the wettest seasons. In Udine the climate is humid subtropical according to Köppen’s classification.

4.6 Validation of the methodology

The proposed methodology was validated through calculation of the Energy Performance (*EP*) and a comparison of the results obtained by a TMY with those deriving from by a long-term (multi-year) simulation.

In this work, the *EP* is defined as the ratio of the thermal energy need to the conditioned useful floor area. *EP* is split by different energy services: heating (H), cooling (C), humidification (HU), and dehumidification (DHU). More details are available in paragraph 1.4.

The EP of the case studies was calculated by means of Energy Plus 8.5 with one-hour time step. The geometrical model of the building was developed in Design Builder 5.0.1.024.

The main modelling hypotheses are the followings: (a) exterior convection coefficient derived from DOE-2 with the total convection coefficient related and changed in function of the local wind speed; (b) sky temperature derived from the horizontal infrared radiation intensity and used for the calculation of the net long *wavelength thermal radiation flux exchange with the air and surroundings; (c) anisotropic radiance distribution of the sky; (d) ground temperature profile according to the model of Kusuda and Achenbach (1965)* [162]*, which allows the air temperature to be derived at ground level from the weather file; (e) conduction heat fluxes, calculated with the Conduction Transfer Functions (Ceylan and Myers 1980; Seem 1987; Ouyang and Haghighat 1991) expressed as a function of the environmental temperatures (interior and exterior).*

The following boundary conditions are considered: (a) the internal heat gains (sensible and latent) and ventilation flow rate are derived from UNI/TS 11300-1 (Italian Organisation for Standardisation 2014), and are represented by daily profiles; (b) the solar shadings are activated when solar irradiance exceeds 300 $W \cdot m^{-2}$*. There is not any solar shading reduction from external obstacles.*

4.7 Results and discussion

Each TMY is identified by an array of three numbers, e.g. (0.50; 0.20; 0.30)*, of which the first one is the weighting coefficient* for dry bulb outdoor temperatures, the second for solar irradiance and the last for relative humidity.

For each energy service (S), the "best" TMY is defined as the TMY that best approximates the energy need calculated on long-term data.

The representativeness of a TMY is assessed through two different indexes. The first one, $\iota_{\Delta EP_S}$*, as reported in Eq. (20)* $\iota_{\Delta EP_S} = \frac{|\Delta EP_S|}{\overline{EP}_S} = \frac{|EP_S - \overline{EP}_S|}{\overline{EP}_S}$ (20*, is the relative absolute deviation of* EP_S *for a specific energy service (S) and for the given TMY.*

$$\iota_{\Delta EP_S} = \frac{|\Delta EP_S|}{\overline{EP}_S} = \frac{|EP_S - \overline{EP}_S|}{\overline{EP}_S} \tag{20}$$

The $\iota_{\Delta EP_S}$ *indicator does not provide sufficient indications on the representativeness of the TMY for single months, as there may be compensations of energy needs among the monthly deviations. To take into account EP monthly differences the results are also analysed using the standard deviation divided by the long-term mean.*

The second index, $\iota_{\sigma EP_S}$*, as reported in Eq. (21), is the relative standard deviation of monthly energy performance referred to a specific energy service (*$EP^M{}_S$*).*

$$\iota_{\sigma EP_S} = \frac{\sigma_{EP^M{}_S}}{\overline{EP^M}_S} = \frac{\sqrt{\sum_{m=1}^{N_m}\left(EP^M{}_{S,m} - \overline{EP^M}_{S,m}\right)^2 / \left(N_m - 1\right)}}{\overline{EP^M}_S} \tag{21}$$

where N_m *is the number of months for which the considered energy service is provided.* $\overline{EP^M}_S$ represent the mean value from multiyear for single month.

4.7.1 Yearly EP relative deviation ($\iota_{\Delta EP_S}$)

To simplify the reading of the results, they have been summarized in tables divided by energy need. The coefficient with the highest value is highlighted in red.

The results relating to this index are also reported, although it has been considered not very representative because compensations can occur between monthly energy needs.

Table 98 Yearly EP relative deviation. Heating energy service. Aggregation of optimal TMYs configuration for building typology and geographic location.

		NI.W	NI.w	I.W	I.w
AG	SFH	C57(0.00;0.30;0.70)	C54(0.20;0.20;0.60)	C55(0.30;0.10;0.60) C59(0.20;0.10;0.70) C60(0.30;0.00;0.70) C62(0.10;0.10;0.80) C63(0.20;0.00;0.80) C64(0.00;0.10;0.90)	C39(0.00;0.70;0.30)
	AB	C55(0.30;0.10;0.60) C59(0.20;0.10;0.70) C60(0.30;0.00;0.70) C62(0.10;0.10;0.80) C63(0.20;0.00;0.80) C64(0.00;0.10;0.90)			
	OB	C31(0.00;0.70;0.30)			
PA	SFH	C65(0.10;0.00;0.90) C66(0.00;0.00;1.00)	C5(0.40;0.60;0.00) C18(0.60;0.30;0.10)	C35(0.40;0.30;0.30) C42(0.30;0.30;0.40) C43(0.40;0.20;0.40) C48(0.20;0.30;0.50) C49(0.30;0.20;0.50) C53(0.10;0.30;0.60) C54(0.20;0.20;0.60) C57(0.00;0.30;0.70) C58(0.10;0.20;0.70) C59(0.20;0.10;0.70) C62(0.10;0.10;0.80) C63(0.20;0.00;0.80)	C17(0.50;0.40;0.10)
	AB	C5(0.40;0.60;0.00) C18(0.60;0.30;0.10)	C4(0.30;0.70;0.00) C15(0.30;0.60;0.10) C16 C25(0.30;0.50;0.20)		
	OB	C6(0.50;0.50;0.00)	C65 (0.10;0.00;0.90) C66 (0.00;0.00;1.00)		
RG	SFH	C46(0.00;0.50;0.50) C52(0.00;0.40;0.60)		C8(0.70;0.30;0.00) C17(0.50;0.40;0.10)	C46(0.00;0.50;0.50), C52(0.00;0.40;0.60)
	AB	C30(0.80;0.00;0.20)	C20(0.80;0.10;0.10) C29(0.70;0.10;0.20) C37(0.60;0.10;0.30) C38(0.70;0.00;0.30)		C8(0.70;0.30;0.00)
	OB	C64(0.00;0.10;0.90) C65(0.10;0.00;0.90) C66(0.00;0.00;1.00)	C61(0.00;0.20;0.80)		C45(0.60;0.00;0.40) C51(0.50;0.00;0.50) C56(0.40;0.00;0.60)
TO	SFH	C32(0.10;0.60;0.30)	C31 (0.00;0.70;0.30)	C63(0.20;0.00;0.80) C64(0.00;0.10;0.90) C65(0.10;0.00;0.90) C66(0.00;0.00;1.00)	C33(0.20;0.50;0.30) C34(0.30;0.40;0.30) C49 (0.30;0.20;0.50)
	AB	C9(0.80;0.20;0.00)			C30 (0.80;0.00;0.20)
	OB	31(0.00;0.70;0.30)			
UD	SFH	C30(0.80;0.00;0.20)		C12(0.00;0.90;0.10)	C4 (0.30;0.70;0.00) C14(0.20;0.70;0.10)
	AB	C28(0.60;0.20;0.20)		C64(0.00;0.10;0.90)	
	OB	C44(0.50;0.10;0.40) C50(0.40;0.10;0.50)	C35(0.40;0.30;0.30), C38(0.70;0.00;0.30), C45(0.60;0.00;0.40), C50 (0.40;0.10;0.50)	C47(0.10;0.40;0.50) C53(0.10;0.30;0.60)	

Table 99 Yearly EP relative deviation. Cooling energy service. Aggregation of optimal TMYs configuration for building typology and geographic location.

		I.W	I.w	NI.w	NI.W
AG	SFH	C21(0.90;0.00;0.10) C61(0.00;0.20;0.80) C64(0.00;0.10;0.90) C65(0.10;0.00;0.90) C66(0.00;0.00;1.00)	C39(0.00;0.70;0.30)	C46(0.00;0.50;0.50) C52(0.00;0.40;0.60)	C40(0.00;0.70;0.30)
	AB	C7(0.60;0.40;0.00)	C9(0.80;0.20;0.00)	C21(0.90;0.00;0.10)	
	OB	C2(0.10;0.90;0.00), C13(0.10;0.80;0.10) C22(0.00;0.80;0.20)		C42(0.30;0.30;0.40), C43(0.40;0.20;0.40)	
PA	SFH	C6(0.50;0.50;0.00) C18(0.60;0.30;0.10)		C5(0.40;0.60;0.00) C16(0.40;0.50;0.10) C17(0.50;0.40;0.10)	C38(0.70;0.00;0.30), C45(0.60;0.00;0.40)
	AB	C8(0.70;0.30;0.00),	C10(0.90;0.10;0.00)		C11(1.00;0.00;0.00)
	OB	C9(0.80;0.20;0.00)		C29 (0.70;0.10;0.20)	
RG	SFH	C5 (0.40;0.60;0.00)	C6(0.50;0.50;0.00)	C56(0.40;0.00;0.60) C60(0.30;0.00;0.70) C63(0.20;0.00;0.80)	
	AB	C19(0.70;0.20;0.10)			
	OB	C27(0.60;0.30;0.10)	C35(0.40;0.30;0.30)	C58(0.10;0.20;0.70)	
TO	SFH			C40(0.00;0.70;0.30) C46(0.00;0.50;0.50)	
	AB		C32(0.10;0.60;0.30)		
	OB				
UD	SFH	C20(0.80;0.10;0.10) C49(0.30;0.20;0.50) C55(0.30;0.10;0.60)	C38(0.70;0.00;0.30)	C33(0.20;0.50;0.30)	C27(0.60;0.30;0.10)
	AB	C30(0.80;0.00;0.20)	C37 (0.60;0.10;0.30)		
	OB	C64(0.00;0.10;0.90)			

Table 100 Yearly EP relative deviation. Humidification energy service. Aggregation of optimal TMYs configuration for building typology and geographic location.

<table>
<tr><th></th><th></th><th>NI.W</th><th>NI.w</th><th>I.W</th><th>I.w</th></tr>
<tr><td rowspan="3">AG</td><td>SFH</td><td colspan="2" rowspan="2">C31(0.00;0.70;0.30)</td><td rowspan="2">C23(0.10;0.70;0.20)</td><td rowspan="2">C43(0.40;0.20;0.40)</td></tr>
<tr><td>AB</td></tr>
<tr><td>OB</td><td>C49(0.30;0.20;0.50)</td><td>C41(0.20;0.40;0.40)
C42(0.30;0.30;0.40)</td><td colspan="2">C56(0.40;0.00;0.60)</td></tr>
<tr><td rowspan="4">PA</td><td>SFH</td><td colspan="2" rowspan="2">C39(0.00;0.70;0.30)</td><td colspan="2">C43 (0.40;0.20;0.40)</td></tr>
<tr><td>AB</td><td>C27(0.50;0.30;0.20)
C51(0.50;0.00;0.50)</td><td rowspan="2">C39(0.00;0.70;0.30)
C46 (0.00;0.50;0.50)</td></tr>
<tr><td rowspan="2">OB</td><td>C26(0.40;0.40;0.20)
C34(0.30;0.40;0.30)</td><td>C33(0.20;0.50;0.30)</td><td>C31(0.00;0.70;0.30)</td></tr>
<tr><td colspan="2">C29(0.70;0.10;0.20)
C38(0.70;0.00;0.30)
C45(0.60;0.00;0.40)</td><td>C4(0.30;0.70;0.00)
C15(0.30;0.60;0.10)
C25(0.30;0.50;0.20)</td><td rowspan="2">C18(0.60;0.30;0.10)</td></tr>
<tr><td rowspan="3">RG</td><td>SFH</td><td colspan="2">C47(0.10;0.40;0.50)</td><td>C54(0.20;0.20;0.60)</td></tr>
<tr><td>AB</td><td colspan="2">C18(0.60;0.30;0.10)</td><td colspan="2">C17(0.50;0.40;0.10)</td></tr>
<tr><td>OB</td><td colspan="2">C19(0.70;0.20;0.10)</td><td colspan="2">C10(0.90;0.10;0.00) C11(1.00;0.00;0.00)
C21(0.90;0.00;0.10) C50(0.40;0.10;0.50)</td></tr>
<tr><td rowspan="3">TO</td><td>SFH</td><td>C31 (0.00;0.70;0.30)</td><td>C49 (0.30;0.20;0.50)
C64 (0.00;0.10;0.90)
C65 (0.10;0.00;0.90)
C66 (0.00;0.00;1.00)</td><td rowspan="2">C9(0.80;0.20;0.00)</td><td>C19(0.70;0.20;0.10)
C20(0.80;0.10;0.10)
C29(0.70;0.10;0.20)
C30(0.80;0.00;0.20)
C60(0.30;0.00;0.70)</td></tr>
<tr><td>OB</td><td>C37(0.60;0.10;0.30)
C44(0.50;0.10;0.40)
C45(0.60;0.00;0.40)
C50(0.40;0.10;0.50)
C51(0.50;0.00;0.50)</td><td>C63(0.20;0.00;0.80)</td><td>C5(0.40;0.60;0.00)
C6(0.50;0.50;0.00)
C7(0.60;0.40;0.00)
C8(0.70;0.30;0.00)
C16(0.40;0.50;0.10)
C17(0.50;0.40;0.10)
C18(0.60;0.30;0.10)
C26(0.40;0.40;0.20)
C27(0.60;0.30;0.10)
C28(0.60;0.20;0.20)
C39(0.00;0.70;0.30)</td></tr>
<tr><td>AB</td><td colspan="2">C42(0.30;0.30;0.40)</td><td>C60(0.30;0.00;0.70)</td><td>C32(0.10;0.60;0.30)</td></tr>
<tr><td rowspan="3">UD</td><td>SFH</td><td>C52 (0.00;0.40;0.60)</td><td>C40(0.00;0.70;0.30)</td><td>C57(0.00;0.30;0.70)</td><td>C5(0.40;0.60;0.00)</td></tr>
<tr><td>AB</td><td colspan="4"></td></tr>
<tr><td>OB</td><td colspan="2">C66(0.00;0.00;1.00)</td><td colspan="2">C55 (0.00;0.30;0.70)</td></tr>
</table>

Table 101 Yearly EP relative deviation. De-Humidification energy service. Aggregation of optimal TMYs configuration for building typology and geographic location.

		I.W	I.w	NI.W	NI.w
AG	AB	C44 (0.50;0.10;0.40) C50(0.40;0.10;0.50)	C45(0.60;0.00;0.40), C51(0.50;0.00;0.50)	C40(0.00;0.70;0.30)	
	SFH	C62(0.10;0.10;0.80) C63(0.20;0.00;0.80)	C61(0.00;0.20;0.80) C64(0.00;0.10;0.90) C65(0.10;0.00;0.90) C66(0.00;0.00;1.00)		C55(0.30;0.10;0.60)
	OB				
PA	SFH	C57(0.00;0.30;0.70)		C5(0.40;0.60;0.00) C16(0.40;0.50;0.10) C17(0.50;0.40;0.10) C57(0.00;0.30;0.70)	C57(0.00;0.30;0.70)
	OB	C8(0.70;0.30;0.00)			
	AB	C59(0.20;0.10;0.70) C60(0.30;0.00;0.70)			
RG	OB	C61(0.00;0.20;0.80)	C50(0.40;0.10;0.50)	C63(0.20;0.00;0.80)	
	SFH	C16(0.40;0.50;0.10)	C1(0.00;1.00;0.00) C2 (0.10;0.90;0.00) C12(0.00;0.90;0.10)	C45(0.60;0.00;0.40)	C33(0.20;0.50;0.30)
	AB			C52(0.00;0.40;0.60)	
TO	SFH	C32(0.10;0.60;0.30)	C30 (0.80;0.00;0.20)		
	AB	C56(0.40;0.00;0.60)	C43(0.40;0.20;0.40)	C30(0.80;0.00;0.20)	C39(0.00;0.70;0.30)
	OB	C52(0.00;0.40;0.60)	C53 (0.10;0.30;0.60)	C34(0.30;0.40;0.30)	
UD	SFH	C31(0.00;0.70;0.30)	C39(0.00;0.70;0.30)		C28(0.60;0.20;0.20)
	AB	C30 (0.80;0.00;0.20)		C29(0.70;0.10;0.20)	
	OB	C49(0.30;0.20;0.50)	C55(0.30;0.10;0.60)	C63(0.20;0.00;0.80)	

Table 102 Yearly EP relative deviation. Aggregated heating energy service (Heating + Humidification). Aggregation of optimal TMYs configuration for building typology and geographic location.

		NI.W	NI.w	I.w	I.W
AG	SFH	C46(0.00;0.50;0.50) C47 (0.10;0.40;0.50) C52(0.00;0.40;0.60) C57(0.00;0.30;0.70) C64(0.00;0.10;0.90)	C56(0.40;0.00;0.60) C64(0.00;0.10;0.90)	C25(0.30;0.50;0.20)	C19(0.70;0.20;0.10)
	AB	C55(0.30;0.10;0.60)	C37(0.60;0.10;0.30) C44(0.50;0.10;0.40) C59(0.20;0.10;0.70) C62(0.10;0.10;0.80) C63(0.20;0.00;0.80)	C39(0.00;0.70;0.30)	C43(0.40;0.20;0.40)
	OB	C64(0.00;0.10;0.90)		C10(0.90;0.10;0.00)	C37(0.60;0.10;0.30) C44(0.50;0.10;0.40)
PA	SFH	C16(0.40;0.50;0.10)	C6(0.50;0.50;0.00) C24(0.20;0.60;0.20)	C32(0.10;0.60;0.30)	C27(0.60;0.30;0.10)
	AB		C35(0.40;0.30;0.30) C42(0.30;0.30;0.40) C43(0.40;0.20;0.40)	C39(0.00;0.70;0.30) C46(0.00;0.50;0.50)	C16(0.40;0.50;0.10) C22(0.00;0.80;0.20)
	OB	C57 (0.00;0.30;0.70)			C31 (0.00;0.70;0.30)
RG	AB		C52(0.00;0.40;0.60)	C58(0.10;0.20;0.70)	C59(0.20;0.10;0.70)
	SFH			C57(0.00;0.30;0.70)	C8(0.70;0.30;0.00)
	OB	C39 (0.00;0.70;0.30)		C60(0.30;0.00;0.70)	C19(0.70;0.20;0.10)
TO	SFH	C32(0.10;0.60;0.30)	C31(0.00;0.70;0.30)	C55(0.30;0.10;0.60)	C9(0.80;0.20;0.00)
	AB		C54(0.20;0.20;0.60)	C31(0.00;0.70;0.30)	
	OB				
UD	AB	C60(0.30;0.00;0.70)	C22(0.00;0.80;0.20)		C63(0.20;0.00;0.80)
	SFH	C30(0.60;0.10;0.30)		C8(0.70;0.30;0.00) C9(0.80;0.20;0.00)	C43(0.40;0.20;0.40) C52(0.00;0.40;0.60)
	OB	C37(0.60;0.10;0.30) C44 (0.50;0.10;0.40) C50(0.40;0.10;0.50) C60(0.30;0.00;0.70)		C62(0.10;0.10;0.80)	

Table 103 Yearly EP relative deviation. Aggregated heating energy service (Cooling + Dehumidification). Aggregation of optimal TMYs configuration for building typology and geographic location.

		NI.W	NI.w	I.w	I.W
AG	SFH	C46(0.00;0.50;0.50)	C52 (0.00;0.40;0.60)	C56 (0.40;0.00;0.60)	
	OB			C50(0.40;0.10;0.50)	C51(0.50;0.00;0.50)
	AB	C55(0.30;0.10;0.60)		C39(0.00;0.70;0.30)	C39(0.00;0.70;0.30) C50(0.40;0.10;0.50) C51(0.50;0.00;0.50)
PA	SFH	C57(0.00;0.30;0.70)	C38(0.70;0.00;0.30) C45(0.60;0.00;0.40)	C6(0.50;0.50;0.00) C18(0.50;0.50;0.00) C57(0.00;0.30;0.70)	20(0.80;0.10;0.10)
	OB		C29(0.70;0.10;0.20)		
	AB			C8(0.70;0.30;0.00)	
RG	SFH	C31(0.00;0.70;0.30) C32(0.10;0.60;0.30)	C54(0.20;0.20;0.60) C55(0.30;0.10;0.60) C56(0.40;0.00;0.60) C59(0.20;0.10;0.70) C60(0.30;0.00;0.70) C61(0.00;0.20;0.80) C63(0.20;0.00;0.80)	C42(0.30;0.30;0.40)	
	AB		C39(0.00;0.70;0.30)	C3(0.20;0.80;0.00) C4(0.30;0.70;0.00) C14(0.20;0.70;0.10)	C13(0.10;0.80;0.10) C15(0.30;0.60;0.10)
	OB	C42(0.30;0.30;0.40) C64(0.00;0.10;0.90)	C31(0.00;0.70;0.30) C32(0.10;0.60;0.30)		
TO	AB	C40(0.10;0.50;0.40)	C46(0.00;0.50;0.50)	C31 (0.00;0.70;0.30)	
	SFH				
	OB		C31 (0.00;0.70;0.30)	C39(0.00;0.60;0.40)	
UD	SFH	C8(0.70;0.30;0.00) C9(0.80;0.20;0.00) C28(0.60;0.20;0.20) C38(0.70;0.00;0.30)	C61(0.00;0.20;0.80)	C48(0.20;0.30;0.50) C58(0.10;0.20;0.70)	C19(0.70;0.20;0.10) C42(0.30;0.30;0.40)
	OB		C33(0.20;0.50;0.30)		C22(0.00;0.80;0.20)
	AB	C64(0.00;0.10;0.90)			

4.7.2 Monthly *EP* relative standard deviation ($\iota_{\sigma EP_S}$)

Below are reported some considerations divided by energy need for building services, for typologies of building, and their design and technological variants.

4.7.2.1 Heating energy service

a) Agrigento

As regards the single family houses, the most representative TMYs are C59 (0.20;0.10;0.70), C62 (0.10;0.10;0.80), C63 (0.20;0.00;0.80) with the exception of the single family house with low WWR that is best characterized by the C34 (0.30; 0.40; 0.30). The configurations C55 (0.30; 0.10; 0.60) and C60 (0.30; 0.00; 0.70) represent the second choice of best TMY for all the variants of this case study.

Concerning the Apartment Block and the Office Building with poorly insulated building envelope, the best TMYs are C55 (0.30; 0.10; 0.60), C59 (0.20; 0.10; 0.70), C60 (0.30; 0.00; 0.70), C62 (0.10; 0.10; 0.80), C63 (0.20; 0.00; 0.80), and C64 (0.00; 0.10; 0.90). These configurations show the same value as the parameter, $\iota_{\sigma EP_H}$. For Apartment Block and Office Building, the variants with high thermal insulation have been neglected since the heating energy needs are zero. The poorly insulated single family house and apartment block variants have as their best TMYs the combinations C59 (0.20; 0.10; 0.70), C62 (0.10; 0.10; 0.80), and C63 (0.20; 0.00; 0.80). The poorly insulated office buildings and apartment block variants have the C60 configuration (0.30; 0.00; 0.70) as best TMY.

For Agrigento, the analysis of the best configurations shows that in the chosen combination, the parameter that has the greatest weight is the air relative humidity, which generally has values greater than or equal to 0.50. The other parameters have an influence that is negligible.

b) Palermo

For highly insulated single family houses with high WWR the best TMYs are C35 (0.40; 0.30; 0.30), C42 (0.30; 0.30; 0.40), C43 (0.40; 0.20; 0.40), C48 (0.20; 0.30; 0.50), C49 (0.30; 0.20; 0.50), C53 (0.10; 0.30; 0.60), C57 (0.00; 0.30; 0.70), C58 (0.10; 0.20; 0.70), C59 (0.20; 0.10; 0.70), C61 (0.00; 0.20; 0.80), C62 (0.10; 0.10; 0.80) and C63 (0.20; 0.00; 0.80); other TMYs offering good performance are C64 (0.00; 0.10; 0.90), C65 (0.10; 0.00; 0.90), and C66 (0.00; 0.00; 1.00). For the Apartment Block and the Office Building, the variants with high thermal insulation have been neglected since the heating energy needs are zero. In the case of SFH.I.w. the most representative TMY configuration is C17 (0.50; 0.40; 0.10).

The TMYs C5 (0.40; 0.60; 0.00) and C18 (0.60; 0.30; 0.10) offer good representativeness for all buildings except for SFH.IW and OB.NI.SH, while C6 (0.50; 0.50; 0.00) represents the best configuration for the poorly insulated single family house and the office buildings.

Concerning the Apartment Block and the Office Building with poorly-insulated building envelope, the best TMYs are the configurations C4 (0.30; 0.70; 0.00), C15 (0.30; 0.60; 0.10), C16 (0.40; 0.50; 0.10), and C25 (0.30; 0.50; 0.20).

c) Ragusa

For the highly insulated single family house with low WWR, the best TMYs are C10 (0.90; 0.10; 0.00), C11 (1.00; 0.00; 0.00), C20 (0.80; 0.10; 0.10), C21 (0.90; 0.00; 0.10), C29 (0.70; 0.10; 0.20), C30 (0.80; 0.00; 0.20), C37 (0.60; 0.10; 0.30), and C38 (0.70; 0.00; 0.30).

For the highly insulated apartment block, the most representative configurations are C8 (0.70; 0.30; 0.00), and C17 (0.50; 0.40; 0.10). Instead, the best configurations for the poorly insulated apartment block are C20 (0.80; 0.10; 0.10), C29 (0.70; 0.10; 0.20), C30 (0.80; 0.00; 0.20), C37 (0.60; 0.10; 0.30) and C38 (0.70; 0.00; 0.30).

Regarding the poorly insulated office building, the most representative TMYs are C9 (0.80;0.20;0.00), C10 (0.90;0.10;0.00), C11 (1.00;0.00;0.00), and C21 (0.90;0.00;0.10).

While, in order of reliability according to parameter $\iota_{\sigma EP_H}$ the second best TMYs are C20 (0.80; 0.10; 0.10), C29 (0.70; 0.10; 0.20), C30 (0.80; 0.00; 0.20), C37 (0.60; 0.10; 0.30) and C38 (0.70; 0.00; 0.30).

Otherwise, for the highly insulated office building the minimum value of the relative standard deviation ($\iota_{\sigma EP,H}$) corresponds to the combinations C28 (0.60;0.20;0.20), C36 (0.50;0.20;0.30), and C44 (0.50;0.10;0.40). Both the poorly insulated single family houses and office buildings show as best combination the TMY C9 (0.80; 0.20; 0.00) From the identified configurations it can be deduced that the parameter that has the greatest weight is the one related to the dry-bulb temperature which always has values greater than or equal to 0.50. The other parameters in the composition of the optimal tern have a lower weight. Therefore, the influence of air temperature is generally dominant.

d) Turin

Eight different configurations, C9 (0.80;0.20;0.00), C10 (0.90;0.10;0.00), C11 (1.00;0.00;0.00), C19 (0.70;0.20;0.10), C20 (0.80;0.10;0.10), C21 (0.90;0.00;0.10), C30 (0.80;0.00;0.20), and C38 (0.70;0.00;0.30), show equal performance for the single family houses in all its design and technological variants.

These TMYs are the most representative also for all the case studies related to the apartment block building, with the exception of the highly insulated building with high WWR. This latter is well represented by the configuration C31 (0.00; 0.70; 0.30). This TMY also have a good performance for the office building in all its configurations; for the variant poorly insulated, is also representative the combination C60 (0.30; 0.00; 0.70). From the identified configurations it can be deduced that the parameter that has the greatest weight for the single family house is the one related to the dry-bulb temperature which has generally values greater than or equal to 0.50. The other parameters in the composition of the optimal tern have a lower weight. The same considerations are valid to the apartment block case study except for the configuration highly insulated and with high WWR. For the Office building the climatic parameter which is most relevant in the ternary configuration is that relating to solar irradiance.

e) Udine

Two configurations, C11 (1.00;0.00;0.00) and C21 (0.90;0.00;0.10), show equal performance for the single family houses; for the variant highly insulated, the best configurations are C27 (0.50;0.30;0.20), and C43 (0.40;0.20;0.40). For the Apartment Block and the Office Building, in case of poorly insulated building envelope, the best configuration is C28 (0.60; 0.20; 0.20). Instead for the same case studies, in case of highly insulated building the minimum value of the relative standard deviation ($\iota_{\sigma EP_H}$) corresponds to C61 (0.00; 0.20; 0.80), and C64 (0.00; 0.10; 0.90).

f) TMYs Correspondences between location and building typology

Eight configurations, C9 (0.80;0.20;0.00), C10 (0.90;0.10;0.00), C11 (1.00;0.00;0.00), C19 (0.70;0.20;0.10), C20 (0.80;0.10;0.10), C21 (0.90;0.00;0.10), C29 (0.70;0.10;0.20) and C30 (0.80;0.00;0.20) are common for Ragusa and Turin for the apartment block typology poor insulated and with high WWR. As regard the poor insulated variant, C20 (0.80;0.10;0.10), C29 (0.70;0.10;0.20), and C30 (0.80;0.00;0.20) represent the best TMY configurations. For the office building, the configuration C60 (0.30;0.00;0.70) is representative both for Agrigento and Turin.

Both for Agrigento and Palermo, for the highly insulated single family house with high WWR, the combinations C59 (0.20; 0.10; 0.70), and C62 (0.10; 0.10; 0.80) are the best TMYs. Both for Udine and Palermo, for the highly insulated single family house with high WWR, the best TMY is the combination C43(0.40;0.20;0.40). In Table 104 is reported the general situation.

The table reports on the abscissa all the combinations of TMYs, while on the ordinate the selected case studies which have been grouped by geographic location, typology of building and technological and design variant. The best TMY is represented with dark grey cell and with symbol “x”, while the second best TMY is reported in light grey cell and symbol “y”.

Table 104 Monthly EP relative standard deviation. Optimum weighting coefficients for climate variables for heating energy service.

			TMY																																																														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
		T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.0	0.1	0.2	0.3	0.4	0.5	0.0	0.1	0.2	0.3	0.4	0.0	0.1	0.2	0.3	0.0	0.1	0.2	0.0	0.1	0.0
		I	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.5	0.4	0.3	0.2	0.1	0.0	0.4	0.3	0.2	0.1	0.0	0.3	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0
		RH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0
AG	SFH	I.W.																																																					y				x	y		x	x	x		
		I.w.																																x																					y					y						
		NI.W.																																																					y				x	y		x	x			
		NI.w.																																																					y				x	y		x	x			
	AB	I.W.																																																																
		I.w.																																																																
		NI.W.																																y																					x				x	x		x	x	x		
		NI.w.																																																y					y	x				x	x		x	x	x		
	OB	I.sh.																																																																
		I.SH.																																																																
		NI.sh.																																																					y				y	x		y	y			
		NI.SH.																																																					x				x	x		x	x	y		
PA	SFH	I.W.																																	x							x	x					x	x				x	x			x	x	x		x	x		y	y	y
		I.w.					y												x	y																																														
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		NI.w.				x	y										x	x		y							x																																									
	OB	I.sh.																																																																
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		NI.SH.				y		x									y	y									y																																									
RG	SFH	I.W.								x									x		y									y								y								y																						
		I.w.									y	x	x									x	x								x	x							x	x																												
		NI.W.								y	x									y									y																																								
		NI.w.							y	y	x	y	y										y																																													
	AB	I.W.						y	y	x									x																																																	
		I.w.								x									x											y								y								y																						
		NI.W.										x	x									x	x							y	x	x						y	x	x						y																						
		NI.w.										y	y									x	y								x	x							x	x																												
	OB	I.sh.																			y									x								x								x																						
		I.SH.																			y									x								x								x																						
		NI.sh.									x	x	x									y	x								y	y							y	y																												
		NI.SH.									x	x	x									y	x								y	y							y	y																												
TO	SFH	I.W.									x	x	x								x	x	x								x	x								y																												
		I.w.									y	y	y								y	y	y									y								x																												
		NI.W.									x	x	x								x	x	x								x	x								y																												
		NI.w.									x	x	x								x	x	x								x	x								y																		y				y						
	AB	I.W.	y	y	y									y	y									y	y								x																																			
		I.w.									x	x	x								x	x	x								y	x																																				
		NI.W.									x	x	x								x	x	x								x	x								y																		y										
		NI.w.									x	x	x								x	x	x								x	x								y																												
	OB	I.sh.									y	y	y								y	y	y								y	y	x																																			
		I.SH.									y	y	y								y	y	y								y	y	x																																			
		NI.sh.																															y																													x						
		NI.SH.																															y																													x						
UD	SFH	I.W.																																				y						x	y						y																
		I.w.																			y								x																																							
		NI.W.								y	y	y	x									y	x								y																																					
		NI.w.										y	x									y	x								y																																					
	AB	I.W.																																																													x			x	y	y
		I.w.																																																													x			x	y	y
		NI.W.					y	y	y										y	y										x																																						
		NI.w.					y	y	y										y	y										x																																						
	OB	I.sh.																																																													x			x	y	y
		I.SH.																																																													x			x	y	y
		NI.sh.					y																							x																																						
		NI.SH.					y	y	y										y	y										x																																						

To facilitate further reading each table has been decoded by combining the TMYs that best represent each building type based on the selected location.

The parameter that has the most weight in the tern has been highlighted in red. The black cells indicate the lack of specific energy need.

In the search of optimal configuration, for the coldest localities the influence of air temperature is generally dominant. However, the highly insulated buildings with high WWR and many internal gain (for example the apartment blocks) do not respect this consideration.

Table 105 Monthly EP relative standard deviation. Heating energy service. Aggregation of optimal TMYs configuration for building typology and geographic location.

		NI.w	NI.W	I.W	I.w
PA	SFH	C6(0.50;0.50;0.00)		C59(0.30;0.20;0.50) C61(0.00;0.20;0.80) C62(0.10;0.10;0.80) C63(0.20;0.00;0.80)	C17(0.50;0.40;0.10)
	OB				■
	AB		C5(0.40;0.60;0.00) C18(0.60;0.30;0.10)	■	■
RG	SFH	C9(0.80;0.20;0.00)		C8(0.70;0.30;0.00) C17(0.50;0.40;0.10)	C20(0.80;0.10;0.10) C30(0.80;0.00;0.20) C29(0.70;0.10;0.20) C38(0.70;0.00;0.30) C21(0.90;0.00;0.10) C10(0.90;0.10;0.00) C11(1.00;0.00;0.00)
	AB	C10(0.90;0.10;0.00), C11(1.00;0.00;0.00)			
	OB			C28(0.60;0.20;0.20), C36(0.60;0.20;0.20)	
TO	SFH				C38(0.70;0.00;0.30)
	AB	C30(0.80;0.00;0.20)		C31(0.00;0.70;0.30)	C19(0.70;0.20;0.10) C9(0.80;0.20;0.00) C20(0.80;0.10;0.10) C30(0.80;0.00;0.20) C10(0.90;0.10;0.00) C21(0.90;0.00;0.10) C11(1.00;0.00;0.00)
	OB	C60(0.30;0.00;0.70)			
AG	AB			■	■
	OB			■	■
	SFH				C34(0.30;0.40;0.30)
UD	SFH	C11(1.00;0.00;0.00),C21(0.90;0.00;0.10)		C43(0.40;0.20;0.40)	
	AB	C28(0.60;0.20;0.20)		C61(0.00;0.20;0.80), C64(0.00;0.10;0.90)	
	OB				

4.7.2.2 Cooling energy service

a) Agrigento

TYM C21 (0.90; 0.00; 0.10) is representative for all case studies except for the highly insulated apartment blocks. These buildings are represented by the combinations C7 (0.60; 0.40; 0.00) and C9 (0.80; 0.20; 0.00). For all buildings, the second best TMYs in order of representativeness are C10 (0.90; 0.10; 0.00) and C11 (1.00; 0.00; 0.00). The parameter that has the greatest weight is the one related to the dry-bulb temperature which always has values greater than or equal to 0.60.

b) Palermo

Two configurations, C10 (0.90;0.10;0.00) and C11 (1.00;0.00;0.00), show a good performance for all cases study with exception of the highly insulated office building which is best represented by the combination C8 (0.70; 0.30; 0.00). In the selected configurations, the weighting coefficient related to dry-bulb temperature is greater than 0.70.

c) Ragusa

The minimum value of the relative standard deviation ($\iota_{\sigma EP,C}$) for all case studies, with exception for the highly insulated office building, corresponds to C19 (0.70;0.20;0.10). This exception is best represented by the combination C7 (0.60; 0.40; 0.00). For the single family houses poor insulated and with low WWR, the best configurations are C10 (0.90; 0.10; 0.00), C11 (1.00; 0.00; 0.00), C19 (0.70; 0.20; 0.10), C20(0.80; 0.10; 0.10), C21(0.90; 0.00; 0.10), C28 (0.60; 0.20; 0.20), C29 (0.70; 0.10; 0.20), C30 (0.80; 0.00; 0.20), C36 (0.50; 0.20; 0.30), C37 (0.60; 0.10; 0.30), C38 (0.70; 0.00; 0.30), C43 (0.40; 0.20; 0.40), and C44 (0.50; 0.10; 0.40). Two configurations, C7(0.60;0.40;0.00) and C9 (0.80;0.20;0.00), show a good performance for the highly insulated single family houses and the highly insulated office buildings.

d) Turin

Two configurations, C40 (0.10;0.50;0.40) and C46 (0.00;0.50;0.50), show a good performance for all cases studies with exception for the single family house with low insulation and low WWR and the apartment block with high insulation and low WWR. The single family houses with low insulation are better represented by C57 (0.00; 0.30; 0.70) while the apartment block with low WWR and high insulation is represented by C32 (0.10; 0.60; 0.30). In the selected configurations, the weighting coefficient related to solar irradiation is generally greater than 0.30.

e) Udine

For the single family houses the best TMY is C11 (1.00; 0.00; 0.00), except for the variant with low WWR which is best characterized by the configuration C33 (0.20; 0.50; 0.30). Both for the Apartment block and the Office building, the best TMY, for all building envelope variants, is C37 (0.60; 0.10; 0.30).

f) TMYs Correspondences between location and building typology

The single family house with low thermal insulation and low WWR variant have the same combinations C10 (0.90; 0.10; 0.00) and C11 (1.00; 0.00; 0.00) for Palermo and Ragusa.

The single family house with low thermal insulation presents as best TMY the same combination C11 (1.00; 0.00; 0.00) for Udine and Palermo.

As regards the case study Apartment Block with high thermal insulation and low WWR, Palermo and Agrigento present the same combinations of best TMY 10 (0.90; 0.10; 0.00) and 11 (1.00; 0.00; 0.00). In Table 107 is reported the general situation.

In the search of optimal configuration, for the hottest localities (Agrigento, Palermo, and Ragusa) the influence of dry-bulb temperature is always dominant. Also for the coldest locality (Udine) the influence of dry-bulb temperature is dominant. The only exception for this case study concerns the space cooling of single family house with large transparent surfaces and highly insulated envelopes; in this case, in the best TMY the weighting coefficient of solar irradiance increases.

Table 106 Monthly EP relative standard deviation. Optimum weighting coefficients for climate variables for cooling energy service

			TMY																																																														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
		T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.0	0.1	0.2	0.3	0.4	0.5	0.0	0.1	0.2	0.3	0.4	0.0	0.1	0.2	0.3	0.0	0.1	0.2	0.0	0.1	0.0
		I	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.5	0.4	0.3	0.2	0.1	0.0	0.4	0.3	0.2	0.1	0.0	0.3	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0
		RH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0
AG	SFH	I.W.							x	x	x	x	x								x	x	y																																													
		I.w.										y	y									y	x																																													
		NI.W.										y	y									y	x																																													
		NI.w.										y	y									y	x																																									y	y	y	y	y	y
	AB	I.W.							x	y	x	y	y								y																																														
		I.w.							x	x	x	x	x								x	y																																													
		NI.W.										y	y									y	x																																													
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		NI.sh.								y	y	x	x										y									y																																				
		NI.SH.										x	x										y																																													
RG	SFH	I.W.							x	x	x										y								y								y																																	
		I.w.																			x								y								y						x																									
		NI.W.																			x								y								y																																	
		NI.w.										x	x								x	x	x							x	x	x						x	x	x					x	x	y				y																	
	AB	I.W.																			x																y																																	
		I.w.																			x								y																																									
		NI.W.																			x								y																																									
		NI.w.																			x								y																																									
	OB	I.sh.							x	y	x																																																									
		I.SH.							x	y	y																																																									
		NI.sh.																			x								y								y						y																									
		NI.SH.																			x								y								y						y																									
TO	SFH	I.W.																															y								y	x						x																				
		I.w.																															y								y	x						x																				
		NI.W.																															y								y	x						x											x									
		NI.w.																																																										y	x									
	AB	I.W.																															y									x						x																				
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		I.SH.																															y								y	x						x																				
		NI.sh.																																y								x						x																				
		NI.SH.																																								x						x											y									
UD	SFH	I.W.											x										x									y																																				
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Table 107 Monthly EP relative standard deviation. Cooling energy service. Aggregation of optimal TMYs configuration for building typology and geographic location.

<table>
<tr><th></th><th></th><th>NI.W</th><th>NI.w</th><th>I.w</th><th>I.W</th></tr>
<tr><td rowspan="3">AG</td><td>SFH</td><td colspan="2" rowspan="3">C21(0.90;0.00;0.10)</td><td colspan="2"></td></tr>
<tr><td>AB</td><td colspan="2">C7(0.60;0.40;0.00), C9(0.80;0.20;0.00)</td></tr>
<tr><td>OB</td><td colspan="2"></td></tr>
<tr><td rowspan="3">PA</td><td>SFH</td><td colspan="2" rowspan="3">C10(0.90;0.10;0.00), C11 (1.00;0.00;0.00)</td><td></td><td>C8(0.70;0.30;0.00)
C9(0.80;0.20;0.00)
C10(0.90;0.10;0.00)
C11 (1.00;0.00;0.00)</td></tr>
<tr><td>AB</td><td colspan="2" rowspan="2">C8(0.70;0.30;0.00)</td></tr>
<tr><td>OB</td></tr>
<tr><td rowspan="3">RG</td><td>SFH</td><td rowspan="3">C19(0.70;0.20;0.10)</td><td>C10(0.90;0.10;0.00)
C11 (1.00;0.00;0.00)
C20(0.80;0.10;0.10)
C21(0.90;0.00;0.10)</td><td></td><td>C7(0.60;0.40;0.00)
C8(0.70;0.30;0.00)
C9(0.80;0.20;0.00)
C19(0.70;0.20;0.10)</td></tr>
<tr><td>OB</td><td></td><td></td><td>C7(0.60;0.40;0.00)</td></tr>
<tr><td>AB</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">TO</td><td>SFH</td><td></td><td>C57(0.00;0.30;0.70)</td><td></td><td></td></tr>
<tr><td>AB</td><td></td><td></td><td>C32(0.10;0.60;0.30)</td><td></td></tr>
<tr><td>OB</td><td colspan="4">C40 (0.10;0.50;0.40), C46(0.00;0.50;0.50)</td></tr>
<tr><td rowspan="3">UD</td><td>SFH</td><td colspan="3">C11(1.00;0.00;0.00)</td><td>C33(0.20;0.50;0.30)</td></tr>
<tr><td>AB</td><td colspan="4" rowspan="2">C37(0.60;0.10;0.30)</td></tr>
<tr><td>OB</td></tr>
</table>

4.7.2.3 Humidification energy service

a) Agrigento

For the single family house, the optimal TMYs configurations vary according to the characteristics of the building envelope. In particular, the best configuration are: C49 (0.30;0.20;0.50) for highly insulated single family house with high WWR, C34 (0.30;0.40;0.30) for highly insulated single family house with low WWR and for poorly insulated single family house with high WWR and C33(0.20;0.50;0.30) for poorly insulated single family house with low WWR.

For the Apartment blocks and the office buildings the best TMY is C56 (0.40;0.00;0.60).

Two configurations, C41 (0.20;0.40;0.40) and C42 (0.30;0.30;0.40) show a good performance respectively for the poorly insulated apartment block and with low WWR and the poorly insulated office building with windows with low performance blinds. Instead, for the building variant with low insulated single family house and with low WWR the best combination is represented by C56 (0.40;0.00;0.60).

For Agrigento, the TMY that best approximates long term EP_{HU} does not consider air temperature as a selection parameter; but only solar irradiance and water vapour pressure in equal measure.

b) Palermo

For the single family houses the best TMYs are C4 (0.30;0.70;0.00), C15 (0.30;0.60;0.10), and C25 (0.30;0.50;0.20) with exception for the highly insulated single family houses with low WWR for which the best TMY is C29 (0.70;0.10;0.20).

C29 (0.70;0.10;0.20), C38 (0.70;0.00;0.30), and C46 (0.00;0.50;0.50) represent the best TMYs configuration for the poorly insulated apartment blocks and the office buildings. Differently, for the highly insulated apartment blocks with high WWR and the highly insulated office building with windows with low performance blinds the best configurations are C4 (0.30;0.70;0.00), C15 (0.30;0.60;0.10), and C25 (0.30;0.50;0.20).

C5 (0.40;0.60;0.00) and C18 (0.60;0.30;0.10) represent the best configurations for the poorly insulated apartment block with low WWR.

C32 (0.10;0.60;0.30) is the best TMY for the highly insulated office building with windows with high shading performance blinds.

c) Ragusa

C61 (0.00;0.20;0.80) show good performance for all variant of the single family house with exception for the highly insulated building with high WWR which is best represented by the configurations C51 (0.50;0.00;0.50), and C56 (0.40;0.00;0.60). It must be noted that both TMYs are composed by the same months in the winter season. As regard the highly insulated apartment blocks, the combination C17 (0.50; 0.40; 0.10) provides a good representativeness while the combination C18 (0.60; 0.30; 0.10) represents the best TMY for the poorly insulated apartment blocks.

C19 (0.70;0.20;0.10) is the best TMY for the poorly insulated office building while the highly insulated office building are well represented by the configuration C51 (0.50;0.00;0.50), and C56 (0.40;0.00;0.60).

d) Turin

The single family houses with low WWR are represented by the combination C32 (0.10;0.60;0.30). The other variants with high WWR, highly and poorly insulated, are respectively well represented by the combination C9 (0.80;0.20;0.00), and C60 (0.30;0.00;0.70).

C42 (0.30;0.30;0.40) represents the best combination for the poorly insulated apartment blocks and office buildings. The remaining case studies, the highly insulated apartment block with low and high WWR are well represented respectively by C32 (0.10;0.60;0.30) and C60 (0.30;0.00;0.70).

Concerning the highly insulated office building, it is well represented by C60 (0.30;0.00;0.70) for the variant with windows with low shading performance blinds and C59 (0.20;0.10;0.70) for the case with windows with highly shading performance blinds.

e) Udine

For the single family house, the best TMY configuration is C60 (0.30;0.00;0.70). For the other case study with low WWR are C5 (0.40; 0.60; 0.00) for the highly insulated single family house and C37 (0.60;0.10;0.30) for the poorly insulated single family houses.

As regard the apartment block and the office building, the best TMY is the C66 (0.00;0.00;1.00) with the exception for the building with highly insulated building envelope which is well characterized by the combination C36 (0.50;0.20;0.30).

Table 108 Monthly EP relative standard deviation. Optimum weighting coefficients for climate variables for humidification energy service

			TMY																																																															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
		T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.0	0.1	0.2	0.3	0.4	0.5	0.0	0.1	0.2	0.3	0.4	0.0	0.1	0.2	0.3	0.0	0.1	0.2	0.0	0.1	0.0
		I	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.5	0.4	0.3	0.2	0.1	0.0	0.4	0.3	0.2	0.1	0.0	0.3	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0
		RH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0
AG	SFH	I.W.																																															x	y	y															
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PA	SFH	I.W.				x											x										x				y																						y															
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As regards the energy need for humidification the minimum values of $\iota_{\sigma EP_{HU}}$ it varies considerably based on the geographic location and typology of building.

Table 109 Monthly EP relative standard deviation. Humidification energy service. Aggregation of optimal TMYs configuration for building typology and geographic location.

<table>
<tr><th></th><th></th><th>NI.w</th><th>NI.W</th><th>I.W</th><th>I.w</th></tr>
<tr><td rowspan="3">AG</td><td>SFH</td><td>C3(0.20;0.80;0.00)</td><td>C34(0.30;0.40;0.30)</td><td>C49(0.30;0.20;0.50)</td><td>C34(0.30;0.40;0.30)</td></tr>
<tr><td>AB</td><td>C41(0.20;0.40;0.40)</td><td rowspan="2">C49(0.30;0.20;0.50)</td><td rowspan="2" colspan="2">C56(0.40;0.00;0.60)</td></tr>
<tr><td>OB</td><td>C42(0.30;0.30;0.40)</td></tr>
<tr><td rowspan="4">PA</td><td>SFH</td><td colspan="2"></td><td rowspan="4">C4(0.30;0.70;0.00),
C15(0.30;0.60;0.10),
C25(0.30;0.50;0.20)</td><td>C29(0.70;0.10;0.20)</td></tr>
<tr><td rowspan="2">AB</td><td rowspan="3" colspan="2">C29(0.70;0.10;0.20) C38(0.70;0.00;0.30)
C46(0.00;0.50;0.50)</td><td>C5(0.40;0.60;0.00)</td></tr>
<tr><td>C18(0.60;0.30;0.10)</td></tr>
<tr><td>OB</td><td>C32 (0.10;0.60;0.30)</td></tr>
<tr><td rowspan="3">RG</td><td>SFH</td><td colspan="2">61(0.00;0.20;0.80)</td><td>C51(0.50;0.00;0.50)
C56(0.40;0.00;0.60)</td><td>C61(0.00;0.20;0.80)</td></tr>
<tr><td>AB</td><td colspan="2">C8(0.70;0.30;0.00)</td><td colspan="2">C7(0.60;0.40;0.00)</td></tr>
<tr><td>OB</td><td colspan="2">C19(0.70;0.20;0.10)</td><td colspan="2">C51(0.50;0.00;0.50), C56(0.40;0.00;0.60)</td></tr>
<tr><td rowspan="3">TO</td><td>OB</td><td rowspan="2" colspan="2">42(0.30;0.30;0.40)</td><td rowspan="2">C60(0.30;0.00;0.70)</td><td>C59(0.20;0.10;0.70)</td></tr>
<tr><td>AB</td><td rowspan="2">C32(0.10;0.60;0.30)</td></tr>
<tr><td>SFH</td><td>C32 (0.10;0.60;0.30)</td><td rowspan="2">C60(0.30;0.00;0.70)</td><td>C9(0.80;0.20;0.00)</td></tr>
<tr><td rowspan="3">UD</td><td>SFH</td><td>C37(0.60;0.10;0.30)</td><td></td><td>C5(0.40;0.60;0.00)</td></tr>
<tr><td>AB</td><td rowspan="2" colspan="2">C66(0.00;0.00;1.00)</td><td colspan="2"></td></tr>
<tr><td>OB</td><td colspan="2">C36(0.50;0.20;0.30)</td></tr>
</table>

4.7.2.4 Dehumidification energy service

a) Agrigento

Four configurations, C44 (0.50;0.10;0.40), C45 (0.60;0.00;0.40), C50 (0.40;0.10;0.50), and C51 (0.50;0.00;0.50), show a good performance for all cases study with exception of the poorly insulated Apartment blocks which are best represented by the combination C40 (0.10;0.50;0.40). In all configuration the relative humidity weighting coefficient worth at least 0.40.

b) Palermo

Two configurations, C59 (0.20;0.10;0.70), and C60 (0.30;0.00;0.70) show a good performance for all cases study. In the selected TMYs the priority role of the relative humidity is evident. In all TMY configurations the relative humidity weighting coefficient worth at least 0.70. The selected TMYs are very similar to each other.

c) Ragusa

C51 (0.50;0.00;0.50) shows a good performance for all single family houses with exception for the insulated single family house with low WWR which is best represented by the TMY combinations C56 (0.40;0.00;0.60), C60 (0.30;0.00;0.70), and C63 (0.20;0.00;0.80).

As regard the apartment block the best TMYs are C63 (0.20;0.00;0.80) for the poorly insulated apartment block, while the highly insulated apartment block with low WWR and highly insulated apartment block with high WWR are better represented respectively by the TMYs C50 (0.40; 0.10; 0.50) and C61 (0.00; 0.20;

0.80). For the poorly insulated office building, the best TMY configurations are C20 (0.80;0.10;0.10), C28 (0.60;0.20;0.20), C29 (0.70;0.10;0.20), C36 (0.50;0.20;0.30), C37 (0.60;0.10;0.30), C38 (0.70;0.00;0.30), C43 (0.40;0.20;0.40), C44 (0.50;0.10;0.40). The highly insulated office building with blinds and shading devices (High and low reduction factor) are better represented respectively by the TMYs C45 (0.60;0.00;0.40), and C50 (0.40;0.10;0.50).

For Ragusa, the TMYs that best approximates long term EP_{HU} does not solar irradiance as a selection parameter; but only air temperature and water vapour pressure.

d) Turin

For the single family house, the optimal TMYs configurations vary according to the characteristics of the building envelope. In particular, the best configuration are: C30 (0.80;0.00;0.20) for highly insulated single family house with high WWR, C42 (0.30;0.30;0.40) for highly insulated single family house with low WWR, C32 (0.10;0.60;0.30) for poorly insulated single family house with high WWR and C53(0.10;0.30;0.60) for poorly insulated single family house with low WWR.

Also for the apartment block, the optimal TMYs configurations vary according to the characteristics of the building envelope. In particular, the best configuration are: C56 (0.40;0.00;0.60) for highly insulated apartment block with high WWR, C43 (0.40;0.20;0.40) for highly insulated apartment block with low WWR, C30 (0.80;0.00;0.20) for poorly insulated apartment block with high WWR and C39 (0.00;0.60;0.40) for poorly insulated apartment block with low WWR.

The office building typology has as a best TMY combination C42 (0.30; 0.30; 0.40) with the exception for the variant with high thermal insulation and windows with high performance blinds which is best represented by the combination C56 (0.40; 0.00; 0.60).

e) Udine

The combination C38 (0.70; 0.00; 0.30) is the most representative for the poorly insulated single family house. Instead, the highly insulated single family houses with high and low WWR are better represented respectively by the TMYs C29 (0.70;0.10;0.20), and C42 (0.30;0.30;0.40). As regards the apartment blocks, the minimum value of the relative standard deviation ($\iota_{\sigma EP,DHU}$) corresponds to C29 (0.70;0.10;0.20). The highly insulated building variant with low WWR is best represented by the TMY configuration C30 (0.80;0.00;0.20).

For the office buildings, in all building envelope variants, the best TMY is C65 (0.10;0.00;0.90) with the exception for the poorly insulated building with high WWR. For the poorly insulated building with windows with high performance blinds, the combination C48 (0.20;0.30;0.50) is most representative. This combination is also the best for all poorly insulated envelope variant.

Table 110 Monthly EP relative standard deviation. Optimum weighting coefficients for climate variables for Dehumidification energy service

			TMY																																																															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
		T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.0	0.1	0.2	0.3	0.4	0.5	0.0	0.1	0.2	0.3	0.4	0.0	0.1	0.2	0.3	0.0	0.1	0.2	0.0	0.1	0.0
		I	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.5	0.4	0.3	0.2	0.1	0.0	0.4	0.3	0.2	0.1	0.0	0.3	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0
		RH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0
AG	SFH	I.W.																																									x	x				y	x	x															
		I.w.																																									x	x				y	x	x															
		NI.W.																																									x	x				y	x	x															
		NI.w.																																									x	x				y	x	x											y	y			
	AB	I.W.																																					y				x	x					x	x															
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	OB	I.sh.																																					y				x	x					x	x															
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Table 111 Monthly EP relative standard deviation. Dehumidification energy service. Aggregation of optimal TMYs configuration for building typology and geographic location.

		I.W	NI.W	NI.w	I.w
PA	**SFH**	C59(0.20;0.10;0.70), C60(0.30;0.00;0.70)			
	AB				
	OB				
AG	**AB**		C40(0.10;0.50;0.40)		
	SFH	C44(0.50;0.10;0.40), C45(0.60;0.00;0.40), C50(0.40;0.10;0.50), C51 (0.50;0.00;0.50)			
	OB				
RG	**OB**	C50(0.40;0.10;0.50)	C45(0.60;0.00;0.40)	C20(0.80;0.10;0.10), C28(0.60;0.20;0.20) C29(0.70;0.10;0.20), C36(0.50;0.20;0.30)	
	AB	C61 (0.00;0.20;0.80)	C63(0.20;0.00;0.80)		C50(0.40;0.10;0.50)
	SFH	C51(0.50;0.00;0.50)	C51(0.50;0.00;0.50)		C56(0.40;0.00;0.60)
TO	**SFH**	C30(0.80;0.00;0.20)	C32(0.10;0.60;0.30)	C53(0.10;0.30;0.60)	
	OB	C42(0.30;0.30;0.40)			
	AB	C56(0.40;0.00;0.60)	C30(0.80;0.00;0.20)	C39 (0.00;0.60;0.40)	C43(0.40;0.20;0.40)
UD	**SFH**	C29(0.70;0.10;0.20)	C38(0.70;0.00;0.30)		C42(0.30;0.30;0.40)
	AB		C29(0.70;0.10;0.20)		C30(0.80;0.00;0.20)
	OB	C65(0.10;0.00;0.90)	C48 (0.20;0.30;0.50)		C65(0.10;0.00;0.90)

4.7.3 Ternary plot representation (Monthly EP relative standard deviation)

4.7.3.1 Single family house

Table 112 Agrigento. Single Family House. Best TMYs for energy service

CASE STUDY	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
SFH.I.W	59	10 11	49	45	[0.2;0.1;0.7]	[0.9;0.1;0] [1.0;0.0;0]	[0.3;0.2;0.5]	[0.6;0.0;0.4]
SFH.I.w	34	21	34	50 51	[0.3;0.4;0.3]	[0.9;0;0.1]	[0.3;0.4;0.3]	[0.4;0.1;0.5] [0.5;0.0;0.5]
SFH.I.w	59	21	34	50 51	[0.2;0.1;0.7]	[0.9;0;0.1]	[0.3;0.4;0.3]	[0.4;0.1;0.5] [0.5;0.0;0.5]
SFH.NI.w	62	21	33	50 51	[0.1;0.1;0.8]	[0.9;0;0.1]	[0.2;0.5;0.3]	[0.4;0.1;0.5] [0.5;0.0;0.5]

Table 113 Agrigento. Single Family House. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

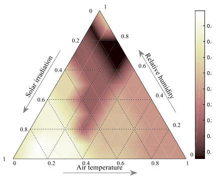
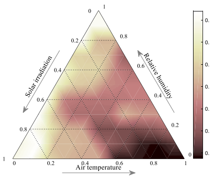
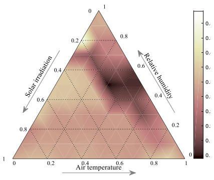
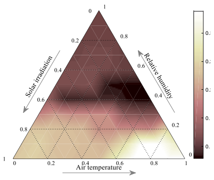
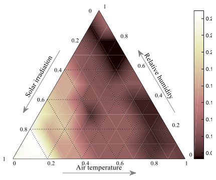
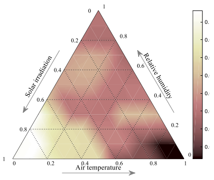
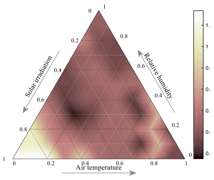
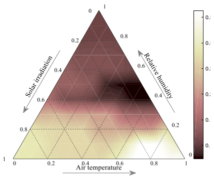
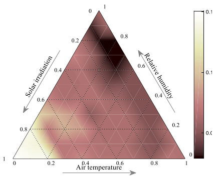
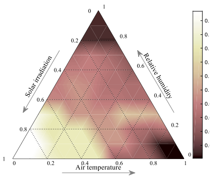
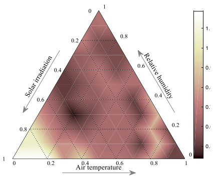
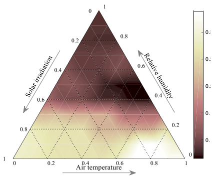
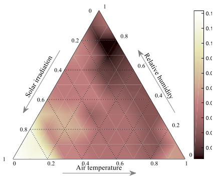
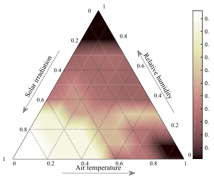
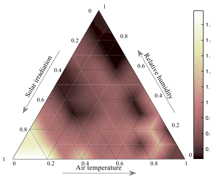
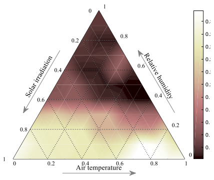
Case study	H	C	HUM	DHUM
SFH.I.W				
SFH.I.w				
SFH.NI.W				
SFH.NI.w				

Table 114 Agrigento. Single Family House. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
SFH.I.W	55	60	[0.3,0.1,0.6]	[0.3,0,0.7]
SFH.I.w	34	60	[0.3,0.4,0.3]	[0.3,0,0.7]
SFH.NI.W	59	62 63	[0.2,0.1,0.7]	[0.1,0.1,0.8] [0.2,0,0.8]
SFH.NI.w	62 63	62 63	[0.1,0.1,0.8] [0.2,0,0.8]	[0.1,0.1,0.8] [0.2,0,0.8]

Table 115 Agrigento. Single Family House. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

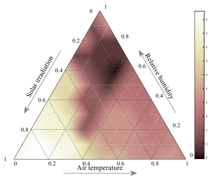
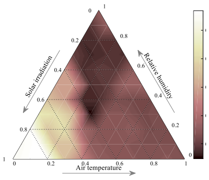
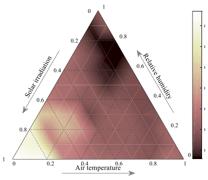
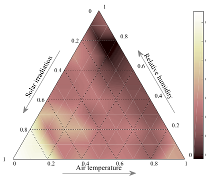
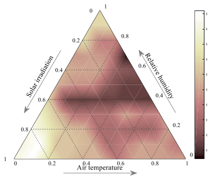
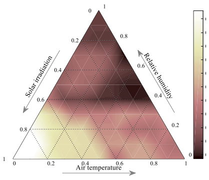
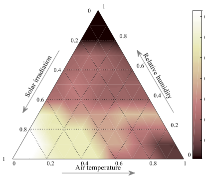
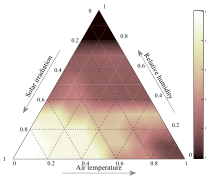
Case study	SFH.I.W	SFH.I.w	SFH.NI.W	SFH.NI.w
H+HUM				
C+DEHUM				

Table 116 Ragusa. Single Family House. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
SFH.I.W	17	7	51	51	[0.5,0.4,0.1]	[0.6,0.4,0.0]	[0.5,0.0,0.5]	[0.5,0.0,0.5]
SFH.I.w	10 11 21	42	61	63	[0.9,0.1,0.0] [1.0,0.0,0.0] [0.9,0.0,0.1]	[0.3,0.3,0.4]	[0.0,0.2,0.8]	[0.2,0.0,0.8]
SFH.NI.W	9	19	61	51	[0.8,0.2,0.0]	[0.7,0.2,0.1]	[0.0,0.2,0.8]	[0.5,0.0,0.5]
SFH.NI.w	9	19	61	51	[0.8,0.2,0.0]	[0.7,0.2,0.1]	[0.0,0.2,0.8]	[0.5,0.0,0.5]

Table 117 Ragusa. Single Family House. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

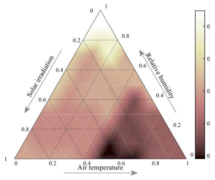
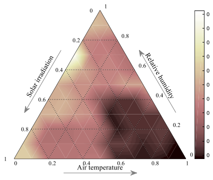
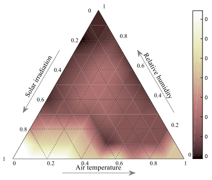
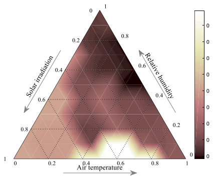
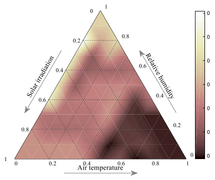
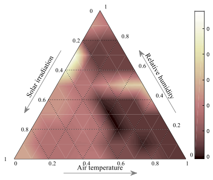
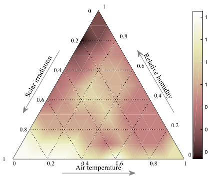
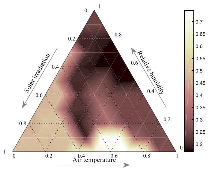
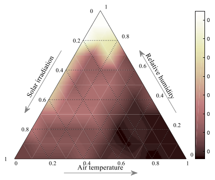
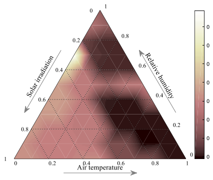
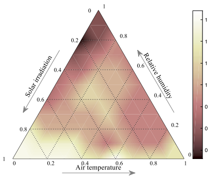
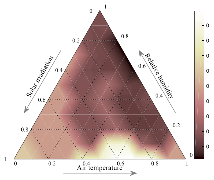
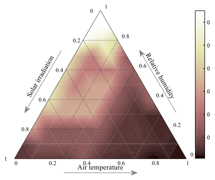
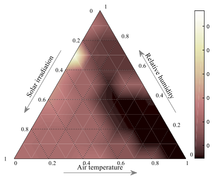
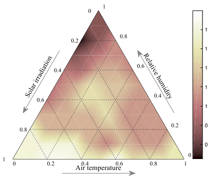
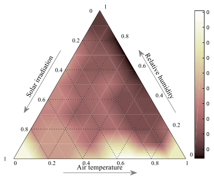
Case study	H	C	HUM	DHUM
SFH.I.W				
SFH.I.w				
SFH.NI.W				
SFH.NI.w				

Table 118 Ragusa. Single Family House. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
SFH.I.W	19	19	[0.7,0.2,0.1]	[0.7,0.2,0.1]
SFH.I.w	17	63	[0.5,0.4,0.1]	[0.2,0.0,0.8]
SFH.NI.W	18	19	[0.6,0.3,0.1]	[0.7,0.2,0.1]
SFH.NI.w	9	45	[0.8,0.2,0.0]	[0.6,0.0,0.4]

Table 119 Ragusa. Single Family House. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

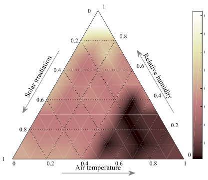
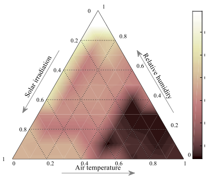
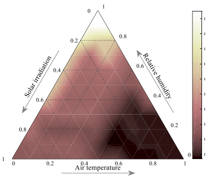
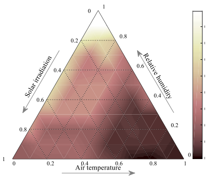
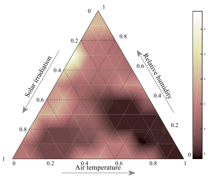
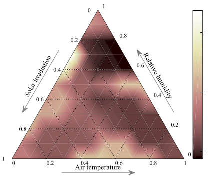
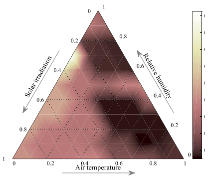
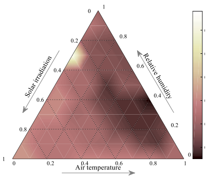
Case study	SFH.I.W	SFH.I.w	SFH.NI.W	SFH.NI.w
H+HUM				
C+DEHUM				

Table 120 Palermo. Single Family House. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
SFH.I.W	54	9	4 15 25	59	[0.2,0.2,0.6]	[0.8,0.2,0]	[0.3,0.7,0] [0.3,0.6,0.1] [0.3,0.5,0.2]	[0.2,0.1,0.7]
SFH.I.w	17	10 11	29	60	[0.5,0.4,0.1]	[0.9,0.1,0] [1,0,0]	[0.7,0.1,0.2]	[0.3,0,0.7]
SFH.NI.W	6	10 11	4 15 25	60	[0.5,0.5,0]	[0.9,0.1,0] [1,0,0]	[0.3,0.7,0] [0.3,0.6,0.1] [0.3,0.5,0.2]	[0.3,0,0.7]
SFH.NI.w	6	10 11	4 15 25	59	[0.5,0.5,0]	[0.9,0.1,0] [1,0,0]	[0.3,0.7,0] [0.3,0.6,0.1] [0.3,0.5,0.2]	[0.2,0.1,0.7]

Table 121 Palermo. Single Family House. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

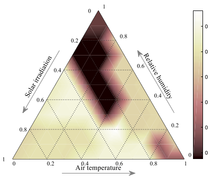
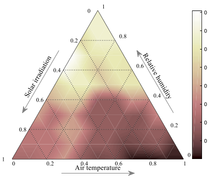
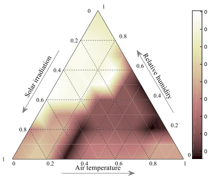
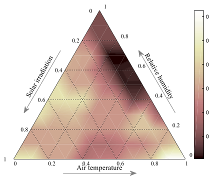
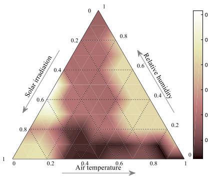
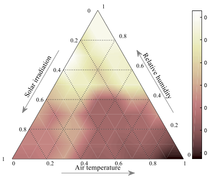
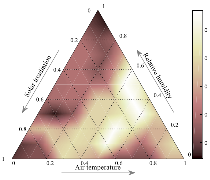
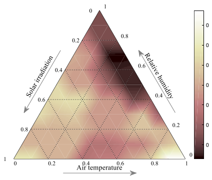
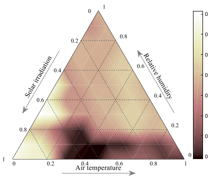
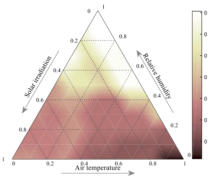
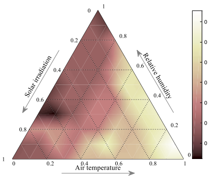
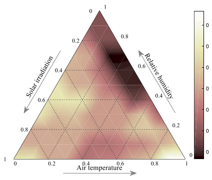
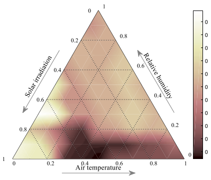
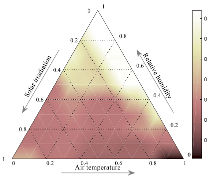
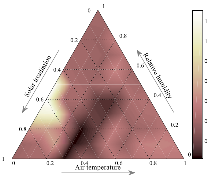
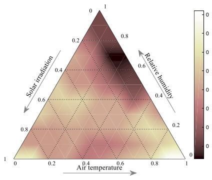
Case study	H	C	HUM	DHUM
SFH.I.W				
SFH.I.w				
SFH.NI.W				
SFH.NI.w				

Table 122 Palermo . Single Family House. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
SFH.I.W	29	9	[0.7,0.1,0.2]	[0.8,0.2,0]
SFH.I.w	6	30	[0.5,0.5,0]	[0.8,0,0.2]
SFH.NI.W	4	30	[0.3,0.7,0]	[0.8,0,0.2]
	15	25	[0.3,0.6,0.1]	[0.3,0.5,0.2]
SFH.NI.w	6	20	[0.5,0.5,0]	[0.8,0.1,0.1]

Table 123 Palermo. Single Family House. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

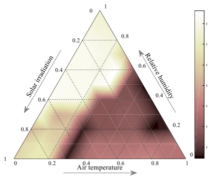
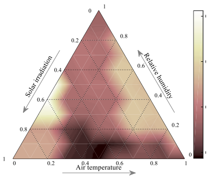
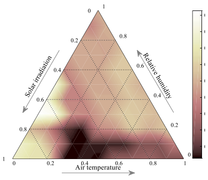
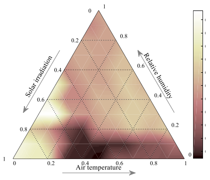
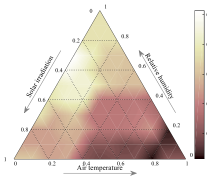
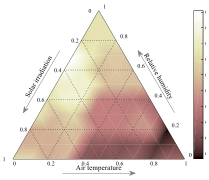
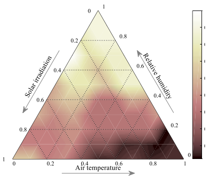
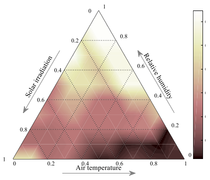
Case study	SFH.I.W	SFH.I.w	SFH.NI.W	SFH.NI.w
H+HUM				
C+DEHUM				

Table 124 Turin. Single Family House. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
SFH.I.W	30	40 46	9	30	[0.8,0,0.2]	[0.1,0.5,0.4] [0.0,0.5,0.5]	[0.8,0.2,0.0]	[0.8,0.0,0.2]
SFH.I.w	38	40 46	32	42	[0.7,0,0.3]	[0.1,0.5,0.4] [0.0,0.5,0.5]	[0.1,0.6,0.3]	[0.3,0.3,0.4]
SFH.NI.W	9	57	60	32	[0.8,0.2,0]	[0.0,0.3,0.7]	[0.3,0.0,0.7]	[0.1,0.6,0.3]
SFH.NI.w	9	57	32	53	[0.8,0.2,0]	[0.0,0.3,0.7]	[0.1,0.6,0.3]	[0.1,0.3,0.6]

Table 125 Turin. Single Family House. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

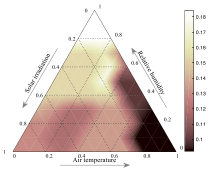
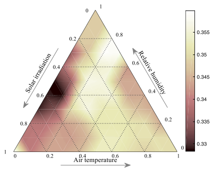
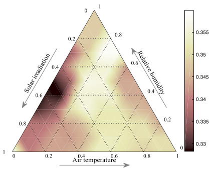
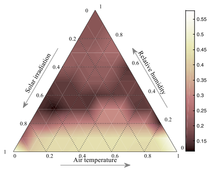
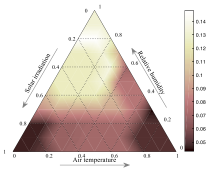
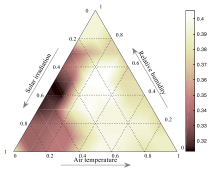
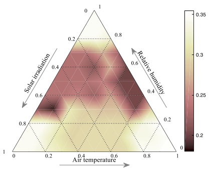
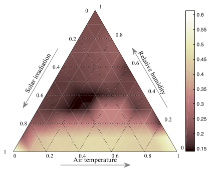
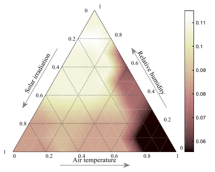
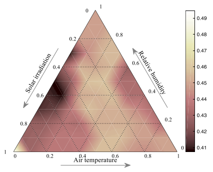
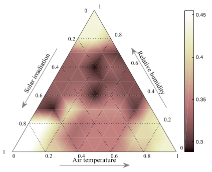
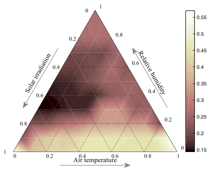
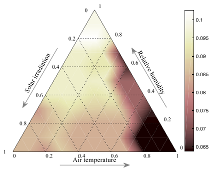
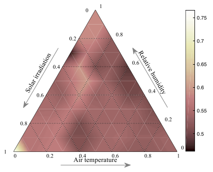
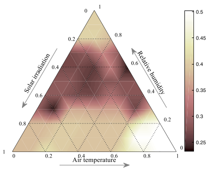
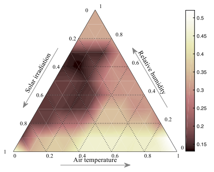
Case study	H	C	HUM	DHUM
SFH.I.W				
SFH.I.w				
SFH.NI.W				
SFH.NI.w				

Table 126 Turin. Single Family House. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [T,I,RH]	C+DHUM [T,I,RH]
SFH.I.W	9	31	[0.8,0.2,0.0]	[0.0,0.7,0.3]
SFH.I.w	38	31	[0.7,0.0,0.3]	[0.0,0.7,0.3]
SFH.NI.W	19	40	[0.7,0.2,0.1]	[0.1,0.5,0.4]
	20	46	[0.8,0.1,0.1]	[0.0,0.5,0.5]
SFH.NI.w	56	57	[0.4,0.0,0.6]	[0.0,0.3,0.7]

Table 127 Turin. Single Family House. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

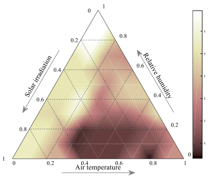
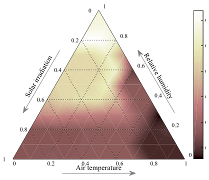
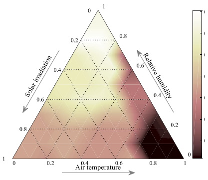
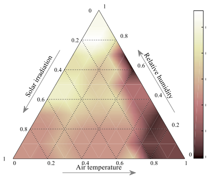
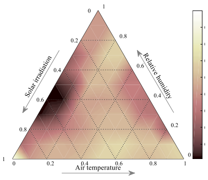
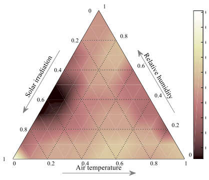
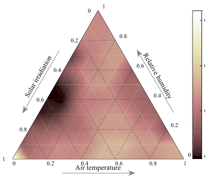
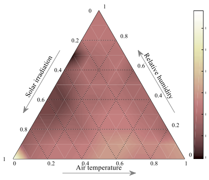
Case study	SFH.I.W	SFH.I.w	SFH.NI.W	SFH.NI.w
H+HUM				
C+DEHUM				

Table 128 Udine. Single Family House. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
SFH.I.W	43	21	60	29	[0.4,0.2,0.4]	[0.9,0.0,0.1]	[0.3,0.0,0.7]	[0.7,0.1,0.2]
SFH.I.w	27	33	5	42	[0.5,0.3,0.2]	[0.2,0.5,0.3]	[0.4,0.6,0.0]	[0.3,0.3,0.4]
SFH.NI.W	11	11	60	37	[1.0,0.0,0.0]	[1.0,0.0,0.0]	[0.3,0.0,0.7]	[0.6,0.1,0.3]
SFH.NI.w	21	11	37	37	[0.9,0.0,0.1]	[1.0,0.0,0.0]	[0.6,0.1,0.3]	[0.6,0.1,0.3]

Table 129 Udine. Single Family House. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

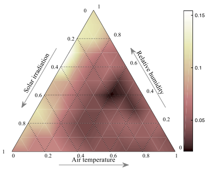
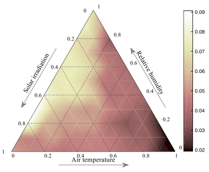
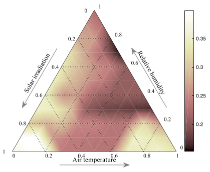
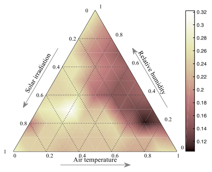
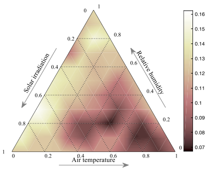
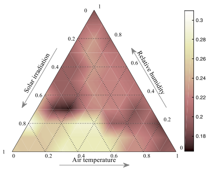
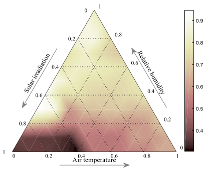
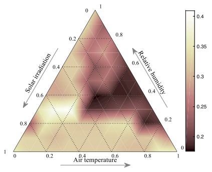
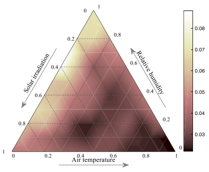
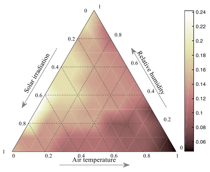
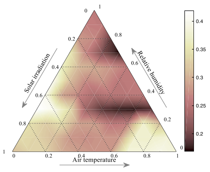
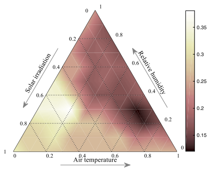
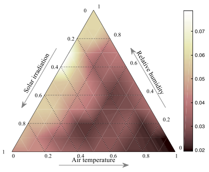
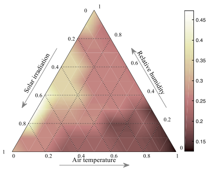
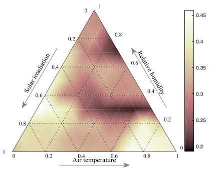
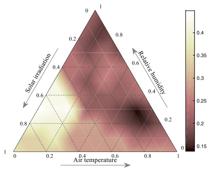
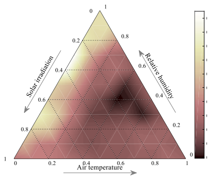
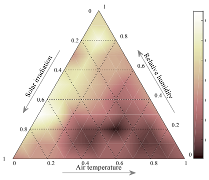
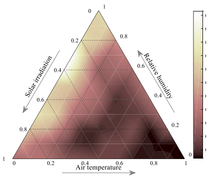
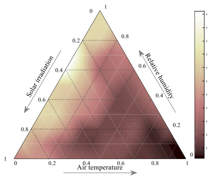
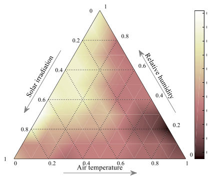
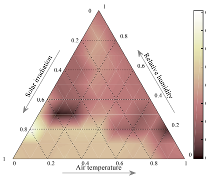
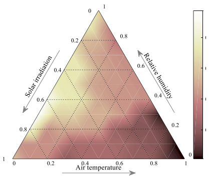
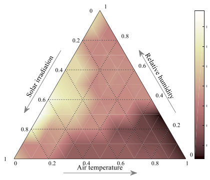
Case study	H	C	HUM	DHUM
SFH.I.W				
SFH.I.w				
SFH.NI. W				
SFH.NI. w				

Table 130 Udine. Single Family House. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [T,I,RH]	C+DHUM [T,I,RH]
SFH.I.W	43	30	[0.4,0.2,0.4]	[0.8,0.0,0.2]
SFH.I.w	27	32	[0.5,0.3,0.2]	[0.1,0.6,0.3]
SFH.NI.W	11	11	[1.0,0.0,0.0]	[1.0,0.0,0.0]
SFH.NI.w	21	38	[0.9,0.0,0.1]	[0.7,0.0,0.3]

Table 131 Udine. Single Family House. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

Case study	SFH.I.W	SFH.I.w	SFH.NI.W	SFH.NI.w
H+HUM				
C+DEHU M				

4.7.3.2 Apartment block

Table 132 Agrigento. Apartment block. Best TMYs for energy service

CASE STUDY	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
AB.I.W	1 2 3	7	56	45	[0.0,1.0,0.0] [0.1,0.9,0.0] [0.2,0.8,0.0]	[0.6,0.4,0]	[0.4,0.0,0.6]	[0.6,0.0,0.4]
AB.I.w	31	7	56	45	[0.0,0.7,0.3]	[0.6,0.4,0]	[0.4,0.0,0.6]	[0.6,0.0,0.4]
AB.NI.W	60	21	49	40	[0.3,0.0,0.7]	[0.9,0,0.1]	[0.3,0.2,0.5]	[0.1,0.5,0.4]
AB.NI.w	55	21	42	40	[0.3,0.1,0.6]	[0.9,0,0.1]	[0.3,0.3,0.4]	[0.1,0.5,0.4]

Table 133 Agrigento. Apartment block. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

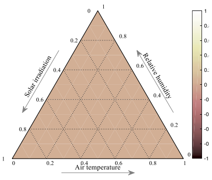
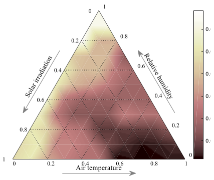
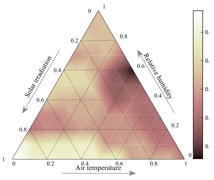
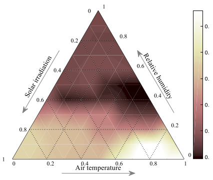
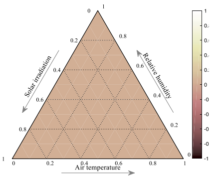
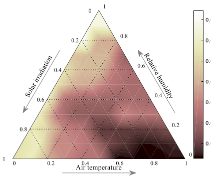
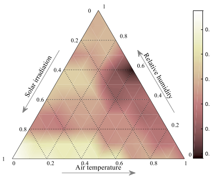
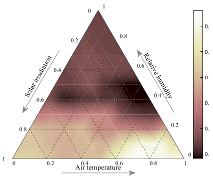
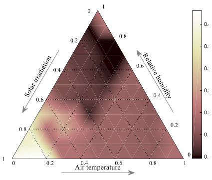
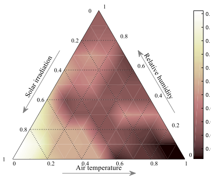
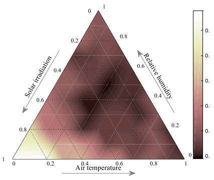
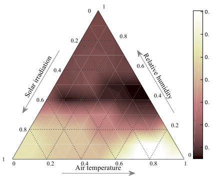
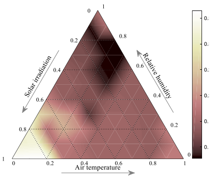
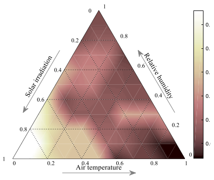
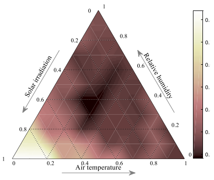
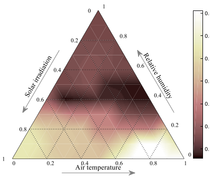
Case study	H	C	HUM	DHUM
AB.I.W				
AB.I.w				
AB.NI. W				
AB.NI. w				

Table 134 Agrigento. Apartment block. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
AB.I.W	56	43	[0.4,0.0,0.6]	[0.4,0.2,0.4]
AB.I.w	56	60	[0.4,0.0,0.6]	[0.3,0.0,0.7]
AB.NI.W	34	60	[0.3,0.4,0.3]	[0.3,0.0,0.7]
AB.NI.w	55	60	[0.3,0.1,0.6]	[0.3,0.0,0.7]

Table 135 Agrigento. Apartment block. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

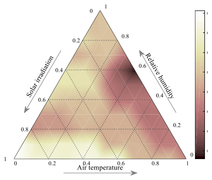
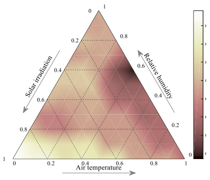
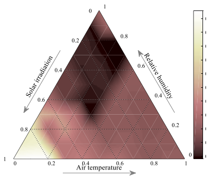
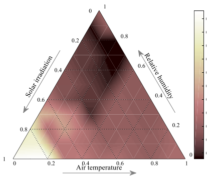
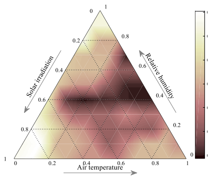
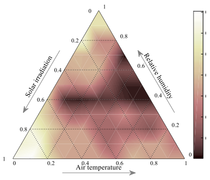
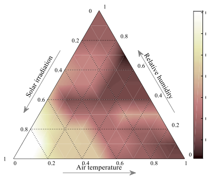
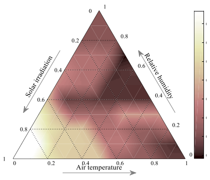
Case study	AB.I.W	AB.I.w	AB.NI.W	AB.NI.w
H+HUM				
C+DEHUM				

Table 136 Palermo. Apartment block. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
AB.I.W	-	9	4 15 25	59	-	[0.8,0.2,0.0]	[0.3,0.7,0.0] [0.3,0.6,0.1] [0.3,0.5,0.2]	[0.2,0.1,0.7]
AB.I.w	-	9	5	59	-	[0.8,0.2,0.0]	[0.4,0.6,0.0]	[0.2,0.1,0.7]
AB.NI.W	5	10 11	29	59	[0.4,0.6,0.0]	[0.9,0.1,0.0] [1.0,0.0,0.0]	[0.7,0.1,0.2]	[0.2,0.1,0.7]
AB.NI.w	16	10 11	38 45	59	[0.4,0.5,0.1]	[0.9,0.1,0.0] [1.0,0.0,0.0]	[0.7,0.0,0.3] [0.6,0.0,0.4]	[0.2,0.1,0.7]

Table 137 Palermo. Apartment block. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

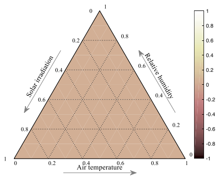
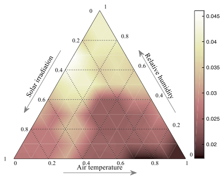
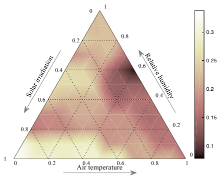
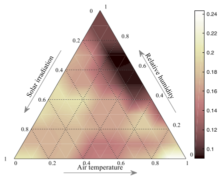
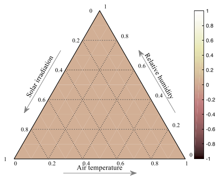
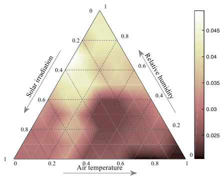
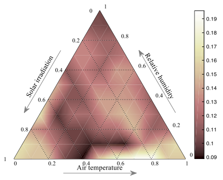
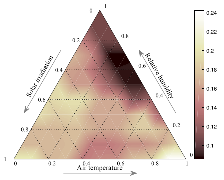
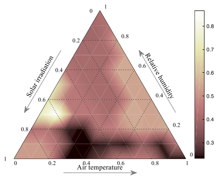
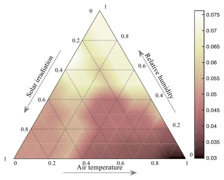
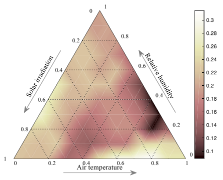
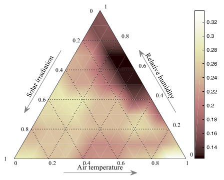
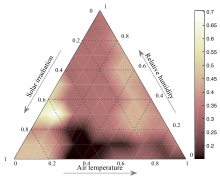
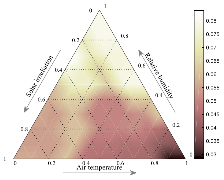
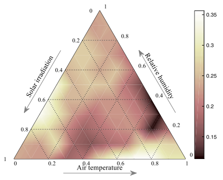
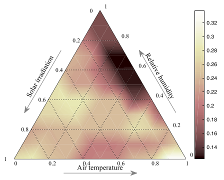
Case study	H	C	HUM	DHUM
AB.I.W				
AB.I.w				
AB.NI.W				
AB.NI.w				

Table 138 Palermo. Apartment block. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
AB.I.W	4 15 25	9	[0.3,0.7,0.0] [0.3,0.6,0.1] [0.3,0.5,0.2]	[0.8,0.2,0.0]
AB.I.w	5	9	[0.4,0.6,0.0]	[0.8,0.2,0.0]
AB.NI.W	16	30	[0.4,0.5,0.1]	[0.8,0.0,0.2]
AB.NI.w	16	30	[0.4,0.5,0.1]	[0.8,0.0,0.2]

Table 139 Palermo. Apartment block. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

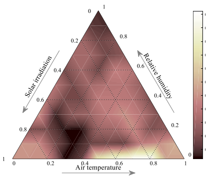
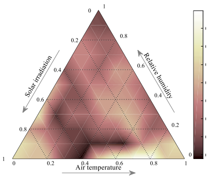
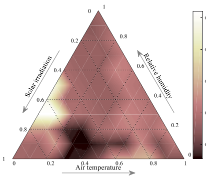
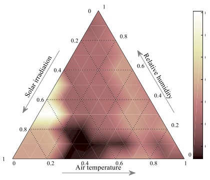
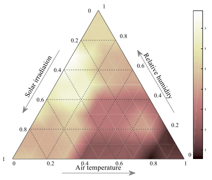
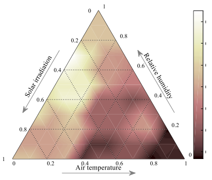
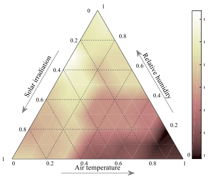
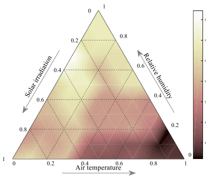
Case study	AB.I.W	AB.I.w	AB.NI.W	AB.NI.w
H+HUM				
C+DEHUM				

Table 140 Ragusa. Apartment block. Best TMYs for energy service

CASE STUDY	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
AB.I.W	17	19	17	61	[0.5,0.4,0.1]	[0.7,0.2,0.1]	[0.5,0.4,0.1]	[0.0,0.2,0.8]
AB.I.w	8	19	17	50	[0.7,0.3,0.0]	[0.7,0.2,0.1]	[0.5,0.4,0.1]	[0.4,0.1,0.5]
AB.NI.W	30	19	18	63	[0.8,0.0,0.2]	[0.7,0.2,0.1]	[0.6,0.3,0.1]	[0.2,0.0,0.8]
AB.NI.w	20 29 37 38	19	18	45	[0.8,0.1,0.1] [0.7,0.1,0.2] [0.6,0.1,0.3] [0.7,0.0,0.3]	[0.7,0.2,0.1]	[0.6,0.3,0.1]	[0.6,0.0,0.4]

Table 141 Ragusa. Apartment block. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

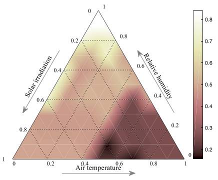
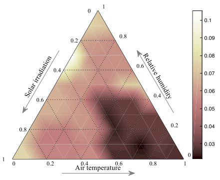
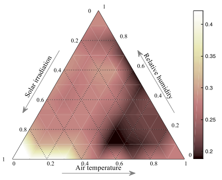
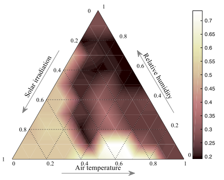
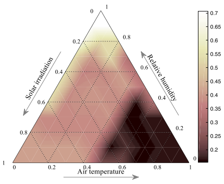
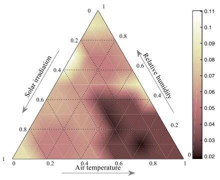
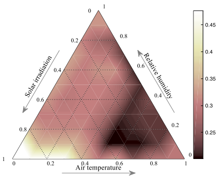
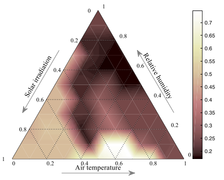
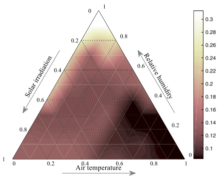
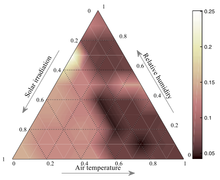
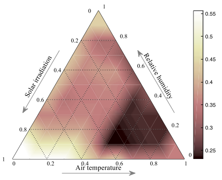
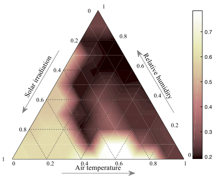
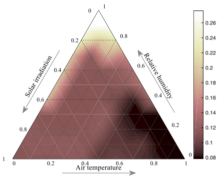
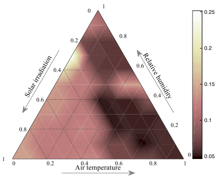
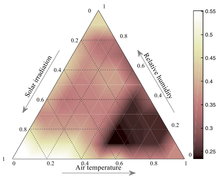
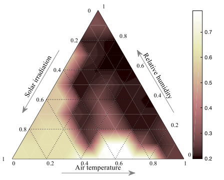
Case study	H	C	HUM	DHUM
AB.I.W				
AB.I.w				
AB.NI. W				
AB.NI.w				

Table 142 Ragusa. Apartment block. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
AB.I.W	17	19	[0.5,0.4,0.1]	[0.7,0.2,0.1]
AB.I.w	17	19	[0.5,0.4,0.1]	[0.7,0.2,0.1]
AB.NI.W	30	19	[0.8,0.0,0.2]	[0.7,0.2,0.1]
AB.NI.w	20 28 36 44	19	[0.8,0.1,0.1] [0.6,0.2,0.2] [0.5,0.2,0.3] [0.5,0.1,0.4]	[0.7,0.2,0.1]

Table 143 Ragusa. Apartment block. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

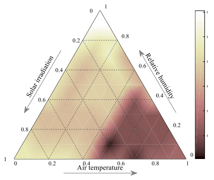
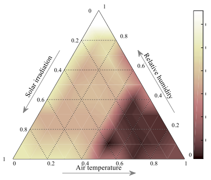
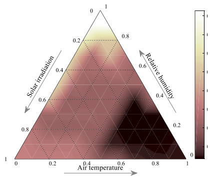
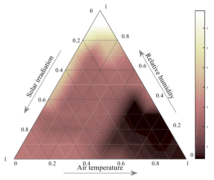
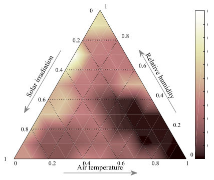
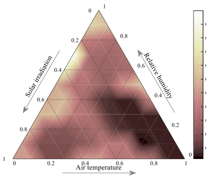
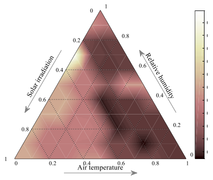
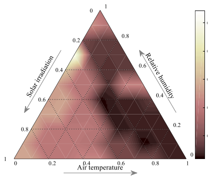
Case study	AB.I.W	AB.I.w	AB.NI.W	AB.NI.w
H+HUM				
C+DEHU M				

Table 144 Turin. Apartment block. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
AB.I.W	31	40 46	60	56	[0.0,0.7,0.3]	[0.1,0.5,0.4] [0.0,0.5,0.5]	[0.3,0.0,0.7]	[0.4,0.0,0.6]
AB.I.w	30	32	32	43	[0.8,0.0,0.2]	[0.1,0.6,0.3]	[0.1,0.6,0.3]	[0.4,0.2,0.4]
AB.NI.W	9	40 46	42	30	[0.8,0.2,0.0]	[0.1,0.5,0.4] [0.0,0.5,0.5]	[0.3,0.3,0.4]	[0.8,0.0,0.2]
AB.NI.w	9	40 46	42	39	[0.8,0.2,0.0]	[0.1,0.5,0.4] [0.0,0.5,0.5]	[0.3,0.3,0.4]	[0.0,0.6,0.4]

Table 145 Turin. Apartment block. Ternary plots of the $\iota_{\sigma EP,\mathrm{S}}$ indicator for the different weighting coefficients configurations

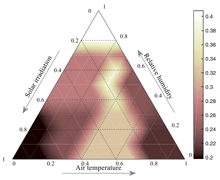
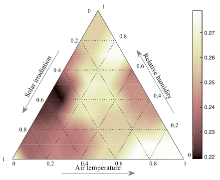
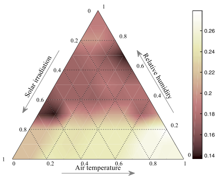
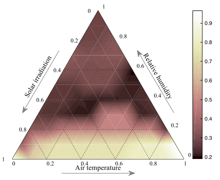
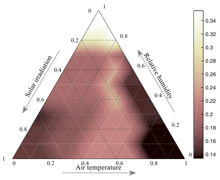
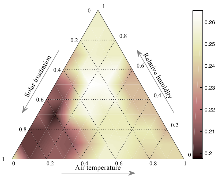
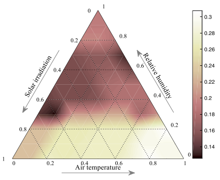
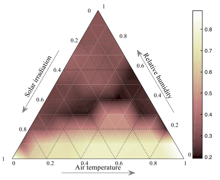
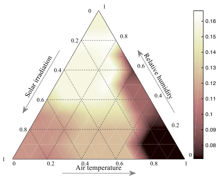
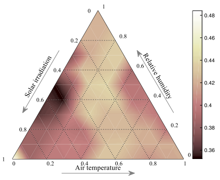
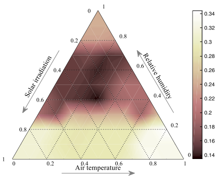
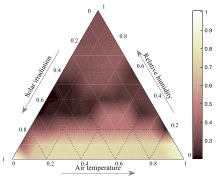
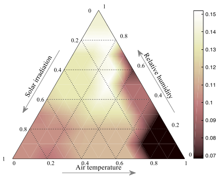
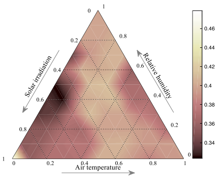
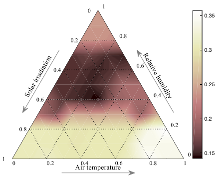
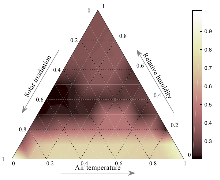
Case study	H	C	HUM	DHUM
AB.I.W				
AB.I.w				
AB.NI.W				
AB.NI.w				

Table 146 Turin. Apartment block. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
AB.I.W	31	40 46	[0,0.7,0.3]	[0.1,0.5,0.4] [0.0,0.5,0.5]
AB.I.w	31	32	[0,0.7,0.3]	[0.1,0.6,0.3]
AB.NI.W	56	40 46	[0.4,0,0.6]	[0.1,0.5,0.4] [0.0,0.5,0.5]
AB.NI.w	56	40 46	[0.4,0,0.6]	[0.1,0.5,0.4] [0.0,0.5,0.5]

Table 147 Turin. Apartment block. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

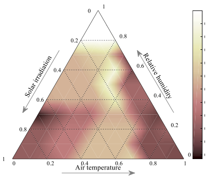
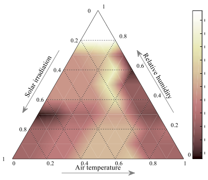
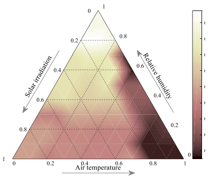
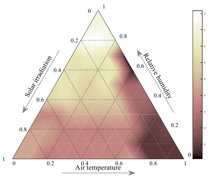
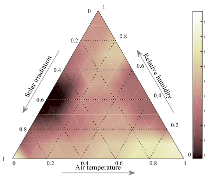
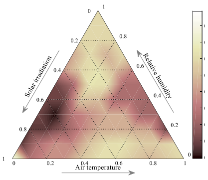
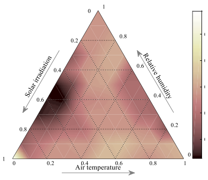
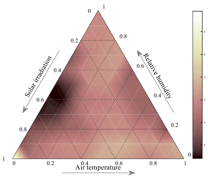
Case study	AB.I.W	AB.I.w	AB.NI.W	AB.NI.w
H+HUM				
C+DEHUM				

Table 148 Udine. Apartment block. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
AB.I.W	64	37	66	29	[0.0,0.1,0.9]	[0.6,0.1,0.3]	[0.0,0.0,1]	[0.7,0.1,0.2]
AB.I.w	64	37	66	30	[0.0,0.1,0.9]	[0.6,0.1,0.3]	[0.0,0.0,1]	[0.8,0.0,0.2]
AB.NI.W	28	37	66	29	[0.6,0.2,0.2]	[0.6,0.1,0.3]	[0.0,0.0,1]	[0.7,0.1,0.2]
AB.NI.w	28	37	66	29	[0.6,0.2,0.2]	[0.6,0.1,0.3]	[0.0,0.0,1]	[0.7,0.1,0.2]

Table 149 Udine. Apartment block. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

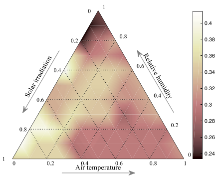
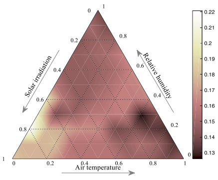
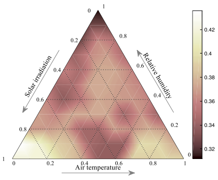
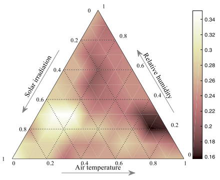
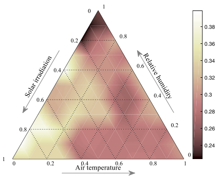
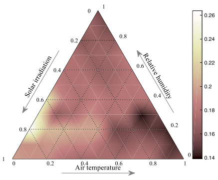
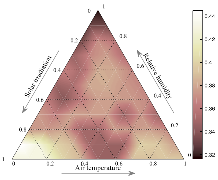
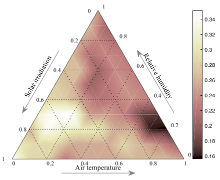
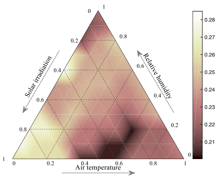
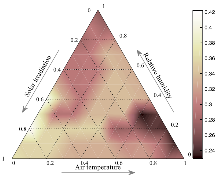
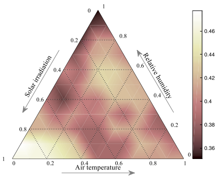
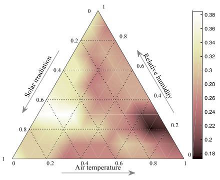
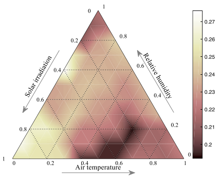
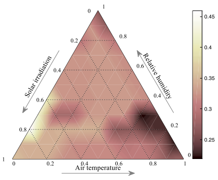
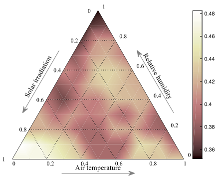
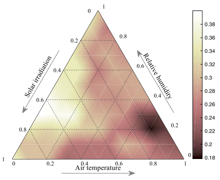
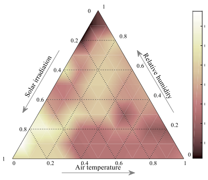
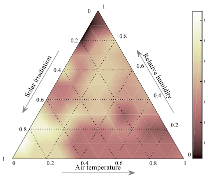
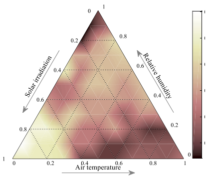
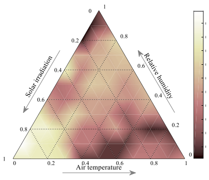
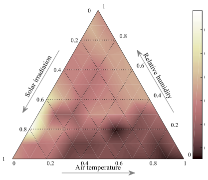
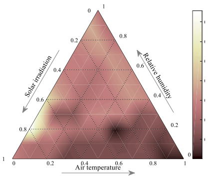
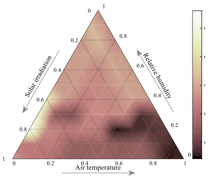
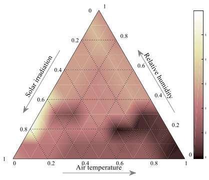
Case study	H	C	HUM	DHUM
AB.I.W				
AB.I.w				
AB.NI.W				
AB.NI.w				

Table 150 Udine. Apartment block. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T*,*I*,*RH*]	C+DHUM [*T*,*I*,*RH*]
AB.I.W	61	27	[0.0,0.2,0.8]	[0.5,0.3,0.2]
AB.I.w	61	27	[0.0,0.2,0.8]	[0.5,0.3,0.2]
AB.NI.W	64	27	[0.0,0.1,0.9]	[0.5,0.3,0.2]
AB.NI.w	64	27	[0.0,0.1,0.9]	[0.5,0.3,0.2]

Table 151 Udine. Apartment block. Ternary plots of the $\iota_{\sigma EP,\mathrm{S}}$ indicator for aggregated energy services

Case study	AB.I.W	AB.I.w	AB.NI.W	AB.NI.w
H+HUM				
C+DEHUM				

4.7.3.3 Office building

Table 152 Agrigento. Office building. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
OB.I.sh	-	21	56	45	-	[0.9,0.0,0.1]	[0.4,0.0,0.6]	[0.6,0.0,0.4]
OB.I.SH	55	21	56	45	[0.3,0.1,0.6]	[0.9,0.0,0.1]	[0.4,0.0,0.6]	[0.6,0.0,0.4]
OB.NI.sh	31	21	42	65 66	[0.0,0.7,0.3]	[0.9,0.0,0.1]	[0.3,0.3,0.4]	[0.1,0.0,0.9] [0.0,0.0,1.0]
OB.NI.SH	60	21	41	50 51	[0.3,0.0,0.7]	[0.9,0.0,0.1]	[0.2,0.4,0.4]	[0.4,0.1,0.5] [0.5,0.0,0.5]

Table 153 Agrigento. Office building. Ternary plots of the $\iota_{\sigma EP,\mathrm{S}}$ indicator for the different weighting coefficients configurations

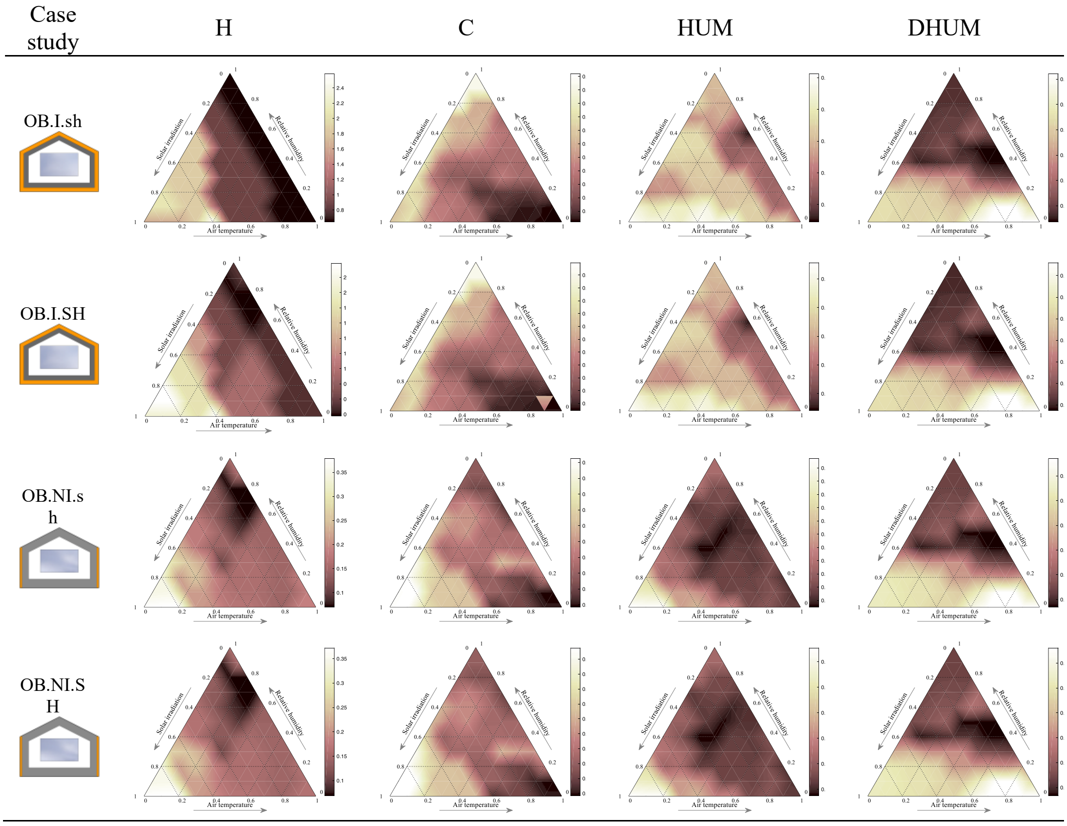


Table 154 Agrigento. Office building. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
OB.I.sh	56	45	[0.4,0.0,0.6]	[0.6,0.0,0.4]
OB.I.SH	56	45	[0.4,0.0,0.6]	[0.6,0.0,0.4]
OB.NI.sh	55	60	[0.3,0.1,0.6]	[0.3,0.0,0.7]
OB.NI.SH	55	60	[0.3,0.1,0.6]	[0.3,0.0,0.7]

Table 155 Agrigento. Office building. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

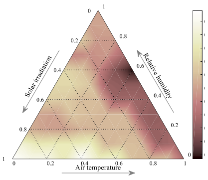
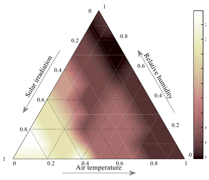
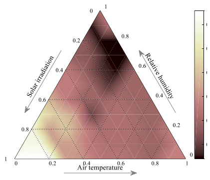
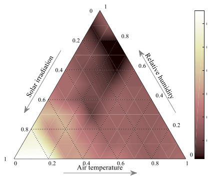
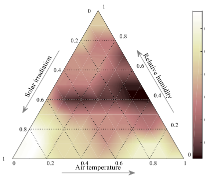
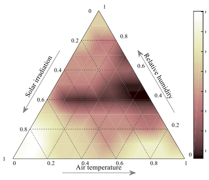
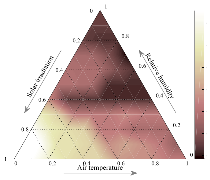
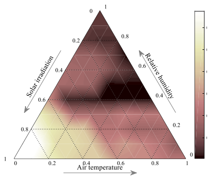
Case study	OB.I.sh	OB.I.SH	OB.NI.sh	OB.NI.SH
H+HUM				
C+DEHUM				

Table 156 Palermo. Office building. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
OB.I.sh	-	8	4 15 25	59	-	[0.7,0.3,0.0]	[0.3,0.7,0.0] [0.3,0.6,0.1] [0.3,0.5,0.2]	[0.2,0.1,0.7]
OB.I.SH	-	8	32	59	-	[0.7,0.3,0.0]	[0.1,0.6,0.3]	[0.2,0.1,0.7]
OB.NI.sh	16	10 11	38 45	60	[0.4,0.5,0.1]	[0.9,0.1,0.0] [1.0,0.0,0.0]	[0.7,0.0,0.3]	[0.3,0.0,0.7]
OB.NI.SH	6	10 11	38 45	60	[0.5,0.5,0.0]	[0.9,0.1,0.0] [1,0.0,0.0.0]	[0.7,0.0,0.3] [0.6,0.0,0.4]	[0.3,0.0,0.7]

Table 157 Palermo. Office building. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

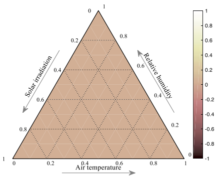
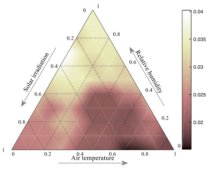
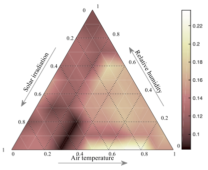
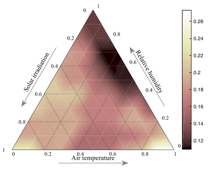
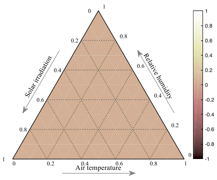
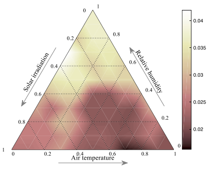
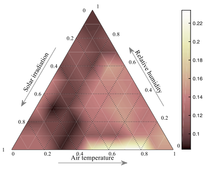
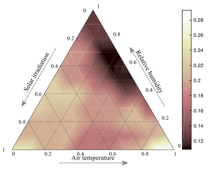
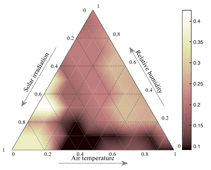
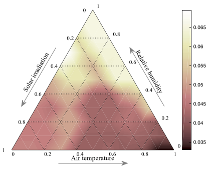
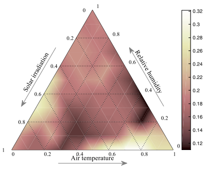
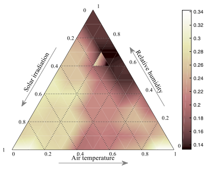
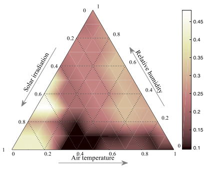
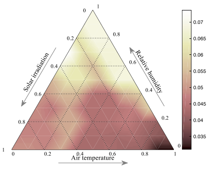
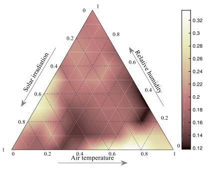
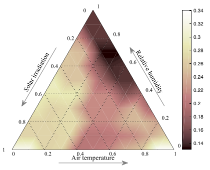
Case study	H	C	HUM	DHUM
OB.I.sh				
OB.I.SH				
OB.NI.sh				
OB.NI.S H				

Table 158 Palermo. Office building. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
OB.I.sh	4	30	[0.3,0.7,0.0]	[0.8,0.0,0.2]
	15		[0.3,0.6,0.1]	
	25		[0.3,0.5,0.2]	
OB.I.SH	32	9	[0.1,0.6,0.3]	[0.8,0.2,0.0]
OB.NI.sh	4	30	[0.3,0.7,0.0]	[0.8,0.0,0.2]
	15		[0.3,0.6,0.1]	
	25		[0.3,0.5,0.2]	
OB.NI.SH	4	30	[0.3,0.7,0.0]	[0.8,0.0,0.2]
	15		[0.3,0.6,0.1]	
	25		[0.3,0.5,0.2]	

Table 159 Palermo. Office building. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

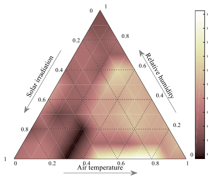
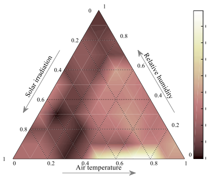
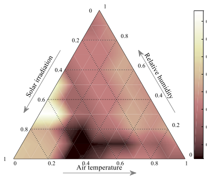
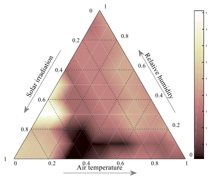
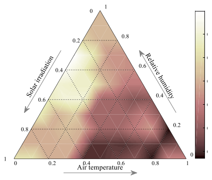
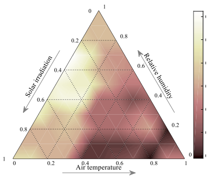
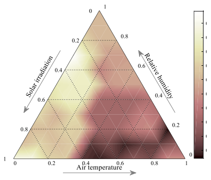
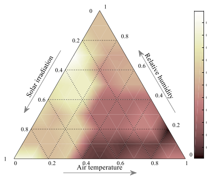
Case study	OB.I.sh	OB.I.SH	OB.NI.sh	OB.NI.SH
				
H+HUM				
C+DEHUM				

Table 160 Ragusa. Office building. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
OB.I.sh	28	7	56	50	[0.6,0.2,0.2]	[0.6,0.4,0.0]	[0.4,0.0,0.6]	[0.4,0.1,0.5]
	36				[0.5,0.2,0.3]			
	44				[0.5,0.1,0.4]			
OB.I.SH	28	7	56	45	[0.6,0.2,0.2]	[0.6,0.4,0.0]	[0.4,0.0,0.6]	[0.6,0.0,0.4]
OB.NI.sh	9	19	19	43	[0.8,0.2,0.0]	[0.7,0.2,0.1]	[0.7,0.2,0.1]	[0.4,0.2,0.4]
OB.NI.SH	9	19	19	28	[0.8,0.2,0.0]	[0.7,0.2,0.1]	[0.7,0.2,0.1]	[0.6,0.2,0.2]

Table 161 Ragusa. Office building. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

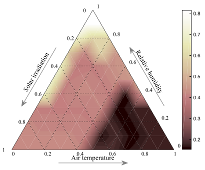
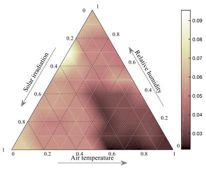
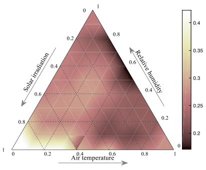
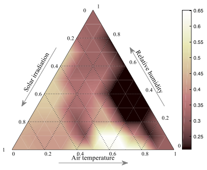
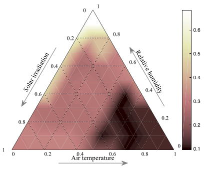
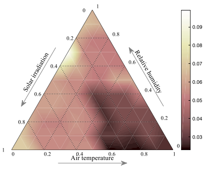
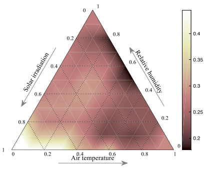
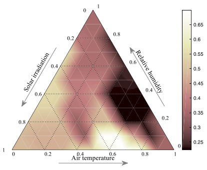
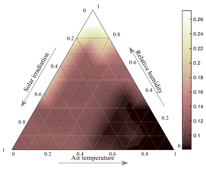
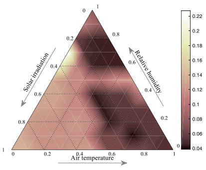
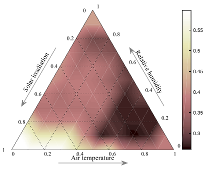
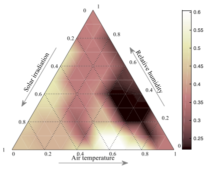
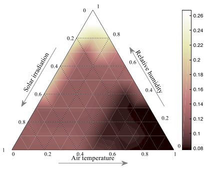
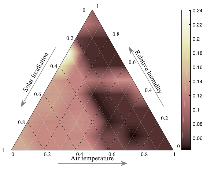
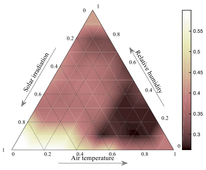
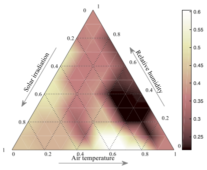
Case study	H	C	HUM	DHUM
OB.I.sh				
OB.I.SH				
OB.NI.sh				
OB.NI.SH				

Table 162 Ragusa. Office building. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
OB.I.sh	17	43	[0.5,0.4,0.1]	[0.4,0.2,0.4]
OB.I.SH	19	43	[0.7,0.2,0.1]	[0.4,0.2,0.4]
OB.NI.sh	30	60	[0.8,0.0,0.2]	[0.3,0.0,0.7]
OB.NI.SH	20	60	[0.8,0.1,0.1]	[0.3,0.0,0.7]
	29		[0.7,0.1,0.2]	
	37		[0.6,0.1,0.3]	
	38		[0.7,0.0,0.3]	

Table 163 Ragusa. Office building. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

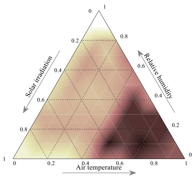
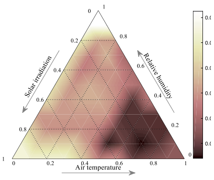
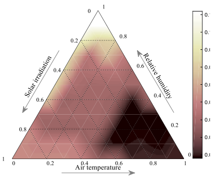
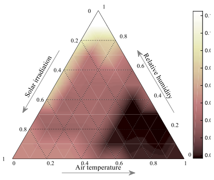
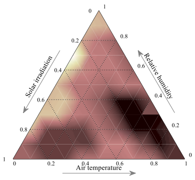
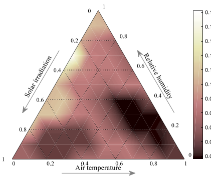
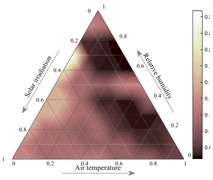
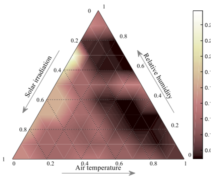
Case study	OB.I.sh	OB.I.SH	OB.NI.sh	OB.NI.SH
H+HUM				
C+DEHUM				

Table 164 Turin. Office building. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
OB.I.sh	31	40 46	60	42	[0.0,0.7,0.3]	[0.1,0.5,0.4] [0.0,0.5,0.5]	[0.3,0.0,0.7]	[0.3,0.3,0.4]
OB.I.SH	31	40 46	59	56	[0.0,0.7,0.3]	[0.1,0.5,0.4] [0.0,0.5,0.5]	[0.2,0.1,0.7]	[0.4,0.0,0.6]
OB.NI.sh	60	40 46	42	42	[0.3,0.0,0.7]	[0.1,0.5,0.4] [0.0,0.5,0.5]	[0.3,0.3,0.4]	[0.3,0.3,0.4]
OB.NI.SH	31	40 46	63	34	[0.0,0.7,0.3]	[0.1,0.5,0.4] [0.0,0.5,0.5]	[0.2,0.0,0.8]	[0.3,0.4,0.3]

Table 165 Turin. Office building. Ternary plots of the $\iota_{\sigma EP,\mathrm{S}}$ indicator for the different weighting coefficients configurations

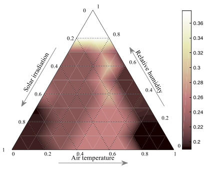
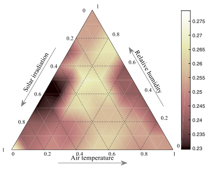
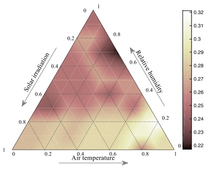
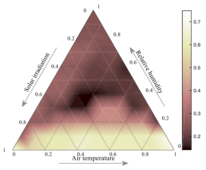
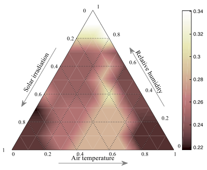
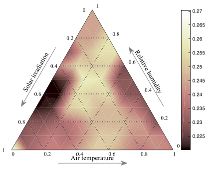
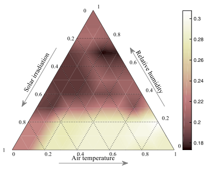
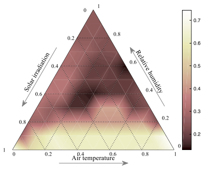
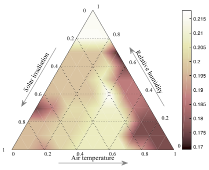
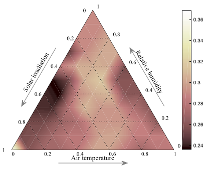
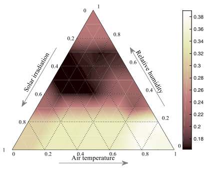
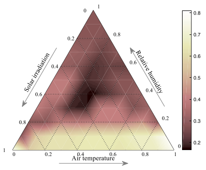
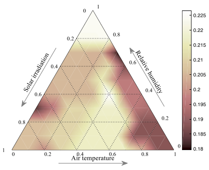
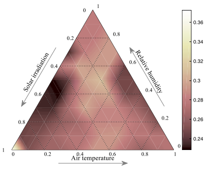
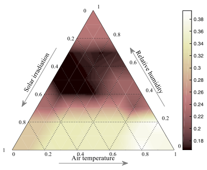
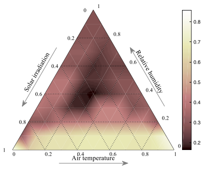
Case study	H	C	HUM	DHUM
OB.I.sh				
OB.I.SH				
OB.NI.sh				
OB.NI.SH				

Table 166 Turin. Apartment block. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T,I,RH*]	C+DHUM [*T,I,RH*]
OB.I.sh	31	39	[0,0.7,0.3]	[0.0,0.6,0.4]
OB.I.SH	31	32	[0,0.7,0.3]	[0.1,0.6,0.3]
OB.NI.sh	31	32	[0,0.7,0.3]	[0.1,0.6,0.3]
OB.NI.SH	31	32	[0,0.7,0.3]	[0.1,0.6,0.3]

Table 167 Turin. Office building. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

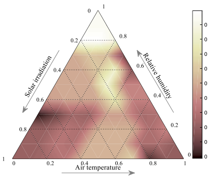
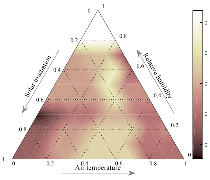
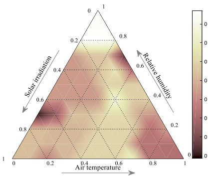
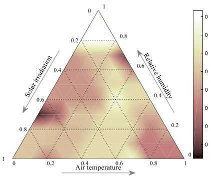
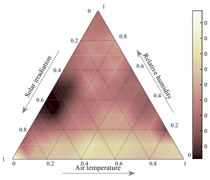
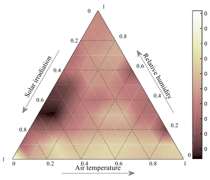
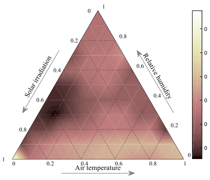
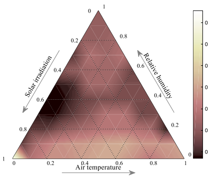
Case study	OB.I.sh	OB.I.SH	OB.NI.sh	OB.NI.SH
H+HUM				
C+DEHUM				

Table 168 Udine. Office building. Best TMYs for energy service

Case study	H	C	HUM	DHUM	H [*T,I,RH*]	C [*T,I,RH*]	HUM [*T,I,RH*]	DHUM [*T,I,RH*]
OB.I.sh	64	37	36	65	[0.0,0.1,0.9]	[0.6,0.1,0.3]	[0.5,0.2,0.3]	[0.1,0.0,0.9]
OB.I.SH	64	37	36	59	[0.0,0.1,0.9]	[0.6,0.1,0.3]	[0.5,0.2,0.3]	[0.2,0.1,0.7]
OB.NI.sh	28	37	66	48	[0.6,0.2,0.2]	[0.6,0.1,0.3]	[0.0,0.0,1.0]	[0.2,0.3,0.5]
OB.NI.SH	28	37	66	48	[0.6,0.2,0.2]	[0.6,0.1,0.3]	[0.0,0.0,1.0]	[0.2,0.3,0.5]

Table 169 Udine. Office building. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for the different weighting coefficients configurations

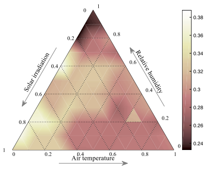
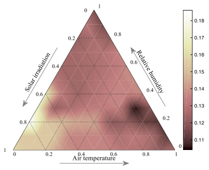
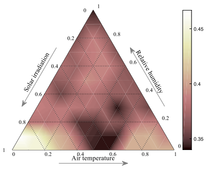
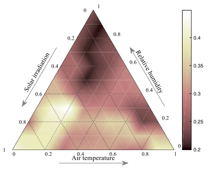
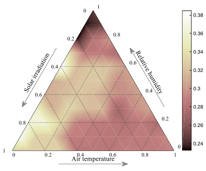
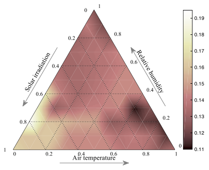
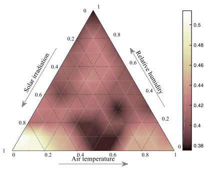
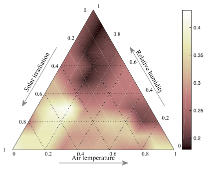
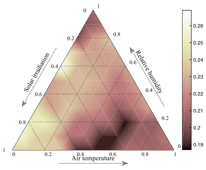
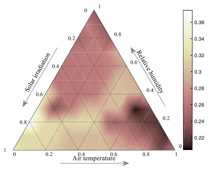
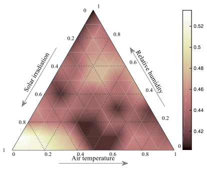
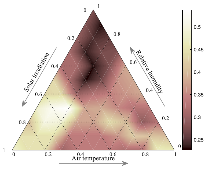
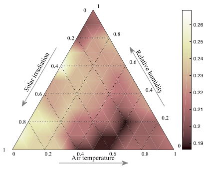
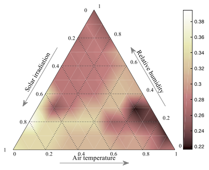
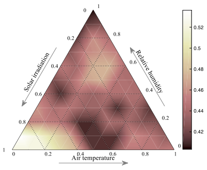
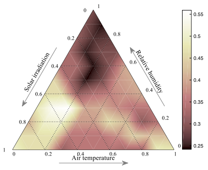
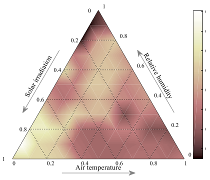
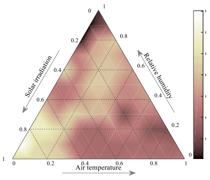
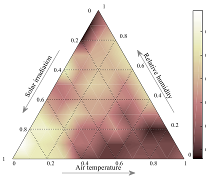
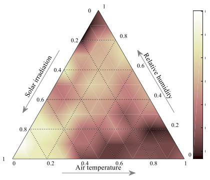
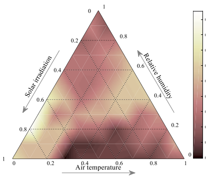
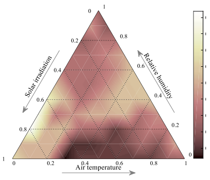
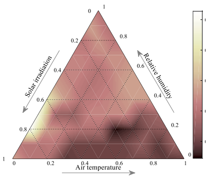
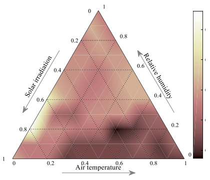
Case study	H	C	HUM	DHUM
OB.I.sh				
OB.I.SH				
OB.NI.sh				
OB.NI.SH				

Table 170 Udine. Office building. Best TMYs for aggregated energy service

Case study	H+HUM	C+DHUM	H+HUM [*T*,*I*,*RH*]	C+DHUM [*T*,*I*,*RH*]
OB.I.sh	61 64	4	[0.0,0.2,0.8] [0.0,0.1,0.9]	[0.3,0.7,0.0]
OB.I.SH	61 64	4	[0.0,0.2,0.8] [0.0,0.1,0.9]	[0.3,0.7,0.0]
OB.NI.sh	61 64	27	[0.0,0.2,0.8] [0.0,0.1,0.9]	[0.5,0.3,0.2]
OB.NI.SH	61 64	27	[0.0,0.2,0.8] [0.0,0.1,0.9]	[0.5,0.3,0.2]

Table 171 Udine. Office building. Ternary plots of the $\iota_{\sigma EP,S}$ indicator for aggregated energy services

Case study	OB.I.sh	OB.I.SH	OB.NI.sh	OB.NI.SH
H+HUM				
C+DEHUM				

4.7.4 Evaluation of aggregated energy services

The final part of the study concerned the use of TMYs for the evaluation of aggregated energy needs. The analysis was carried out by evaluating the sum of the energy needs according to equation (22) *where the aggregated energy services (S1+S2) can be either heating plus humidification, or cooling plus dehumidification.*

$$\sigma_{EP^{\mathrm{M}}{}_{\mathrm{S1+S2}}} = \sqrt{\sum_{\mathrm{m}=1}^{N_{\mathrm{m}}}\left(EP^{\mathrm{M}}{}_{\mathrm{S1+S2,m}} - \overline{EP^{\mathrm{M}}}{}_{\mathrm{S1+S2,m}}\right)^{2} / \left(N_{\mathrm{m}} - 1\right)} \qquad (22)$$

The optimum weighting coefficients for climate variables for different energy services and building types are shown in Table 173 and Table 175, *also for aggregated* services.

4.7.4.1 Aggregated heating energy services (Heating + Humidification)

a) Agrigento

For the single family houses with low thermal insulation the best TMYs are C59 (0.20;0.10;0.70), C61 (0.00;0.20;0.80), and C63 (0.20;0.00;0.80). The variant with high thermal insulation is best characterized by the configurations C34 (0.30;0.40;0.30), and C55 (0.30;0.10;0.60).

Four configurations, C55 (0.30;0.10;0.60), C59 (0.20;0.10;0.70), C61 (0.00;0.20;0.80), and C63 (0.20;0.00;0.80), show a good performance for the apartment block with low thermal insulation.

Both for the Apartment block and the Office building, the best TMY, for all building envelope variants, is C56 (0.40;0.00;0.60).

In all the selected TMY configurations the parameter relating to the solar radiation has values lower than 0.40, while the parameter that has the greatest weight is the relative humidity of the air. This happens because in the aggregated heating energy service (Heating + Humidification) the weight of sensible energy needs is negligible.

b) Palermo

For the high insulated single family houses the best TMYs are: C6 (0.50;0.50;0.00), e C17 (0.50;0.40;0.10) for the variant with low WWR, and C29 (0.70;0.10;0.20) and C51 (0.50;0.00;0.50) for the variant with high WWR.

The single family houses with low thermal insulation and low WWR are represented by the configuration C6 (0.50;0.50;0.00).

For the apartment block, the office building and the low insulated single family house with high WWR, the best combinations are C4 (0.30;0.70;0.00), C15 (0.30;0.60;0.10), and C25 (0.30;0.50;0.20). In these cases, the solar radiation emerges as a priority parameter.

c) Ragusa

The minimum value of the relative standard deviation ($\iota_{\sigma EP_{H+HUM}}$) corresponds to C17 (0.50;0.40;0.10) for the single family houses with high thermal insulation, and to C9 (0.80;0.20;0.00) for the single family houses with low thermal insulation.

As regards the high insulated Apartment block and high insulated office building the best TMY configuration is the C17 (0.50; 0.40; 0.10).

As regards the Apartment Block with high thermal insulation and low WWR, the minimum value of the relative standard deviation ($\iota_{\sigma EP_{H+HUM}}$) corresponds to C30 (0.80;0.00;0.20) and C20 (0.80;0.10;0.10), C29 (0.70;0.10;0.20), C37 (0.60;0.10;0.30) and C38 (0.70;0.00;0.30) for the apartment Block with low thermal insulation and low WWR.

Instead, eight configurations, C20 (0.80;0.10;0.10), C28 (0.60;0.20;0.20), C29 (0.70;0.10;0.20), C30 (0.80;0.00;0.20), C36 (0.50;0.20;0.30), C37 (0.60;0.10;0.30), C38 (0.70;0.00;0.30), C44 (0.50;0.10;0.40), show equal performance for poorly insulated office building.

For Ragusa, in the search of optimum weighting coefficients for climate variables for aggregated heating energy service, the influence of dry-bulb air temperature is generally dominant.

C17 (0.50; 0.40; 0.10) is the TMY that offers the most representative results for all the highly insulated buildings analysed. Therefore, for this category of buildings, air temperature and solar radiation have similar weights with a priority role of the air temperature.

d) Turin

Six configurations, C9 (0.80;0.20;0.00), C10 (0.90;0.10;0.00), C11 (1.00;0.00;0.00), C19 (0.70;0.20;0.10), C20 (0.80;0.10;0.10), C21 (0.90;0.00;0.10), C29 (0.70;0.10;0.20), show a good performance for the low insulated single family house and with high WWR. Instead, for the building variant with low insulated single family house and with low WWR the best combination is represented by C56 (0.40;0.00;0.60).

The configuration C9 (0.80;0.20;0.00) is the most representative for the high insulated single family house with high WWR, instead C38 (0.70;0.00;0.30) is the best configuration for the variant with low WWR.

As regards the office building and the apartment block, the minimum value of the relative standard deviation ($\iota_{\sigma EP,DHU}$) corresponds to C31 (0.00;0.70;0.30) with exception for the low insulated building variant, for which the C56 (0.40;0.00;0.60) is the most representative.

e) Udine

For the lowly insulated single family houses the best TMYs are C11 (1.00; 0.00; 0.00) and C21 (0.90; 0.00; 0.10). For the highly insulated single family houses with high WWR the best TMYs are the C37 (0.60; 0.10; 0.30) and C43 (0.40; 0.20; 0.40), while for the variant with low WWR the most representative TMY combination is C27 (0.50; 0.30; 0.20).

For the office buildings, in all their building envelope variants, the best TMYs are C61 (0.00; 0.20; 0.80) and C64 (0.00; 0.10; 0.90).

As regard the apartment block, in the highly insulated variant, the best TMY configuration is C61 (0.00; 0.20; 0.80); for the variant with lowly insulation the most representative combination is C64 (0.00; 0.10; 0.90).

Table 172 Optimum weighting coefficients for climate variables for aggregated heating energy service (Heating + Humidification)

			TMY																																																															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
		T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.0	0.1	0.2	0.3	0.4	0.5	0.0	0.1	0.2	0.3	0.4	0.0	0.1	0.2	0.3	0.0	0.1	0.2	0.0	0.1	0.0
		I	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.5	0.4	0.3	0.2	0.1	0.0	0.4	0.3	0.2	0.1	0.0	0.3	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0
		RH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0
AG	SFH	I.W.																																															y						x											
		I.w.																																x																								y								
		NI.W.																																																				y				x	x		x	x	y		
		NI.w.																																																				y				x	y		x	x			
	AB	I.W.																																																				y	x										
		I.w.																																																				y	x										
		NI.W.																																x							y	y														x				x	x		x	x	y		
		NI.w.																																																				x				x	y		x	x	x		
	OB	I.sh.																																																				y	x										
		I.SH.																																																y	y				y	x										
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RG	SFH	I.W.								y									x		x									x								x								x																						
		I.w.								y									x			y								y	y	y						y	y	y						y																						
		NI.W.								y	x								y	x									x																																							
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		NI.sh.																	y	y		x							y	x	x	x						x	x	x						x																						
		NI.SH.																	y	y	y	x							y	x	x	x						x	x	x						x																						
TO	SFH	I.W.									x						y										y																																									
		I.w.									y	y	y								y	y	y								y									x																												
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		NI.SH.																													x	y																															x			x		

Table 173 Aggregated heating energy service (Heating + Humidification). Aggregation of optimal TMYs configuration for building typology and geographic location.

<table>
<tr><th></th><th></th><th>NI.W</th><th>NI.w</th><th>I.w</th><th>I.W</th></tr>
<tr><td rowspan="3">AG</td><td>SFH</td><td colspan="2" rowspan="2">C59(0.20;0.10;0.70)
C61(0.00;0.20;0.80)
C63(0.20;0.00;0.80)</td><td>C34(0.30;0.40;0.30)</td><td>C55(0.30;0.10;0.60)</td></tr>
<tr><td>AB</td><td colspan="2" rowspan="2">C56(0.40;0.00;0.60)</td></tr>
<tr><td>OB</td><td colspan="2">C55(0.30;0.10;0.60)</td></tr>
<tr><td rowspan="3">PA</td><td>SFH</td><td></td><td colspan="2">C6(0.50;0.50;0.00)</td><td>C29(0.80;0.00;0.20)
C51(0.50;0.00;0.50)</td></tr>
<tr><td>AB</td><td colspan="2">C4(0.30;0.70;0.00) C15(0.30;0.60;0.10)
C25(0.30;0.50;0.20)</td><td>C5(0.40;0.60;0.00)
C16(0.40;0.50;0.10)
C17(0.50;0.40;0.10)
C18(0.60;0.30;0.10)
C32(0.10;0.60;0.30)</td><td>C4(0.30;0.70;0.00)
C15(0.30;0.60;0.10)
C25(0.30;0.50;0.20)</td></tr>
<tr><td>OB</td><td colspan="3"></td><td>C32(0.20;0.50;0.30)</td></tr>
<tr><td rowspan="3">RG</td><td>SFH</td><td colspan="2">C9(0.80;0.20;0.00)</td><td colspan="2" rowspan="3">C17(0.50;0.40;0.10)</td></tr>
<tr><td>AB</td><td>C30(0.80;0.00;0.20)</td><td></td></tr>
<tr><td>OB</td><td colspan="2">C20(0.80;0.10;0.10), C29(0.70;0.10;0.20)
C37(0.60;0.10;0.30), C38(0.70;0.00;0.30)</td></tr>
<tr><td rowspan="3">TO</td><td>SFH</td><td>C9(0.80;0.20;0.00)
C10(0.90;0.10;0.00)
C11(1.00;0.00;0.00)
C19(0.70;0.20;0.10)
C20(0.80;0.10;0.10)
C21(0.90;0.00;0.10)
C29(0.70;0.10;0.20)</td><td rowspan="2">C56(0.40;0.00;0.60)</td><td>C38(0.70;0.00;0.30)</td><td>C9(0.80;0.20;0.00)</td></tr>
<tr><td>AB</td><td></td><td colspan="2" rowspan="2">C31(0.50;0.20;0.30)</td></tr>
<tr><td>OB</td><td colspan="2"></td></tr>
<tr><td rowspan="3">UD</td><td>SFH</td><td colspan="2">C11(1.00;0.00;0.00),C21 (0.90;0.00;0.10)</td><td>C27(0.50;0.30;0.20)</td><td>C37(0.60;0.10;0.30)
C43(0.40;0.20;0.40)</td></tr>
<tr><td>AB</td><td colspan="2">C64(0.00;0.10;0.90)</td><td colspan="2">C61(0.00;0.20;0.80)</td></tr>
<tr><td>OB</td><td colspan="4">C61(0.00;0.20;0.80), C64(0.00;0.10;0.90)</td></tr>
</table>

4.7.4.2 Aggregated cooling energy services (Cooling + Dehumidification)

a) Agrigento

The combination C60 (0.30;0.00;0.70) shows a good performance for the highly insulated single family house and for all building envelope variations of the apartment block.

Instead, two configurations C62 (0.10;0.10;0.80), and C63 (0.20;0.00;0.80) show equal performance for poorly insulated single family houses. This case study, in the slightly insulated variant with highly WWR is represented also by the configurations C61 (0.00;0.20;0.80), C64 (0.00;0.10;0.90), C65 (0.10;0.00;0.90), and C66 (0.00;0.00;1.00).

For the highly insulated office building the best configuration is C45 (0.60; 0.00; 0.40), while for the variant with low thermal insulation the best configuration is represented by C60 (0.30; 0.00; 0.70).

In the selected configurations, the weighting coefficient related to water vapour pressure is generally greater than 0.50; that highlights the weight of this variable for the considered energy service.

b) Palermo

The combination C30 (0.80;0.00;0.20) shows a good performance for the single family houses, for all building envelope variations with exception for the poorly insulated building envelope that is best represented by the combination C20 (0.80;0.10;0.10).

As regards the highly insulated office building and the apartment block, the minimum value of the relative standard deviation ($\iota\sigma_{EP,C+DHU}$) corresponds to C9 (0.80;0.20;0.00). The lowly insulated building variant are best represented by the TMY configuration C30 (0.80;0.00;0.20).

c) Ragusa

For single family houses with high WWR, the best TMY is the C19 (0.70; 0.20; 0.10). The poorly insulated single family house with low WWR is best represented by the combination C45 (0.60; 0.00; 0.40) and the highly insulated single family house with low WWR from the combinations C56 (0.40; 0.00; 0.60), C60 (0.30; 0.00; 0.70), and C63 (0.20; 0.00; 0.80).

For the apartment block, in all its building envelope variants, the best TMY configuration is C19 (0.70;0.20;0.10).

Eight configurations, C20 (0.80;0.10;0.10), C28 (0.60;0.20;0.20), C29 (0.70;0.10;0.20), C36 (0.50;0.20;0.30), C37 (0.60;0.10;0.30), C38 (0.70;0.00;0.30), C43 (0.40;0.20;0.40), and C44 (0.50;0.10;0.40), show a good performance for the highly insulated office building. Instead, for the variant with poorly insulated the best combinations are represented by C56 (0.40;0.00;0.60), C60 (0.30;0.00;0.70), and C63 (0.20;0.00;0.80).

d) Turin

As regards the highly insulated single family houses, the lowest relative standard deviation ($\iota\sigma_{EP,C+DHU}$) corresponds to C31 (0.00;0.70;0.30), and C39 (0.00;0.60;0.40).

Instead, for the poorly insulated single family houses the optimal combinations vary according the WWR and are C40 (0.10; 0.50; 0.40) and C46 (0.00; 0.50; 0.50) for the variant with high WWR and C57 (0.00; 0.30; 0.70) for the alternative with low WWR.

As regard the apartment block the best TMYs are C40 (0.10; 0.50; 0.40), and C46 (0.00; 0.50; 0.50); instead the highly insulated variant with low WWR is best represented by the configuration C32 (0.10; 0.60; 0.30).

For the office buildings, in all their variants except highly insulated envelope with low WWR, the best TMY configuration is C32 (0.10;0.60;0.30). This exception is represented by TMY configuration C39 (0.00; 0.60; 0.40).

e) Udine

For the single family house, the optimal TMYs configurations vary according to the characteristics of the building envelope. In particular, the best configuration are: C30 (0.80;0.00;0.20) for highly insulated single family house with high WWR, C32 (0.10;0.60;0.30) for highly insulated single family house with low WWR, C11 (1.00;0.00;0.00) for poorly insulated single family house with high WWR and C38 (0.70;0.00;0.30) for poorly insulated single family house with low WWR.

For the office building and the apartment block, the best TMY configuration is C27 (0.50; 0.30; 0.20), with the exception of the highly insulated office building that is best characterized by the TMY combination C4 (0.30; 0.70; 0.00).

Table 174 Optimum weighting coefficients for climate variables for aggregated cooling energy service (Cooling + Dehumidification)

			TMY																																																																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
		T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.0	0.1	0.2	0.3	0.4	0.5	0.0	0.1	0.2	0.3	0.4	0.0	0.1	0.2	0.3	0.0	0.1	0.2	0.0	0.1	0.0
		I	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.5	0.4	0.3	0.2	0.1	0.0	0.4	0.3	0.2	0.1	0.0	0.3	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0
		RH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0
AG	SFH	I.W.																																									y																			x						
		I.w.																																												y						y	y									x						
		NI.W.																				y																																								x	x	x	x	x	x
		NI.w.																																																												y	x	x	y	y	y
	AB	I.W.																																								x			y	y															x						
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		NI.w.																				y																																							x						
	OB	I.sh.																																								y			x	x					y	y															
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	AB	I.W.								x												y									y																																				
		I.w.								x																					y																																				
		NI.W.																			y										x																																				
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	OB	I.sh.				y	y			x							y	y	y		y										x																																				
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RG	SFH	I.W.									y	y								x		y																																													
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		NI.W.																		x								y								y																															
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	AB	I.W.									y	y								x		y																																													
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		NI.W.																		x																							y																								
		NI.w.																		x																							y																								
	OB	I.sh.																			x								x	x	y						x	x	x					x	x																						
		I.SH.																			x								x	x	y						x	x	x					x	x																						
		NI.sh.																																									y												y	y	x			y	x			x			
		NI.SH.																			y								y	y							y	y	y					y	y												x				x			x			
TO	SFH	I.W.																														x								x	y						y																				
		I.w.																														x								x	y						y																				
		NI.W.																														y								y	x						x																				
		NI.w.																																							y						y											x									
	AB	I.W.																														y									x						x																				
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		NI.sh.																										x	y																																						
		NI.SH.																										x	y																																						

Table 175 Aggregated heating energy service (Cooling + Dehumidification). Aggregation of optimal TMYs configuration for building typology and geographic location.

		NI.W	**NI.w**	**I.W**	**I.w**
AG	**SFH**	C62 (0.10;0.10;0.80)	C63 (0.20;0.00;0.80)	C60 (0.30;0.00;0.70)	C60 (0.30;0.00;0.70)
	AB	C60 (0.30;0.00;0.70)	C60 (0.30;0.00;0.70)	C60 (0.30;0.00;0.70)	C60 (0.30;0.00;0.70)
	OB	C45 (0.60;0.00;0.40)	C45 (0.60;0.00;0.40)	C45 (0.60;0.00;0.40)	C45 (0.60;0.00;0.40)
PA	**SFH**	C30 (0.80;0.00;0.20)	C30 (0.80;0.00;0.20)	C30 (0.80;0.00;0.20)	C30 (0.80;0.00;0.20)
	AB	C30 (0.80;0.00;0.20)	C30 (0.80;0.00;0.20)	C9 (0.80;0.20;0.00)	C9 (0.80;0.20;0.00)
	OB	C9 (0.80;0.20;0.00)	C9 (0.80;0.20;0.00)	C9 (0.80;0.20;0.00)	C9 (0.80;0.20;0.00)
RG	**SFH**	C19 (0.70;0.20;0.10)	C45 (0.60;0.00;0.40)	C19 (0.70;0.20;0.10)	C56 (0.40;0.00;0.60) C60 (0.30;0.00;0.70) C63 (0.20;0.00;0.80)
	AB	C19 (0.70;0.20;0.10)	C19 (0.70;0.20;0.10)	C19 (0.70;0.20;0.10)	C19 (0.70;0.20;0.10)
	OB	C56 (0.40;0.00;0.60) C60 (0.30;0.00;0.70) C63 (0.20;0.00;0.80)	C56 (0.40;0.00;0.60) C60 (0.30;0.00;0.70) C63 (0.20;0.00;0.80)	C20 (0.80;0.10;0.10), C28 (0.60;0.20;0.20) C29 (0.70;0.10;0.20), C36 (0.50;0.20;0.30) C37 (0.60;0.10;0.30), C38 (0.70;0.00;0.30) C43 (0.40;0.20;0.40), C44 (0.50;0.10;0.40)	C20 (0.80;0.10;0.10), C28 (0.60;0.20;0.20) C29 (0.70;0.10;0.20), C36 (0.50;0.20;0.30) C37 (0.60;0.10;0.30), C38 (0.70;0.00;0.30) C43 (0.40;0.20;0.40), C44 (0.50;0.10;0.40)
TO	**SFH**	C32 (0.10;0.60;0.30)	C32 (0.10;0.60;0.30)	C39 (0.00;0.60;0.40)	C39 (0.00;0.60;0.40)
	OB	C40 (0.10;0.50;0.40)	C32 (0.10;0.60;0.30)	C39 (0.00;0.60;0.40)	C39 (0.00;0.60;0.40)
	AB	C46 (0.00;0.50;0.50)	C46 (0.00;0.50;0.50)	C46 (0.00;0.50;0.50)	C32 (0.10;0.60;0.30)
UD	**SFH**	C11 (1.00;0.00;0.00)	C38 (0.70;0.00;0.30)	C29 (0.70;0.10;0.20)	C32 (0.10;0.60;0.30)
	AB	C27 (0.50;0.30;0.20)	C27 (0.50;0.30;0.20)	C27 (0.50;0.30;0.20)	C27 (0.50;0.30;0.20)
	OB	C4 (0.30;0.70;0.00)	C4 (0.30;0.70;0.00)	C4 (0.30;0.70;0.00)	C4 (0.30;0.70;0.00)

4.8 Conclusions

This research *addresses the issue of climatic data utilized as inputs in building energy simulation. In fact, forthcoming developments in energy design and evaluation, in particular for highly insulated buildings, will require TMYs that can guarantee reliable and realistic results.*

In the construction of a TMY, the use of weighting coefficients gives a higher representativeness to the climate parameter that has a higher impact on the energy performance of the building.

The research took into account sixty-six *weighting coefficient configurations, four energy services, two types of building envelopes and two values of WWR. An improvement of the EN ISO 15927-4 standard methodology is proposed, as to increase the estimation accuracy of the EP in the medium and long term.*

Results highlight that different TMYs should be used for assessing EP for single energy services and, in some cases, for different types of buildings. At the opposite the EN ISO 15927-4 standard methodology provides improved representativeness for aggregated energy services.

Table 176, Table 177, and Table 178 consider the energy performance calculated with the TMYs more representative and the energy performance achieved using the TMY of EN ISO 15927 [112]. The asterisk (*), on the other hand, indicates those TMYs that offer a better performance (in term of Monthly EP relative standard deviation) than that determined by the ISO standard [112]. Looking at the reports, we see how the results change by location and by case study examined. Some initial investigation (not included in the thesis) show how even the internal heat gain and the use schedule change the optimal combination. This aspect, therefore, makes this methodology little standardisable because the coefficients could change for each location and for each type of building. In any case, in the choice of optimal configuration, the influence of air temperature is generally dominant for heating and cooling services.

Table 176 Single Family House. Comparison between the EP_S calculated with EN ISO 15927-4 and the new proposal methodology

		AG			PA			RG			TO			UD		
		ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE
SFH.I.W	H	<	>	*	<	<	*	>	>	*	>	>	*	>	<	*
	C	>	<		<	>	*	<	>	*	>	<		<	<	*
	HUM	<	<	*	<	>	*	>	<	*	>	<		<	>	
	DEHUM	<	>	*	<	>		>	<		<	>	*	<	<	
SFH.I.w	H	<	<	*	>	>	*	>	>	*	>	<	*	>	<	*
	C	<	<		<	<	*	<	<	*	>	<		<	>	*
	HUM	<	<	*	<	<	*	>	<	*	>	<	*	>	>	
	DEHUM	<	>	*	<	>	*	<	<		<	>	*	>	>	
SFH.NI.W	H	<	>	*	>	>	*	>	>	*	>	<	*	>	<	
	C	<	<	*	<	>	*	<	>	*	>	<		<	<	*
	HUM	<	<	*	<	<	*	>	>	*	>	<	*	<	<	
	DEHUM	<	<	*	<	>	*	<	>		<	<	*	>	>	
SFH.NI.w	H	<	>	*	>	>	*	>	>	*	>	<		>	<	
	C	<	<	*	<	>		<	>	*	>	<		<	<	*
	HUM	<	<	*	<	<	*	>	>	*	>	>	*	<	<	
	DEHUM	<	<	*	<	>		<	<	*	<	<	*	>	<	

< the TMY has a EP_S value of less than average value on long term
> the TMY has a EP_S value of greater than average value on long term
* the Best TMY has a EP_S value closer to average value on long term

Table 177 Apartment block. Comparison between the EP_S calculated with EN ISO 15927-4 and the new proposal methodology

		AG			PA			RG			TO			UD		
		ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE
AB.I.W	H	<	>		<	<	*	>	<	*	>	<		<	<	*
	C	>	<	*	<	>	*	<	>	*	>	<		<	<	*
	HUM	>	<	*	<	<	*	>	<	*	<	>		<	<	*
	DEHUM	<	<	*	<	>		>	>		<	>	*	<	>	*
AB.I.w	H	<	>	*	<	<		>	<	*	>	<	*	<	<	*
	C	>	<		<	>	*	<	>	*	>	<		<	<	*
	HUM	<	<	*	<	<	*	>	<	*	<	>		<	<	*
	DEHUM	<	>		<	>		>	>		<	>	*	<	>	*
AB.NI.W	H	<	<	*	<	>	*	>	>		>	<	*	<	<	
	C	<	<		<	>	*	<	>	*	>	<		<	>	
	HUM	<	>	*	<	>		>	<	*	>	<	*	<	>	*
	DEHUM	<	>		<	>	*	>	>		<	>	*	<	<	*
AB.NI.w	H	<	>	*	<	>	*	>	>		>	<	*	<	<	*
	C	<	<		<	>	*	<	>	*	>	<		<	<	*
	HUM	<	<		<	>		>	<	*	>	>	*	<	<	*
	DEHUM	<	>	*	<	>	*	<	>		<	>	*	<	<	*

< the TMY has a EP_S value of less than average value on long term
> the TMY has a EP_S value of greater than average value on long term
* the Best TMY has a EP_S value closer to average value on long term

Table 178 Office Building. Comparison between the *EP*s calculated with EN ISO 15927-4 and the new proposal methodology

		AG			PA			RG			TO			UD		
		ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE	ISO 15927	BEST TMY	NOTE
OB.I.sh	H	<	>	*	>	<	*	>	<	*	<	<	*	<	<	*
	C	>	<	*	<	<	*	<	>	*	<	<	*	<	<	
	HUM	<	<	*	<	<	*	>	<	*	<	<	*	<	<	
	DEHUM	<	>	*	<	>	*	>	>		<	>	*	<	>	
OB.I.SH	H	<	>	*	>	<	*	>	>	*	<	<	*	<	<	*
	C	>	<	*	<	<	*	<	>	*	<	<		<	<	
	HUM	<	<	*	<	>	*	>	<	*	<	>		<	<	
	DEHUM	<	>	*	<	>		>	>		<	>	*	<	>	
OB.NI.sh	H	<	>	*	>	>	*	>	>		<	<	*	<	>	*
	C	<	<		<	>	*	<	<	*	<	<		<	<	
	HUM	<	<	*	<	<	*	>	<	*	>	>		<	<	*
	DEHUM	<	>	*	<	>	*	>	<		<	>	*	<	>	*
OB.NI.SH	H	<	>	*	>	>	*	>	>	*	<	<	*	<	>	*
	C	>	<		<	>	*	<	<	*	<	<		<	<	
	HUM	<	<	*	<	<	*	>	<	*	>	>		<	<	*
	DEHUM	<	>		<	>	*	>	<		<	>	*	<	>	*

The authors suggest to implement the procedure specified in the EN ISO 15927-4 standard [112]*,* for the five main Italian climatic zones [159]*, as to differentiate the choice of each TMY month according to the predominant energy service in that month and to the building type.* However, it is noted that to date the national territory is zoned only on the basis of the heating degree days, while the other climatic parameters are not considered.

Since each month has a specific dominant energy service (or group of energy services), the proposal consists of constructing a representative TMY by applying a different weighing combination for each month.

The procedure has been checked for residential buildings and office building for localities where space-heating and/or space-cooling services prevails on the other energy services (humidification and dehumidification). *Nevertheless, the building energy simulations have shown that the energy impact of dehumidification service is not negligible (*Fig. 40*,* Fig. 41*,* Fig. 42*). In other locations, the impact of this energy service could be even more relevant. In particular, for building categories characterized by higher water vapour mass production such as dance halls, bars, restaurants, cinemas, theatres and meeting rooms for conferences the dehumidification service could become dominant. For this reason, the impact of humidification and dehumidification services on the building energy performance has been considered in this work and it represents a main novelty of this study.* The study could still be extended to other energy services provided by the EPBD as lighting.

Moreover, as the examined case studies are buildings with natural ventilation, the wind speed and wind direction have been assumed as having a secondary role; however, for buildings that incorporates techniques of passive ventilation these variables might have a different impact.

Appendix A shows some detailed graphs related to the comparison of energy needs among the standard methodology [112] and the one verified in the present research. This studies allowed me to publish various researches and articles. Below are reported some references:

- G. Murano, V. Corrado, D. Dirutigliano, (2016) *The new Italian climatic data and their effect in the calculation of the energy performance of buildings*, 71st Conference of the Italian Thermal Machines Engineering Association, ATI 2016, 14-16 September 2016, Turin, Italy, Energy Procedia 101C
- G. Murano, D. Dirutigliano, V. Corrado, (2018) *Improved Procedure for the Construction of a Typical Meteorological Year for Assessing the Energy Need of a Residential Building*, Official journal of the International Building Performance Simulation Association (IBPSA)
- M. Libralato, G. Murano, O. Saro, A. De Angelis and V. Corrado, (2019) *Influence of the Multi-year size on the generation of Moisture Reference Years for interstitial condensation risk assessment*, In Friulian Journal of Science
- M. Libralato, G. Murano, O. Saro, A. De Angelis and V. Corrado, (2019) *Generation of Moisture Reference Years for Interstitial Condensation Risk Assessment: Influence of the Meteorological Record Length*, September 2019, Building Simulation 2019 Rome
- M. Libralato, G. Murano, O. Saro, A. De Angelis and V. Corrado, (2018) *Hygrothermal modelling of building enclosures: reference year design for moisture accumulation and condensation risk assessment*, 7th International Building Physics Conference, September 23rh -26th 2018, Syracuse, NY, Use

Annex

Fig. 43 Agrigento. Finkelstein-Schafer statistic of climate variables.

Fig. 44 Palermo. Finkelstein-Schafer statistic of climate variables.

Fig. 45 Ragusa. Finkelstein-Schafer statistic of climate variables.

Fig. 46 Turin. Finkelstein-Schafer statistic of climate variables.

Fig. 47 Udine. Finkelstein-Schafer statistic of climate variables.

Table 179 Composition of TMYs for the city of Agrigento (elaboration according to EN ISO 15927)

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
AG	2008	2006	2014	2013	2013	2011	2008	2014	2014	2002	2012	2008
PA	2004	2011	2011	2006	2007	2008	2008	2004	2016	2008	2011	2008
RG	2005	2006	2006	2012	2010	2008	2002	2002	2006	2015	2007	2005
TO	2004	2011	2003	2010	2004	2005	2008	2014	2002	2013	2006	2003
UD	2009	2009	2015	2015	2007	2004	2009	2000	1999	2008	1997	2009

Table 180 Composition of TMYs for the city of Agrigento

	Weighting coefficients			TMY Composition											
	T	*I*	*RH*	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
C1	0.0	1.0	0.0	2012	2012	2008	2008	2009	2010	2011	2011	2012	2002	2017	2009
C2	0.1	0.9	0.0	2012	2012	2008	2012	2009	2010	2011	2011	2012	2002	2008	2009
C3	0.2	0.8	0.0	2012	2012	2008	2012	2007	2011	2011	2011	2012	2002	2008	2009
C4	0.3	0.7	0.0	2004	2006	2008	2012	2007	2011	2011	2011	2012	2002	2008	2009
C5	0.4	0.6	0.0	2010	2006	2011	2012	2007	2011	2011	2011	2012	2004	2008	2009
C6	0.5	0.5	0.0	2008	2006	2011	2012	2007	2011	2011	2011	2012	2004	2008	2009
C7	0.6	0.4	0.0	2008	2006	2011	2012	2007	2011	2013	2011	2013	2004	2008	2009
C8	0.7	0.3	0.0	2008	2006	2011	2012	2007	2011	2005	2011	2013	2004	2008	2006
C9	0.8	0.2	0.0	2015	2006	2014	2012	2007	2011	2005	2011	2013	2004	2008	2006
C10	0.9	0.1	0.0	2015	2006	2004	2012	2007	2016	2005	2011	2013	2004	2008	2006
C11	1.0	0.0	0.0	2015	2006	2004	2012	2007	2016	2005	2011	2013	2004	2010	2006
C12	0.0	0.9	0.1	2004	2012	2008	2008	2009	2010	2011	2011	2012	2002	2017	2009
C13	0.1	0.8	0.1	2004	2012	2008	2012	2009	2010	2011	2011	2012	2002	2008	2009
C14	0.2	0.7	0.1	2004	2006	2008	2012	2007	2011	2011	2011	2012	2002	2008	2009
C15	0.3	0.6	0.1	2004	2006	2008	2012	2007	2011	2011	2011	2012	2002	2008	2009
C16	0.4	0.5	0.1	2008	2006	2011	2012	2007	2011	2011	2011	2012	2004	2008	2009
C17	0.5	0.4	0.1	2008	2006	2011	2012	2007	2011	2008	2011	2012	2004	2008	2006
C18	0.6	0.3	0.1	2008	2006	2011	2012	2007	2011	2008	2011	2013	2004	2008	2006
C19	0.7	0.2	0.1	2015	2006	2011	2012	2007	2011	2005	2011	2013	2004	2008	2006
C20	0.8	0.1	0.1	2015	2006	2014	2012	2007	2016	2005	2011	2013	2004	2010	2006
C21	0.9	0.0	0.1	2015	2006	2004	2012	2007	2016	2005	2011	2016	2004	2010	2006
C22	0.0	0.8	0.2	2004	2012	2008	2012	2009	2010	2011	2011	2012	2002	2017	2008
C23	0.1	0.7	0.2	2004	2006	2008	2012	2009	2011	2011	2011	2012	2002	2008	2008
C24	0.2	0.6	0.2	2004	2006	2006	2012	2007	2011	2011	2011	2012	2002	2008	2008
C25	0.3	0.5	0.2	2008	2006	2006	2012	2007	2011	2011	2011	2012	2004	2008	2011
C26	0.4	0.4	0.2	2008	2006	2011	2012	2007	2011	2008	2011	2005	2004	2008	2006
C27	0.5	0.3	0.2	2008	2006	2011	2012	2007	2011	2008	2011	2005	2004	2008	2006
C28	0.6	0.2	0.2	2008	2006	2011	2012	2007	2014	2008	2011	2005	2004	2008	2006
C29	0.7	0.1	0.2	2015	2006	2014	2012	2007	2014	2008	2011	2016	2004	2010	2006
C30	0.8	0.0	0.2	2015	2006	2004	2012	2007	2016	2005	2010	2016	2004	2010	2006
C31	0.0	0.7	0.3	2004	2009	2013	2012	2009	2010	2011	2004	2012	2002	2008	2008
C32	0.1	0.6	0.3	2004	2006	2006	2012	2005	2011	2011	2011	2005	2002	2008	2008
C33	0.2	0.5	0.3	2004	2006	2006	2012	2005	2011	2008	2011	2005	2004	2008	2011
C34	0.3	0.4	0.3	2008	2006	2011	2012	2005	2011	2008	2011	2005	2004	2008	2011
C35	0.4	0.3	0.3	2008	2006	2011	2012	2005	2011	2008	2011	2005	2004	2008	2006
C36	0.5	0.2	0.3	2008	2006	2011	2012	2005	2014	2008	2010	2005	2004	2008	2006
C37	0.6	0.1	0.3	2015	2006	2011	2012	2007	2014	2008	2010	2016	2004	2010	2006
C38	0.7	0.0	0.3	2015	2006	2014	2012	2007	2016	2008	2010	2016	2004	2010	2006
C39	0.0	0.6	0.4	2004	2006	2013	2012	2009	2011	2012	2004	2005	2008	2008	2008
C40	0.1	0.5	0.4	2004	2006	2013	2012	2005	2011	2008	2004	2005	2004	2008	2011
C41	0.2	0.4	0.4	2008	2006	2013	2012	2005	2011	2008	2014	2005	2004	2008	2011
C42	0.3	0.3	0.4	2008	2006	2013	2012	2005	2014	2008	2014	2005	2004	2008	2011
C43	0.4	0.2	0.4	2008	2006	2011	2012	2005	2014	2008	2014	2005	2004	2010	2006
C44	0.5	0.1	0.4	2015	2006	2011	2012	2005	2014	2008	2014	2016	2004	2010	2006
C45	0.6	0.0	0.4	2015	2006	2014	2012	2005	2014	2008	2014	2016	2004	2010	2006
C46	0.0	0.5	0.5	2004	2006	2013	2012	2005	2011	2012	2004	2004	2008	2008	2011
C47	0.1	0.4	0.5	2004	2006	2013	2012	2005	2011	2008	2004	2005	2008	2008	2011
C48	0.2	0.3	0.5	2008	2006	2013	2012	2005	2014	2008	2014	2005	2008	2008	2011
C49	0.3	0.2	0.5	2008	2006	2007	2012	2005	2014	2008	2014	2004	2004	2010	2011
C50	0.4	0.1	0.5	2015	2006	2007	2012	2005	2014	2008	2014	2016	2004	2010	2006
C51	0.5	0.0	0.5	2015	2006	2007	2012	2005	2014	2008	2014	2016	2004	2010	2006
C52	0.0	0.4	0.6	2004	2006	2013	2012	2005	2011	2012	2004	2004	2008	2008	2011
C53	0.1	0.3	0.6	2008	2006	2013	2012	2005	2014	2008	2014	2004	2008	2008	2011
C54	0.2	0.2	0.6	2008	2006	2007	2012	2005	2014	2008	2014	2004	2008	2010	2011
C55	0.3	0.1	0.6	2015	2006	2007	2012	2005	2014	2008	2014	2004	2009	2010	2011
C56	0.4	0.0	0.6	2015	2006	2007	2012	2006	2014	2008	2014	2016	2015	2010	2006
C57	0.0	0.3	0.7	2008	2006	2013	2017	2005	2014	2008	2004	2004	2008	2004	2011
C58	0.1	0.2	0.7	2008	2006	2013	2017	2005	2014	2008	2014	2004	2008	2010	2011
C59	0.2	0.1	0.7	2015	2006	2007	2017	2006	2014	2008	2014	2004	2008	2010	2011
C60	0.3	0.0	0.7	2015	2006	2007	2017	2006	2014	2008	2014	2016	2009	2010	2011
C61	0.0	0.2	0.8	2008	2006	2013	2016	2006	2014	2006	2014	2004	2008	2010	2011
C62	0.1	0.1	0.8	2015	2006	2007	2017	2006	2014	2006	2014	2004	2008	2010	2011
C63	0.2	0.0	0.8	2015	2006	2007	2017	2006	2014	2006	2014	2004	2008	2010	2011
C64	0.0	0.1	0.9	2015	2006	2007	2016	2006	2014	2006	2014	2004	2008	2010	2011
C65	0.1	0.0	0.9	2015	2006	2007	2016	2006	2014	2006	2014	2004	2008	2010	2016
C66	0.0	0.0	1.0	2015	2006	2007	2016	2006	2014	2006	2014	2004	2008	2010	2016

Table 181 Composition of TMYs for the city of Palermo

	Weighting coefficients			TMY Composition											
	T	*I*	*RH*	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
C1	0.0	1.0	0.0	2004	2014	2011	2006	2013	2008	2011	2004	2013	2008	2017	2016
C2	0.1	0.9	0.0	2004	2014	2011	2006	2013	2008	2011	2004	2013	2008	2016	2016
C3	0.2	0.8	0.0	2004	2014	2011	2006	2007	2008	2011	2004	2013	2008	2016	2016
C4	0.3	0.7	0.0	2004	2006	2011	2002	2007	2008	2011	2004	2004	2008	2016	2016
C5	0.4	0.6	0.0	2015	2006	2011	2002	2007	2008	2011	2004	2004	2006	2016	2016
C6	0.5	0.5	0.0	2015	2006	2011	2002	2007	2008	2005	2004	2004	2006	2008	2016
C7	0.6	0.4	0.0	2015	2006	2011	2012	2007	2008	2005	2004	2004	2006	2008	2006
C8	0.7	0.3	0.0	2015	2006	2011	2012	2007	2008	2005	2004	2005	2006	2008	2006
C9	0.8	0.2	0.0	2015	2006	2011	2012	2007	2005	2005	2004	2005	2006	2008	2006
C10	0.9	0.1	0.0	2015	2006	2015	2014	2007	2005	2017	2004	2005	2006	2010	2012
C11	1.0	0.0	0.0	2015	2006	2015	2014	2007	2005	2017	2004	2005	2006	2010	2012
C12	0.0	0.9	0.1	2004	2014	2011	2006	2007	2008	2011	2004	2013	2008	2017	2016
C13	0.1	0.8	0.1	2004	2014	2011	2006	2007	2008	2011	2004	2013	2008	2016	2016
C14	0.2	0.7	0.1	2004	2007	2011	2006	2007	2008	2011	2004	2013	2008	2016	2016
C15	0.3	0.6	0.1	2004	2006	2011	2002	2007	2008	2011	2004	2004	2008	2016	2016
C16	0.4	0.5	0.1	2004	2006	2011	2002	2007	2008	2011	2004	2004	2006	2016	2016
C17	0.5	0.4	0.1	2011	2006	2011	2002	2007	2008	2011	2004	2004	2006	2016	2016
C18	0.6	0.3	0.1	2015	2006	2011	2002	2007	2008	2005	2004	2004	2006	2016	2016
C19	0.7	0.2	0.1	2015	2006	2011	2012	2007	2008	2005	2004	2004	2006	2016	2006
C20	0.8	0.1	0.1	2015	2006	2015	2014	2007	2005	2005	2004	2004	2006	2010	2012
C21	0.9	0.0	0.1	2010	2006	2015	2014	2007	2005	2005	2004	2005	2006	2010	2012
C22	0.0	0.8	0.2	2004	2007	2011	2006	2007	2008	2011	2004	2013	2008	2017	2016
C23	0.1	0.7	0.2	2004	2007	2011	2006	2007	2008	2011	2004	2013	2008	2016	2016
C24	0.2	0.6	0.2	2004	2011	2011	2006	2007	2008	2011	2004	2004	2008	2016	2016
C25	0.3	0.5	0.2	2004	2006	2011	2002	2007	2008	2011	2004	2004	2008	2016	2016
C26	0.4	0.4	0.2	2004	2004	2011	2002	2007	2008	2011	2004	2004	2006	2016	2016
C27	0.5	0.3	0.2	2011	2004	2011	2002	2007	2008	2011	2004	2004	2006	2016	2016
C28	0.6	0.2	0.2	2010	2004	2011	2002	2007	2008	2005	2004	2004	2006	2016	2008
C29	0.7	0.1	0.2	2010	2004	2015	2014	2007	2008	2005	2004	2004	2006	2011	2008
C30	0.8	0.0	0.2	2010	2004	2015	2014	2007	2005	2005	2004	2004	2006	2011	2012
C31	0.0	0.7	0.3	2004	2012	2006	2006	2007	2008	2011	2006	2013	2008	2017	2016
C32	0.1	0.6	0.3	2004	2012	2011	2006	2007	2008	2011	2004	2013	2008	2016	2016
C33	0.2	0.5	0.3	2004	2004	2011	2006	2007	2008	2011	2004	2004	2008	2016	2016
C34	0.3	0.4	0.3	2004	2004	2011	2002	2007	2008	2011	2004	2004	2006	2016	2016
C35	0.4	0.3	0.3	2004	2004	2011	2002	2007	2008	2011	2004	2004	2006	2016	2008
C36	0.5	0.2	0.3	2010	2004	2011	2002	2007	2008	2011	2004	2004	2006	2016	2008
C37	0.6	0.1	0.3	2010	2004	2015	2002	2007	2008	2005	2004	2004	2006	2016	2008
C38	0.7	0.0	0.3	2010	2004	2015	2014	2007	2011	2005	2004	2004	2006	2011	2008
C39	0.0	0.6	0.4	2004	2005	2006	2006	2007	2008	2011	2006	2013	2008	2016	2016
C40	0.1	0.5	0.4	2004	2004	2006	2006	2007	2008	2011	2006	2004	2008	2016	2016
C41	0.2	0.4	0.4	2004	2004	2006	2006	2007	2008	2011	2006	2004	2008	2016	2016
C42	0.3	0.3	0.4	2004	2004	2011	2002	2007	2008	2011	2004	2004	2006	2016	2008
C43	0.4	0.2	0.4	2004	2004	2011	2002	2007	2008	2011	2004	2004	2006	2016	2008
C44	0.5	0.1	0.4	2010	2004	2015	2002	2007	2009	2011	2004	2004	2006	2016	2008
C45	0.6	0.0	0.4	2010	2004	2015	2014	2007	2011	2005	2004	2004	2006	2011	2008
C46	0.0	0.5	0.5	2004	2005	2006	2006	2007	2008	2011	2006	2004	2008	2016	2016
C47	0.1	0.4	0.5	2004	2004	2006	2006	2007	2009	2011	2006	2004	2008	2016	2016
C48	0.2	0.3	0.5	2004	2004	2006	2006	2007	2009	2011	2006	2004	2008	2016	2008
C49	0.3	0.2	0.5	2004	2004	2006	2006	2007	2009	2011	2006	2004	2006	2016	2008
C50	0.4	0.1	0.5	2010	2004	2015	2002	2007	2009	2011	2011	2004	2006	2016	2008
C51	0.5	0.0	0.5	2010	2004	2015	2002	2007	2009	2011	2011	2004	2006	2011	2008
C52	0.0	0.4	0.6	2004	2004	2006	2006	2007	2009	2011	2006	2011	2008	2016	2016
C53	0.1	0.3	0.6	2004	2004	2006	2006	2007	2009	2011	2006	2004	2008	2016	2008
C54	0.2	0.2	0.6	2004	2004	2006	2006	2007	2009	2011	2006	2004	2016	2016	2008
C55	0.3	0.1	0.6	2010	2004	2006	2006	2007	2009	2011	2011	2006	2006	2016	2008
C56	0.4	0.0	0.6	2010	2004	2015	2002	2007	2009	2011	2011	2006	2006	2016	2008
C57	0.0	0.3	0.7	2004	2004	2006	2006	2007	2009	2011	2009	2011	2008	2016	2008
C58	0.1	0.2	0.7	2004	2004	2006	2006	2007	2009	2011	2006	2006	2008	2016	2008
C59	0.2	0.1	0.7	2004	2004	2006	2006	2007	2009	2011	2011	2006	2016	2016	2008
C60	0.3	0.0	0.7	2010	2004	2015	2006	2007	2009	2011	2011	2006	2016	2016	2008
C61	0.0	0.2	0.8	2004	2004	2006	2006	2007	2009	2011	2009	2007	2008	2016	2008
C62	0.1	0.1	0.8	2004	2004	2006	2006	2007	2009	2011	2011	2007	2016	2016	2008
C63	0.2	0.0	0.8	2010	2004	2006	2006	2007	2009	2011	2011	2007	2016	2009	2008
C64	0.0	0.1	0.9	2004	2004	2006	2006	2007	2009	2011	2011	2007	2016	2009	2008
C65	0.1	0.0	0.9	2004	2004	2005	2006	2007	2009	2011	2011	2007	2016	2009	2008
C66	0.0	0.0	1.0	2004	2004	2005	2006	2007	2009	2011	2011	2007	2016	2009	2008

Table 182 Composition of TMYs for the city of Ragusa

	Weighting coefficients			TMY Composition											
	T	*I*	*RH*	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
C1	0.0	1.0	0.0	2005	2006	2006	2008	2017	2010	2008	2002	2006	2006	2005	2016
C2	0.1	0.9	0.0	2005	2006	2006	2008	2017	2010	2008	2002	2006	2006	2005	2016
C3	0.2	0.8	0.0	2005	2006	2006	2008	2018	2010	2008	2007	2006	2006	2005	2016
C4	0.3	0.7	0.0	2005	2006	2006	2008	2018	2010	2008	2007	2006	2006	2005	2016
C5	0.4	0.6	0.0	2005	2006	2006	2008	2018	2010	2005	2007	2006	2006	2007	2016
C6	0.5	0.5	0.0	2013	2006	2006	2008	2018	2010	2005	2007	2006	2006	2007	2016
C7	0.6	0.4	0.0	2013	2006	2006	2003	2018	2008	2005	2007	2007	2015	2007	2016
C8	0.7	0.3	0.0	2013	2006	2018	2003	2018	2008	2005	2007	2007	2015	2007	2016
C9	0.8	0.2	0.0	2013	2006	2013	2003	2018	2008	2005	2007	2007	2015	2016	2005
C10	0.9	0.1	0.0	2013	2006	2013	2003	2008	2008	2002	2007	2007	2007	2016	2005
C11	1.0	0.0	0.0	2013	2006	2013	2003	2008	2008	2002	2007	2007	2007	2016	2005
C12	0.0	0.9	0.1	2005	2006	2006	2008	2017	2010	2008	2002	2006	2006	2005	2016
C13	0.1	0.8	0.1	2005	2006	2006	2008	2018	2010	2008	2007	2006	2006	2007	2016
C14	0.2	0.7	0.1	2005	2006	2006	2008	2018	2010	2008	2007	2006	2006	2007	2016
C15	0.3	0.6	0.1	2005	2006	2006	2008	2018	2010	2008	2007	2006	2006	2007	2016
C16	0.4	0.5	0.1	2005	2006	2018	2008	2018	2010	2004	2007	2006	2006	2007	2016
C17	0.5	0.4	0.1	2013	2006	2018	2008	2018	2008	2005	2007	2007	2015	2007	2016
C18	0.6	0.3	0.1	2013	2006	2018	2008	2018	2008	2005	2007	2007	2015	2007	2005
C19	0.7	0.2	0.1	2013	2006	2013	2008	2018	2008	2002	2007	2007	2015	2007	2005
C20	0.8	0.1	0.1	2013	2006	2013	2008	2018	2008	2002	2007	2007	2007	2016	2005
C21	0.9	0.0	0.1	2013	2006	2013	2003	2008	2008	2002	2007	2007	2007	2016	2005
C22	0.0	0.8	0.2	2005	2006	2006	2008	2018	2010	2015	2002	2006	2011	2007	2016
C23	0.1	0.7	0.2	2005	2006	2018	2008	2018	2010	2008	2007	2006	2006	2007	2016
C24	0.2	0.6	0.2	2005	2006	2018	2008	2018	2010	2008	2007	2006	2006	2007	2016
C25	0.3	0.5	0.2	2005	2006	2018	2008	2018	2010	2004	2007	2007	2006	2007	2016
C26	0.4	0.4	0.2	2005	2006	2018	2008	2018	2010	2004	2007	2007	2015	2007	2016
C27	0.5	0.3	0.2	2013	2006	2018	2008	2018	2008	2004	2007	2007	2015	2007	2005
C28	0.6	0.2	0.2	2013	2006	2013	2008	2018	2008	2002	2007	2007	2007	2007	2005
C29	0.7	0.1	0.2	2013	2006	2013	2008	2018	2008	2002	2007	2007	2007	2016	2005
C30	0.8	0.0	0.2	2013	2006	2013	2008	2008	2008	2002	2007	2007	2007	2016	2005
C31	0.0	0.7	0.3	2005	2006	2018	2008	2018	2010	2015	2007	2006	2011	2007	2016
C32	0.1	0.6	0.3	2005	2006	2018	2008	2018	2010	2015	2007	2006	2011	2007	2016
C33	0.2	0.5	0.3	2005	2006	2018	2008	2018	2010	2004	2007	2006	2011	2007	2016
C34	0.3	0.4	0.3	2005	2006	2018	2008	2018	2010	2004	2007	2007	2011	2007	2016
C35	0.4	0.3	0.3	2005	2006	2018	2008	2018	2008	2004	2007	2007	2015	2007	2005
C36	0.5	0.2	0.3	2013	2006	2013	2008	2018	2008	2002	2007	2007	2007	2007	2005
C37	0.6	0.1	0.3	2013	2006	2013	2008	2018	2008	2002	2007	2007	2007	2016	2005
C38	0.7	0.0	0.3	2013	2006	2013	2008	2018	2008	2002	2007	2007	2007	2016	2005
C39	0.0	0.6	0.4	2005	2016	2018	2008	2018	2010	2015	2007	2006	2011	2007	2013
C40	0.1	0.5	0.4	2005	2006	2018	2008	2018	2010	2015	2007	2006	2011	2007	2013
C41	0.2	0.4	0.4	2005	2006	2018	2008	2018	2010	2004	2007	2007	2011	2007	2005
C42	0.3	0.3	0.4	2005	2006	2018	2008	2018	2008	2004	2007	2007	2011	2007	2005
C43	0.4	0.2	0.4	2005	2006	2013	2008	2018	2008	2002	2007	2007	2007	2007	2005
C44	0.5	0.1	0.4	2013	2006	2013	2008	2018	2008	2002	2007	2007	2007	2007	2005
C45	0.6	0.0	0.4	2006	2017	2013	2015	2013	2008	2002	2007	2007	2007	2016	2005
C46	0.0	0.5	0.5	2005	2016	2018	2008	2018	2010	2015	2007	2006	2011	2012	2013
C47	0.1	0.4	0.5	2005	2006	2018	2008	2018	2010	2004	2007	2007	2011	2012	2013
C48	0.2	0.3	0.5	2005	2006	2018	2008	2018	2010	2004	2007	2007	2011	2007	2005
C49	0.3	0.2	0.5	2005	2006	2013	2008	2013	2008	2002	2007	2007	2011	2007	2005
C50	0.4	0.1	0.5	2005	2017	2013	2008	2013	2005	2002	2007	2007	2005	2007	2005
C51	0.5	0.0	0.5	2006	2017	2013	2015	2013	2005	2002	2007	2007	2005	2016	2005
C52	0.0	0.4	0.6	2005	2016	2018	2008	2013	2010	2015	2007	2007	2011	2012	2013
C53	0.1	0.3	0.6	2005	2006	2013	2008	2016	2010	2004	2007	2007	2011	2012	2013
C54	0.2	0.2	0.6	2005	2006	2013	2008	2016	2005	2002	2007	2007	2011	2012	2005
C55	0.3	0.1	0.6	2005	2017	2013	2008	2016	2005	2002	2007	2007	2011	2012	2005
C56	0.4	0.0	0.6	2006	2017	2013	2015	2016	2005	2002	2007	2007	2005	2016	2005
C57	0.0	0.3	0.7	2005	2016	2013	2008	2016	2007	2015	2007	2007	2011	2012	2013
C58	0.1	0.2	0.7	2005	2017	2013	2008	2016	2005	2004	2007	2007	2011	2012	2013
C59	0.2	0.1	0.7	2012	2017	2013	2008	2016	2005	2002	2007	2007	2011	2012	2005
C60	0.3	0.0	0.7	2006	2017	2013	2015	2016	2005	2002	2007	2007	2005	2012	2005
C61	0.0	0.2	0.8	2012	2016	2013	2008	2016	2005	2004	2007	2007	2011	2012	2013
C62	0.1	0.1	0.8	2012	2017	2013	2015	2016	2005	2002	2007	2007	2011	2012	2013
C63	0.2	0.0	0.8	2012	2017	2013	2015	2016	2005	2002	2007	2007	2005	2012	2005
C64	0.0	0.1	0.9	2012	2017	2013	2015	2016	2005	2002	2007	2015	2011	2012	2006
C65	0.1	0.0	0.9	2012	2017	2013	2015	2016	2005	2002	2010	2015	2011	2012	2006
C66	0.0	0.0	1.0	2012	2017	2013	2015	2016	2005	2002	2010	2015	2011	2012	2006

Table 183 Composition of TMYs for the city of Turin

	Weighting coefficients			TMY Composition											
	T	*I*	*RH*	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
C1	0.0	1.0	0.0	2006	2011	2014	2004	2005	2005	2006	2009	2008	2013	2004	2002
C2	0.1	0.9	0.0	2006	2011	2014	2004	2005	2005	2008	2009	2008	2013	2004	2002
C3	0.2	0.8	0.0	2006	2011	2006	2004	2004	2005	2008	2009	2008	2013	2004	2002
C4	0.3	0.7	0.0	2004	2011	2006	2004	2004	2005	2008	2009	2008	2013	2004	2002
C5	0.4	0.6	0.0	2004	2011	2006	2007	2004	2005	2008	2009	2002	2016	2004	2002
C6	0.5	0.5	0.0	2004	2011	2006	2007	2004	2005	2008	2013	2002	2016	2004	2002
C7	0.6	0.4	0.0	2004	2011	2006	2007	2004	2005	2008	2013	2002	2016	2004	2002
C8	0.7	0.3	0.0	2004	2011	2006	2007	2004	2005	2013	2013	2007	2016	2004	2002
C9	0.8	0.2	0.0	2004	2011	2006	2005	2004	2005	2013	2013	2007	2016	2011	2002
C10	0.9	0.1	0.0	2004	2011	2006	2006	2004	2005	2013	2014	2007	2016	2011	2002
C11	1.0	0.0	0.0	2004	2011	2006	2006	2004	2007	2013	2014	2007	2016	2011	2002
C12	0.0	0.9	0.1	2006	2011	2014	2004	2005	2012	2008	2009	2008	2013	2004	2002
C13	0.1	0.8	0.1	2006	2011	2014	2004	2005	2005	2008	2009	2008	2013	2004	2002
C14	0.2	0.7	0.1	2004	2011	2006	2004	2004	2005	2008	2009	2008	2013	2004	2002
C15	0.3	0.6	0.1	2004	2011	2006	2007	2004	2005	2008	2009	2008	2013	2004	2002
C16	0.4	0.5	0.1	2004	2011	2006	2007	2004	2005	2008	2009	2002	2016	2004	2002
C17	0.5	0.4	0.1	2004	2011	2006	2007	2004	2005	2008	2013	2002	2016	2004	2002
C18	0.6	0.3	0.1	2004	2011	2006	2007	2004	2005	2008	2014	2002	2016	2004	2002
C19	0.7	0.2	0.1	2004	2011	2006	2007	2004	2005	2013	2014	2007	2016	2011	2002
C20	0.8	0.1	0.1	2004	2011	2006	2007	2004	2005	2013	2014	2007	2016	2011	2002
C21	0.9	0.0	0.1	2004	2011	2006	2006	2004	2007	2013	2014	2007	2016	2011	2002
C22	0.0	0.8	0.2	2006	2011	2014	2004	2005	2012	2008	2009	2008	2013	2004	2002
C23	0.1	0.7	0.2	2006	2011	2014	2004	2005	2012	2008	2009	2008	2013	2004	2002
C24	0.2	0.6	0.2	2004	2011	2006	2004	2004	2012	2008	2009	2008	2013	2004	2002
C25	0.3	0.5	0.2	2004	2011	2006	2007	2004	2009	2008	2009	2002	2013	2004	2002
C26	0.4	0.4	0.2	2004	2011	2006	2007	2004	2009	2008	2014	2002	2016	2004	2002
C27	0.5	0.3	0.2	2004	2011	2006	2007	2004	2009	2008	2014	2002	2016	2004	2002
C28	0.6	0.2	0.2	2004	2011	2006	2007	2004	2009	2008	2014	2002	2016	2004	2002
C29	0.7	0.1	0.2	2004	2011	2006	2007	2004	2009	2013	2014	2002	2016	2011	2002
C30	0.8	0.0	0.2	2004	2011	2006	2007	2015	2016	2013	2014	2007	2016	2011	2002
C31	0.0	0.7	0.3	2006	2004	2004	2004	2012	2012	2008	2009	2014	2013	2004	2002
C32	0.1	0.6	0.3	2004	2004	2004	2004	2012	2012	2008	2009	2008	2013	2004	2002
C33	0.2	0.5	0.3	2004	2011	2003	2004	2014	2009	2008	2009	2002	2013	2004	2002
C34	0.3	0.4	0.3	2004	2011	2003	2007	2014	2009	2008	2014	2002	2013	2004	2002
C35	0.4	0.3	0.3	2004	2011	2003	2007	2004	2009	2008	2014	2002	2016	2004	2002
C36	0.5	0.2	0.3	2004	2011	2003	2007	2004	2009	2008	2014	2002	2016	2004	2002
C37	0.6	0.1	0.3	2004	2015	2003	2007	2015	2009	2008	2014	2002	2016	2013	2002
C38	0.7	0.0	0.3	2004	2015	2009	2007	2015	2016	2015	2014	2002	2016	2011	2002
C39	0.0	0.6	0.4	2004	2004	2004	2004	2012	2012	2008	2009	2014	2013	2006	2002
C40	0.1	0.5	0.4	2004	2004	2003	2004	2012	2009	2008	2009	2014	2013	2006	2002
C41	0.2	0.4	0.4	2004	2004	2003	2004	2014	2009	2008	2014	2002	2013	2006	2002
C42	0.3	0.3	0.4	2004	2004	2003	2007	2014	2009	2008	2014	2002	2013	2006	2002
C43	0.4	0.2	0.4	2004	2015	2003	2007	2014	2009	2008	2014	2002	2016	2006	2002
C44	0.5	0.1	0.4	2004	2015	2003	2007	2015	2009	2015	2014	2002	2016	2013	2002
C45	0.6	0.0	0.4	2004	2015	2003	2007	2015	2016	2015	2014	2002	2016	2013	2002
C46	0.0	0.5	0.5	2004	2004	2003	2004	2012	2009	2008	2009	2014	2013	2006	2002
C47	0.1	0.4	0.5	2004	2004	2003	2004	2012	2009	2008	2014	2014	2013	2006	2002
C48	0.2	0.3	0.5	2004	2004	2003	2004	2007	2009	2008	2014	2002	2013	2006	2002
C49	0.3	0.2	0.5	2004	2004	2003	2007	2007	2009	2008	2014	2002	2016	2006	2002
C50	0.4	0.1	0.5	2004	2015	2003	2007	2015	2009	2015	2014	2002	2016	2013	2002
C51	0.5	0.0	0.5	2004	2015	2003	2007	2015	2009	2015	2014	2002	2016	2013	2002
C52	0.0	0.4	0.6	2004	2004	2003	2004	2007	2009	2008	2006	2014	2013	2006	2002
C53	0.1	0.3	0.6	2004	2004	2003	2004	2007	2009	2008	2014	2014	2013	2006	2002
C54	0.2	0.2	0.6	2004	2004	2003	2007	2007	2009	2015	2014	2002	2013	2006	2002
C55	0.3	0.1	0.6	2004	2010	2003	2007	2007	2009	2015	2014	2002	2016	2006	2002
C56	0.4	0.0	0.6	2004	2016	2015	2007	2015	2009	2015	2014	2002	2016	2013	2002
C57	0.0	0.3	0.7	2004	2004	2003	2004	2007	2009	2011	2014	2014	2013	2006	2002
C58	0.1	0.2	0.7	2004	2004	2003	2004	2007	2009	2015	2014	2014	2013	2006	2002
C59	0.2	0.1	0.7	2004	2010	2003	2007	2007	2009	2015	2014	2016	2013	2006	2002
C60	0.3	0.0	0.7	2004	2010	2015	2007	2007	2009	2015	2014	2016	2016	2013	2002
C61	0.0	0.2	0.8	2004	2010	2003	2004	2007	2009	2015	2014	2014	2002	2006	2002
C62	0.1	0.1	0.8	2004	2010	2003	2004	2007	2009	2015	2014	2014	2002	2006	2002
C63	0.2	0.0	0.8	2004	2010	2015	2007	2007	2009	2015	2014	2016	2002	2006	2002
C64	0.0	0.1	0.9	2004	2010	2015	2004	2007	2009	2015	2014	2014	2002	2006	2002
C65	0.1	0.0	0.9	2004	2010	2015	2004	2007	2009	2015	2014	2014	2002	2006	2002
C66	0.0	0.0	1.0	2004	2010	2015	2004	2007	2009	2015	2014	2014	2002	2006	2002

Table 184 Composition of TMYs for the city of Udine

	Weighting coefficients			TMY Composition											
	T	*I*	*RH*	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
C1	0.0	1.0	0.0	2016	2015	2009	2016	2007	1999	1998	2004	2015	2016	2016	2008
C2	0.1	0.9	0.0	2016	2015	2009	2016	2007	2004	1998	2004	2015	2016	2016	2008
C3	0.2	0.8	0.0	2016	2015	2009	2016	2007	2004	1998	2004	2015	2016	2016	2008
C4	0.3	0.7	0.0	2016	2015	2009	1999	2007	2010	1998	2004	2015	2015	2016	2008
C5	0.4	0.6	0.0	2016	2008	2015	1999	2007	2010	1998	2004	2015	2015	2016	2008
C6	0.5	0.5	0.0	2009	2008	2015	1999	2007	2010	1998	2004	2015	2015	2016	2008
C7	0.6	0.4	0.0	2009	2008	2015	1999	2007	2010	1998	2004	2015	2015	2016	2008
C8	0.7	0.3	0.0	2009	2008	1999	1999	2007	2010	2004	2004	2013	2015	2016	2008
C9	0.8	0.2	0.0	2009	2008	1999	1999	2007	2010	2004	2004	2013	2015	2016	2008
C10	0.9	0.1	0.0	2009	2008	1999	2004	2015	2010	2005	2004	2013	1999	2016	2008
C11	1.0	0.0	0.0	2009	1997	1999	2004	2015	2010	2005	2004	2013	1999	2016	2008
C12	0.0	0.9	0.1	2016	2015	2009	2016	2007	2004	1998	2004	2015	2016	2005	2008
C13	0.1	0.8	0.1	2016	2015	2009	2016	2007	2004	1998	2004	2015	2016	2016	2008
C14	0.2	0.7	0.1	2016	2015	2009	1999	2007	2004	1998	2004	2015	2016	2016	2008
C15	0.3	0.6	0.1	2016	2008	2009	1999	2007	2010	1998	2004	2015	2015	2016	2008
C16	0.4	0.5	0.1	2009	2008	2009	1999	2007	2010	1998	2004	2015	2015	2016	2008
C17	0.5	0.4	0.1	2009	2008	2015	1999	2007	2010	1998	2004	2015	2015	2016	2008
C18	0.6	0.3	0.1	2009	2008	2015	1999	2007	2010	2004	2004	2015	2015	2016	2008
C19	0.7	0.2	0.1	2009	2008	1999	2002	2007	2010	2004	2004	2013	1999	2016	2008
C20	0.8	0.1	0.1	2009	2008	1999	2004	2007	2010	2005	2004	2013	1999	2016	2008
C21	0.9	0.0	0.1	2009	1997	1999	2004	2015	2010	2005	2000	2004	1999	2016	2008
C22	0.0	0.8	0.2	2010	2015	2009	2001	2007	2004	1998	1996	1999	2016	2005	2008
C23	0.1	0.7	0.2	2010	2015	2009	2001	2007	2004	1998	2004	2015	2016	2005	2008
C24	0.2	0.6	0.2	2009	2008	2009	2017	2007	2004	1998	2004	2015	2016	2005	2008
C25	0.3	0.5	0.2	2009	2008	2009	1999	2007	2004	1998	2004	2015	2015	2016	2008
C26	0.4	0.4	0.2	2009	2008	2009	1999	2007	2004	1998	2004	2015	2015	2016	2008
C27	0.5	0.3	0.2	2009	2008	2009	2002	2007	2010	2009	2004	2015	1999	2016	2008
C28	0.6	0.2	0.2	2009	2008	2015	2002	2007	2010	2009	2004	2004	1999	2016	2008
C29	0.7	0.1	0.2	2009	2008	1999	2004	2007	2010	2005	2000	2004	1999	2016	2008
C30	0.8	0.0	0.2	2009	1997	1999	2004	2006	2010	2005	2000	2004	1999	2016	1996
C31	0.0	0.7	0.3	2010	2015	2009	2001	2007	2004	2016	1996	1999	2016	2005	2005
C32	0.1	0.6	0.3	2010	2008	2009	2017	2007	2004	2016	2004	1999	2016	2005	2005
C33	0.2	0.5	0.3	2009	2008	2009	2017	2007	2004	2016	2004	2015	2016	2005	2008
C34	0.3	0.4	0.3	2009	2008	2009	2017	2007	2004	2009	2016	2015	1999	2005	2009
C35	0.4	0.3	0.3	2009	2008	2009	2002	2007	2004	2009	2016	2015	1999	2005	2009
C36	0.5	0.2	0.3	2009	2008	2009	2002	2007	2004	2009	2016	2004	1999	2016	2009
C37	0.6	0.1	0.3	2009	2008	2009	2002	2007	2010	2009	2000	2004	1999	1997	1996
C38	0.7	0.0	0.3	2009	1997	2009	2004	2007	2010	2005	2000	2004	1999	1997	1996
C39	0.0	0.6	0.4	2010	2008	2009	2017	2007	2004	2016	1996	1999	2016	2005	2005
C40	0.1	0.5	0.4	2010	2008	2009	2017	2007	2004	2016	2016	1999	2016	2005	2009
C41	0.2	0.4	0.4	2009	2008	2009	2017	2007	2004	2016	2016	1999	2009	2005	2009
C42	0.3	0.3	0.4	2009	2008	2009	2017	2007	2004	2009	2016	1999	1999	2005	2009
C43	0.4	0.2	0.4	2009	2008	2009	2015	2007	2004	2009	2016	2004	1999	1997	2009
C44	0.5	0.1	0.4	2009	2008	2009	2015	2007	2004	2009	2016	2004	1999	1997	1996
C45	0.6	0.0	0.4	2009	1997	2009	2015	2007	2004	2009	2016	2004	1999	1997	1996
C46	0.0	0.5	0.5	2010	2008	2009	2017	2007	2004	2016	2016	1999	2016	2005	2005
C47	0.1	0.4	0.5	2010	2008	2009	2017	2007	2004	2016	2016	1999	2009	2005	2009
C48	0.2	0.3	0.5	2009	2008	2009	2017	2007	2004	2009	2016	1999	2009	2005	2009
C49	0.3	0.2	0.5	2009	2008	2009	2015	2007	2004	2009	2016	2004	2009	2005	2009
C50	0.4	0.1	0.5	2009	2008	2009	2015	2007	2004	2009	2016	2004	1999	1997	1996
C51	0.5	0.0	0.5	2009	1997	2009	2015	2007	2004	2009	2016	2004	1999	1997	1996
C52	0.0	0.4	0.6	2010	2008	2009	2017	2007	2004	2016	2016	1999	2009	2005	2006
C53	0.1	0.3	0.6	2010	2008	2009	2017	2007	2004	2016	2016	1999	2009	2005	2009
C54	0.2	0.2	0.6	2009	2008	2009	2015	2007	2004	2009	2016	1999	2009	2005	2009
C55	0.3	0.1	0.6	2009	2008	2009	2015	2007	2004	2009	2016	2004	2009	2005	1996
C56	0.4	0.0	0.6	2009	1997	2009	2015	2007	2004	2009	2016	2004	1999	1997	1996
C57	0.0	0.3	0.7	2010	2008	2009	2017	2007	2004	2016	2016	1999	2009	2013	2006
C58	0.1	0.2	0.7	2010	2008	2009	1996	2007	2004	2009	2016	1999	2009	2005	2009
C59	0.2	0.1	0.7	2009	2008	2009	1996	2007	2004	2009	2016	2004	2009	2005	1996
C60	0.3	0.0	0.7	2009	1997	2009	1996	2007	2004	2009	2016	2004	2008	1997	1996
C61	0.0	0.2	0.8	2010	2008	2009	1996	2007	2013	2016	2016	1999	2009	2013	1999
C62	0.1	0.1	0.8	2010	2008	2009	1996	2007	2004	2009	2016	2012	2009	2005	1999
C63	0.2	0.0	0.8	2009	1997	2009	1996	1999	2004	2009	2016	2004	2009	2005	1996
C64	0.0	0.1	0.9	2010	2008	2009	1996	2007	2013	2010	2016	2012	2009	2013	1999
C65	0.1	0.0	0.9	2010	1997	2009	1996	1999	2004	2009	2016	2012	2009	2013	1999
C66	0.0	0.0	1.0	2010	1997	2009	1996	1999	2013	2010	2016	2012	2009	2013	1999

Single Family House

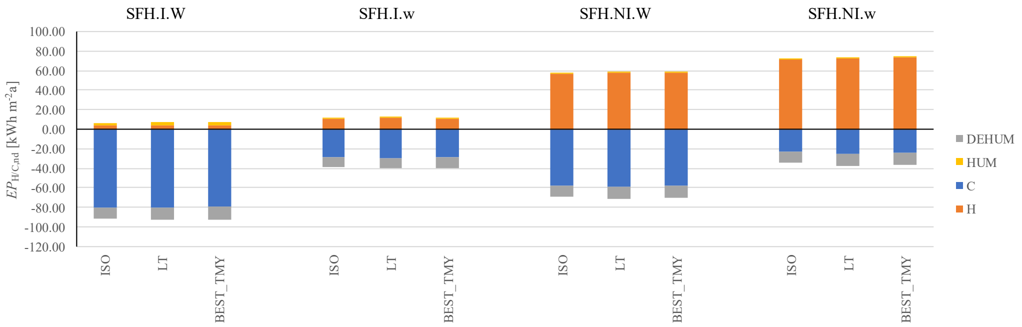

Fig. 48 City of Agrigento. Single Family House. Annual Energy performance comparison of TMYs realized with EN ISO 15927-4, average value on long term, and best TMY

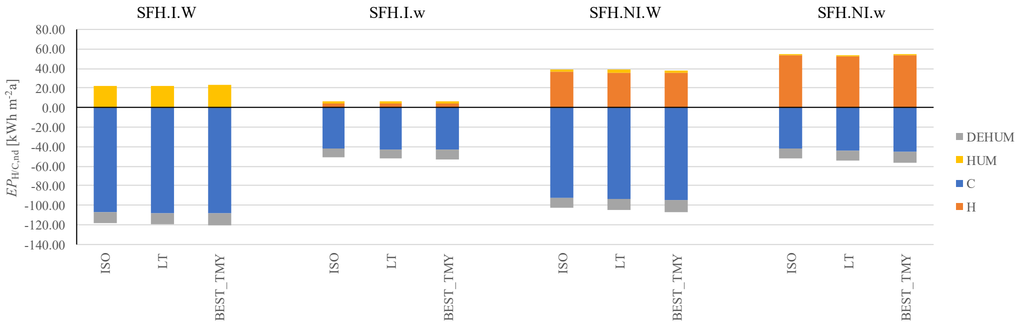

Fig. 49 City of Palermo. Single Family House. Annual Energy performance comparison of TMYs realized with EN ISO 15927-4, average value on long term, and best TMY

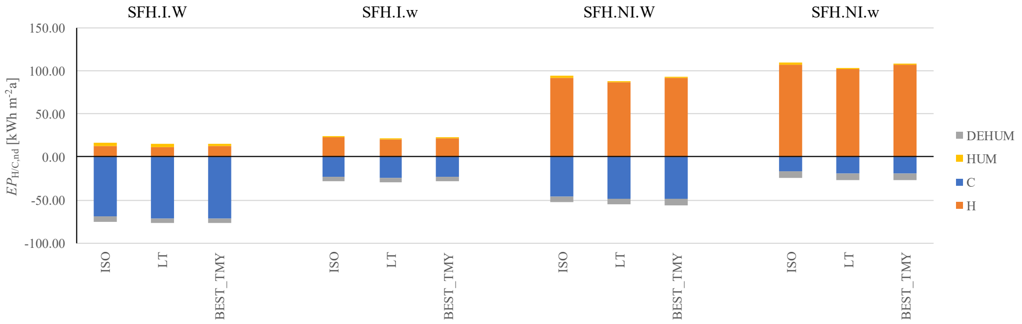

Fig. 50 City of Ragusa. Single Family House. Annual Energy performance comparison of TMYs realized with EN ISO 15927-4, average value on long term, and best TMY

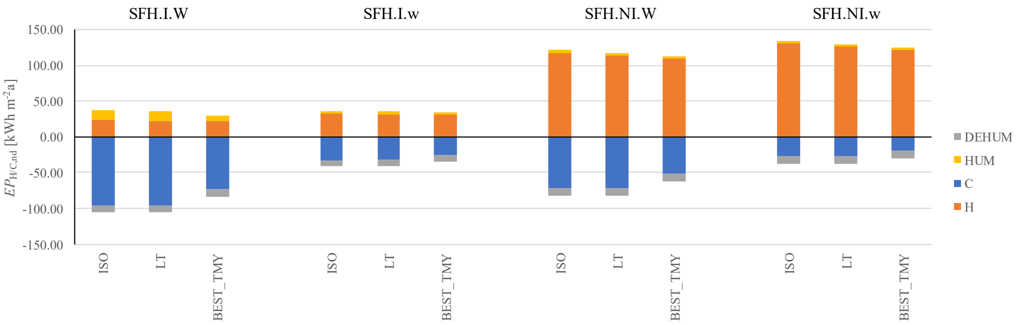

Fig. 51 City of Turin. Single Family House. Annual Energy performance comparison of TMYs realized with ISO 15927-4, average value on long term, and best TMY

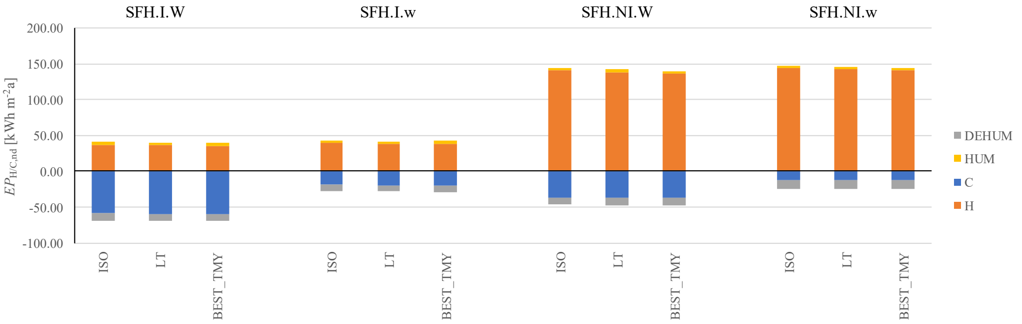

Fig. 52 City of Udine. Single Family House. Annual Energy performance comparison of TMYs realized with ISO 15927-4, average value on long term, and best TMY

Apartment block

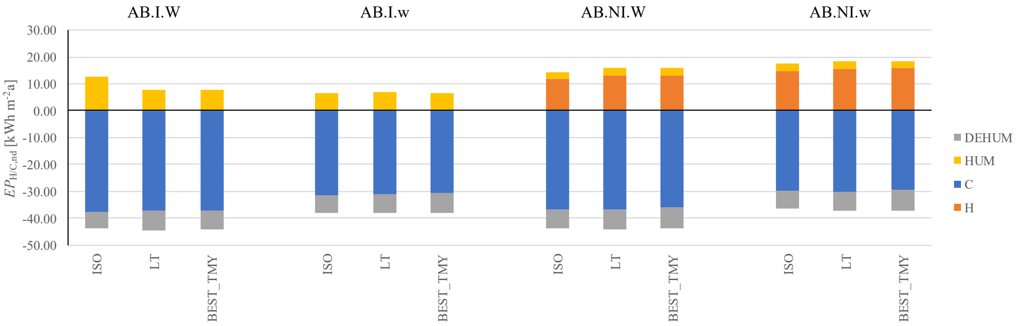

Fig. 53 City of Agrigento. Apartment block. Annual Energy performance comparison of TMYs realized with EN ISO 15927-4, average value on long term, and best TMY

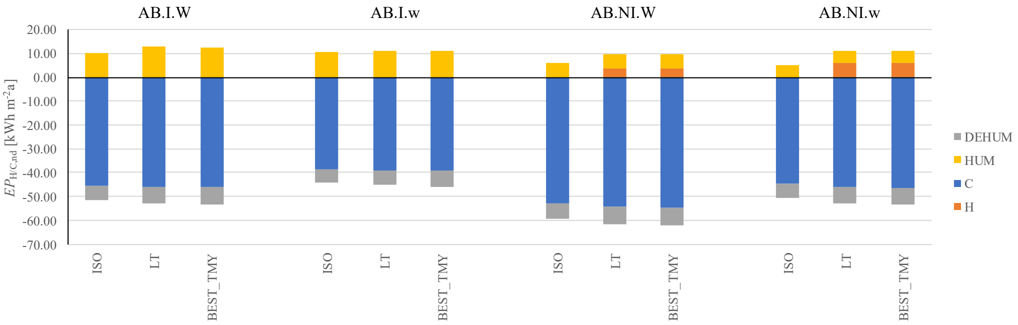

Fig. 54 City of Palermo. Apartment block. Annual Energy performance comparison of TMYs realized with EN ISO 15927-4, average value on long term, and best TMY

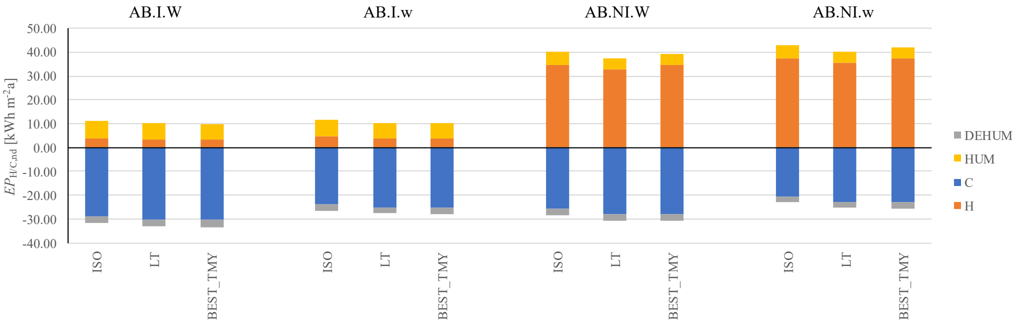

Fig. 55 City of Ragusa. Apartment block. Annual Energy performance comparison of TMYs realized with EN ISO 15927-4, average value on long term, and best TMY

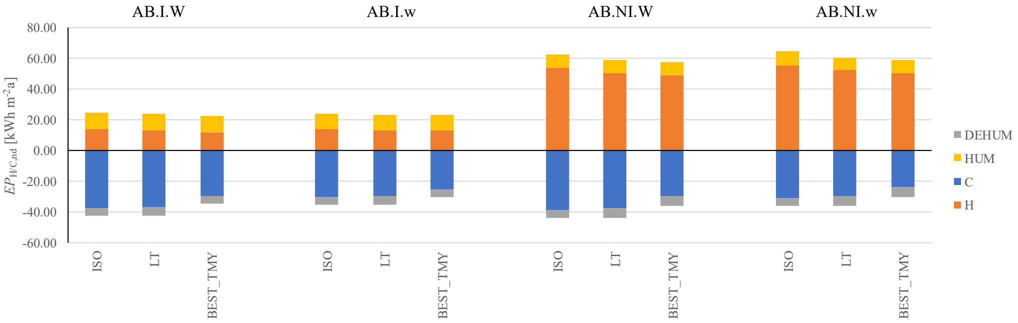

Fig. 56 City of Turin. Apartment block. Annual Energy performance comparison of TMYs realized with ISO 15927-4, average value on long term, and best TMY

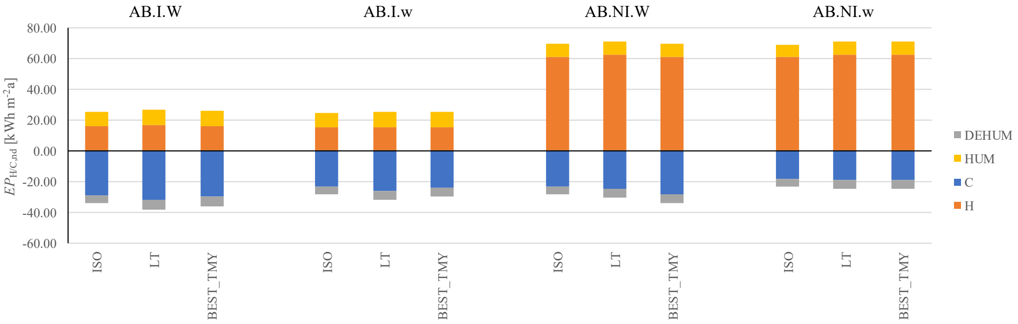

Fig. 57 City of Udine. Apartment block. Annual Energy performance comparison of TMYs realized with EN ISO 15927-4, average value on long term, and best TMY

Office Building

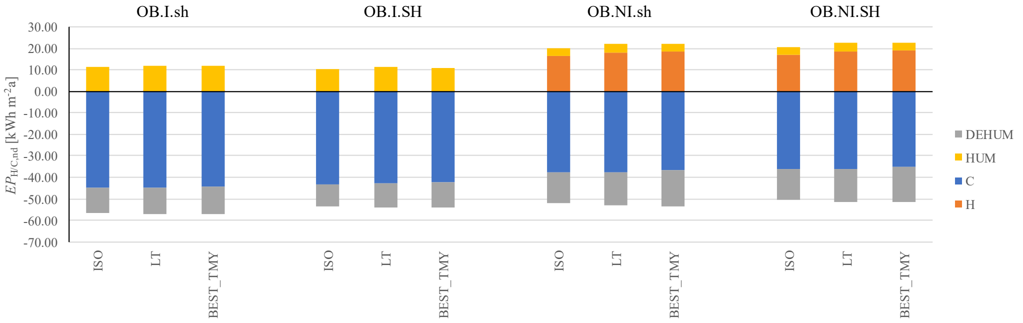

Fig. 58 City of Agrigento. Office Building. Annual Energy performance comparison of TMYs realized with ISO 15927-4, average value on long term, and best TMY

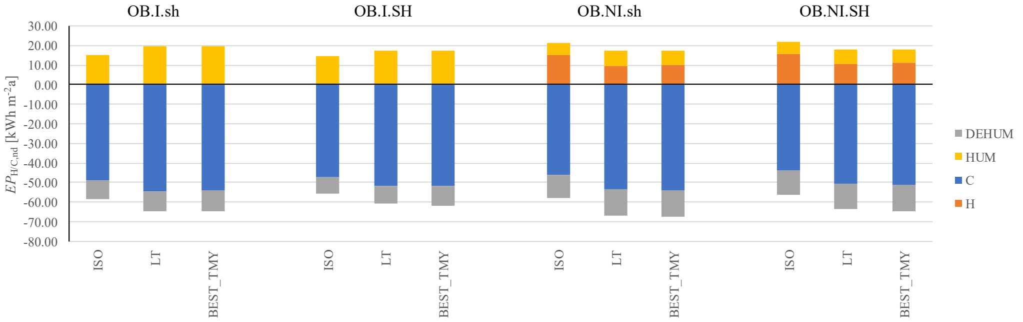

Fig. 59 City of Palermo. Office Building. Annual Energy performance comparison of TMYs realized with ISO 15927-4, average value on long term, and best TMY

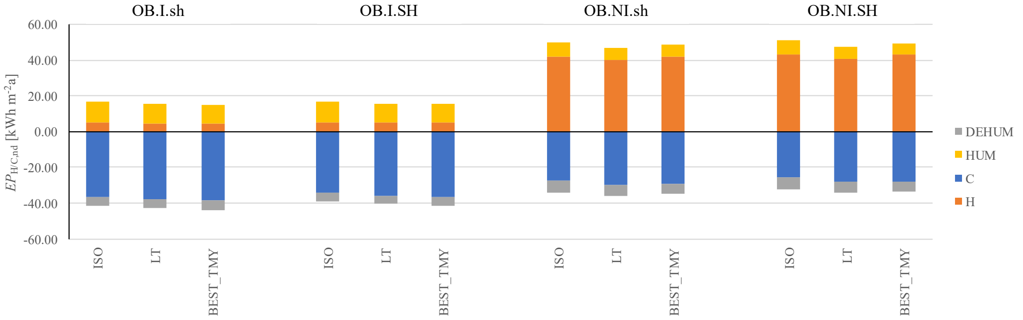

Fig. 60 City of Ragusa. Office Building. Annual Energy performance comparison of TMYs realized with ISO 15927-4, average value on long term, and best TMY

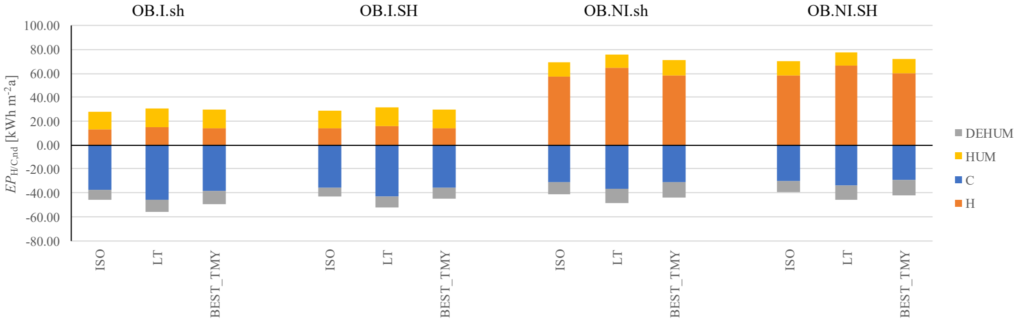

Fig. 61 City of Turin. Office Building. Annual Energy performance comparison of TMYs realized with ISO 15927-4, average value on long term, and best TMY

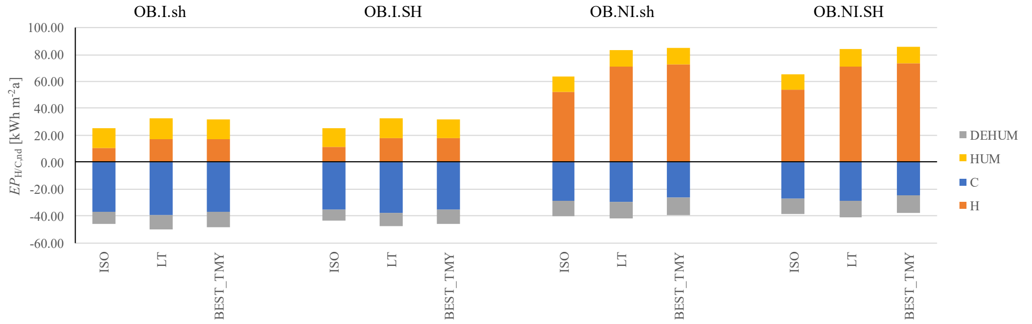

Fig. 62 City of Udine. Office Building. Annual Energy performance comparison of TMYs realized with ISO 15927-4, average value on long term, and best TMY

Variation of energy needs over time

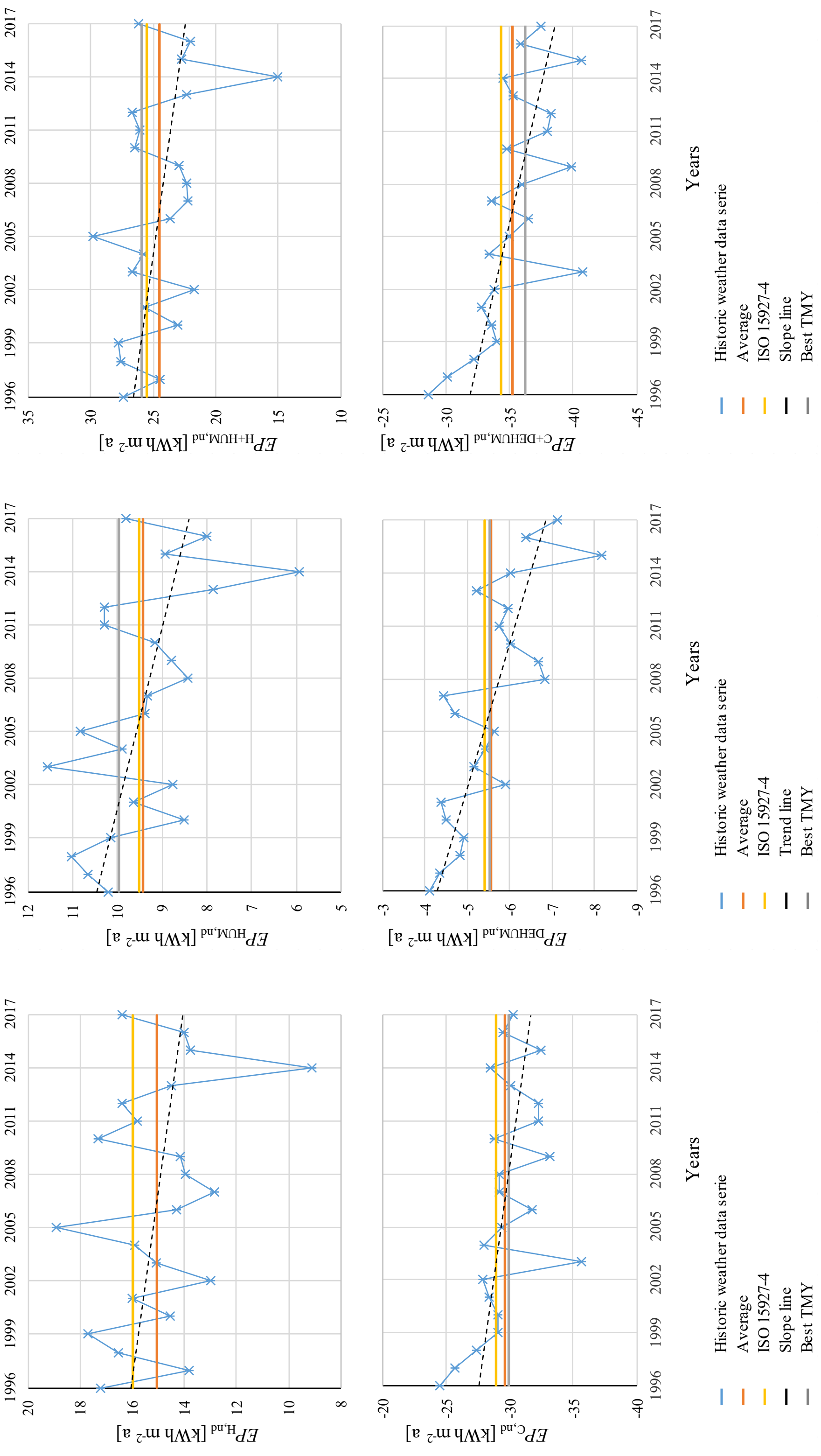

Fig. 63 City of Udine. Apartment block (AB.I.W). Annual Energy performance comparison of TMYs realized with ISO 15927-4, best TMY and annual energy needs

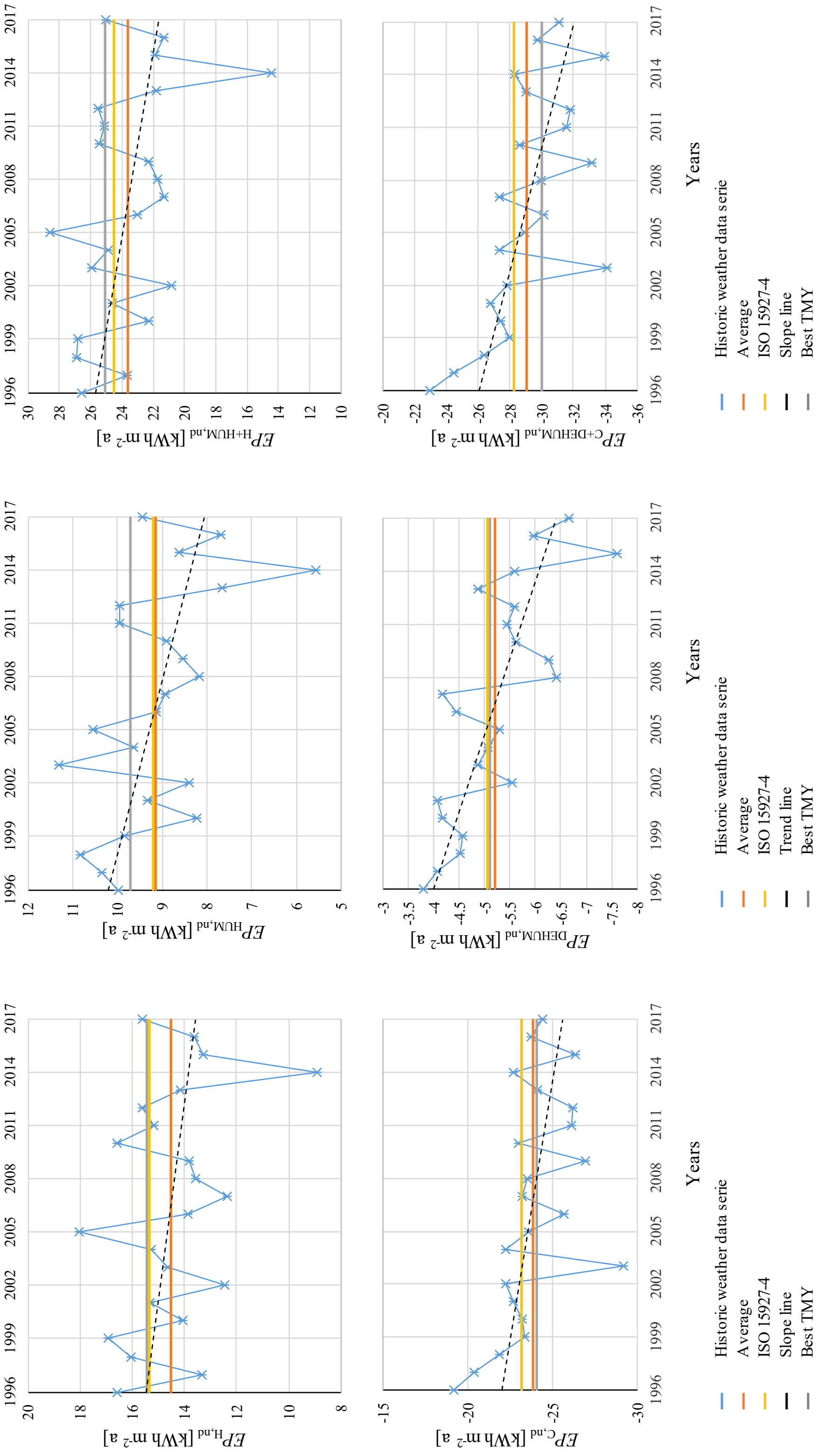

Fig. 64 City of Udine. Apartment block (AB.I.w). Annual Energy performance comparison of TMYs realized with ISO 15927-4, best TMY and annual energy needs

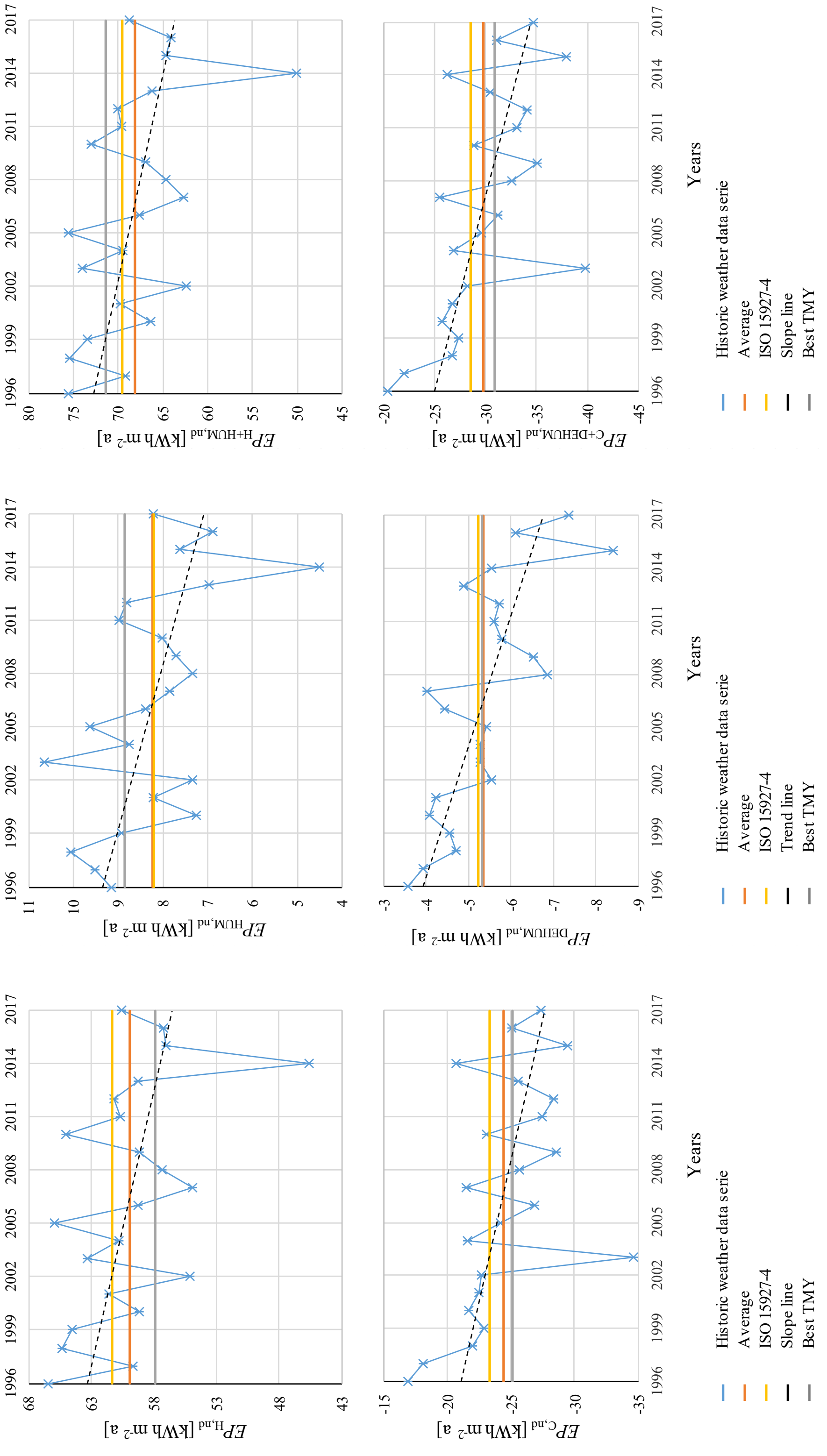

Fig. 65 City of Udine. Apartment block (AB.NI.W). Annual Energy performance comparison of TMYs realized with ISO 15927-4, best TMY and annual energy needs

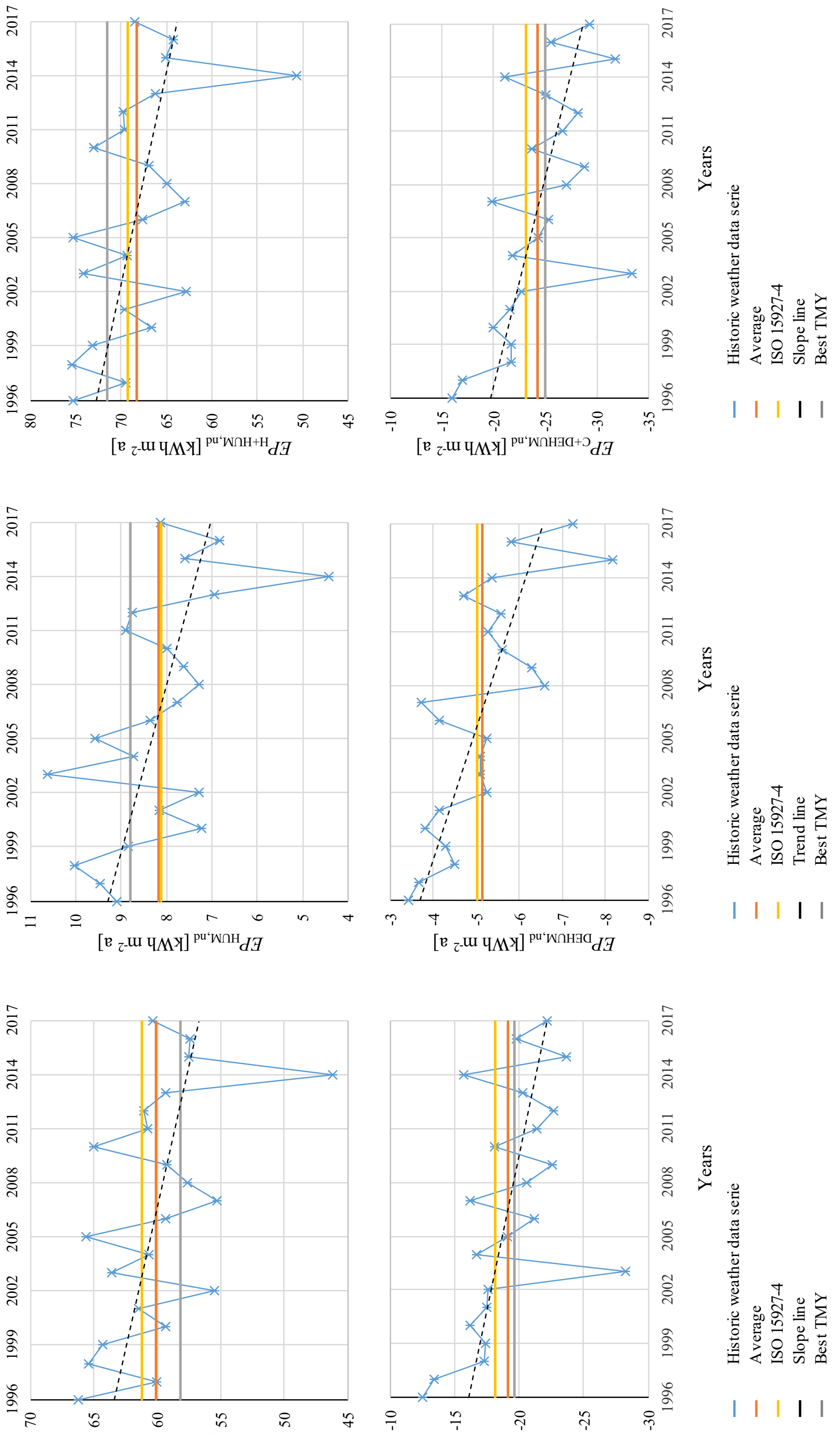

Fig. 66 City of Udine. Apartment block (AB.NI.w). Annual Energy performance comparison of TMYs realized with ISO 15927-4, best TMY and annual energy needs

5 Conclusion

This doctorate work has examined the design of Nearly Zero-Energy Buildings.
The overall aspects on bioclimatic design has not been addressed, while the mandatory requests deriving from Italian legislation were analysed. Also, the variable of ventilation regarding fenestration is not examined.
It is expected that in the coming years the building designs will be increasingly pushed to consume less energy. In general, the building envelope will be characterized by elements with high thermal resistance, by windows able to exploit / limit the solar heat gain according to the season, and by opaque building envelopes able to dampen and mitigate the external climatic stresses. These are also the prerogatives of the legislative decrees and EU Directives published in recent years.
However, the design of NZEB to provide effective results shall be based on calculation methods that can quantify the advantages of using determinate technologies from an energy point of view. In this context, this point has been the focus of my research activity. For each topic investigated, the work phases have been the following: (a) the analysis of scientific literature and technical and legislative regulations (b) the application of complex simulation models to some case studies, (c) a parametric analysis to evaluate the effect of design choices on the *EP* of buildings.
The research activity has been divided into other four points. They are: energy performance requirements of NZEBs, calculation models of building energy performance, the design of NZEBs, and the best choice of climatic data.

5.1 Requirement of NZEBs

The definition of the minimum *EP* of NZEBs is very different between the EU Member States. The variation is mainly due to the different economic, climatic, social, and feature technological states of each country. In any case, in February 2015, the EU has adopted the principle of "*Efficiency First*" through the launch of the Energy Union Communication. This part of the activity has concerned the verification of the new Inter-Ministerial Decree 26/06/2015 (MD). This MD establishes minimum requirements for the EP of buildings, including low energy buildings and Nearly Zero-Energy Buildings. The application of the different case studies has shown that in order to obtain a NZEB there isn't only set of building envelope combinations, but in general there is a limited field of existence that satisfies all the legislative requirements set by the MD.
Starting from the possible energy solutions, therefore, the designer will encourage or not the greater thermal insulation of the different components of the building envelope (transparent, vertical opaque, roof slabs, ground slabs, the correction of thermal bridges).

In the design of NZEBs, every choice on the building envelope components has repercussions on the thermos-physical characteristics of the other elements (for example, the use of high-performance shading device or sunscreens also means more thermal insulation of the opaque envelope, etc.).

The deepening of this issue has allowed me to do a contribution in improving the national reference framework on NZEB. In particular, my studies have therefore considered the methodology of the *notional reference building*.

Another objective of the research was related to the identification of energy needs benchmarks for NZEBs. These benchmarks have been validated with the information available in the bibliography.

5.2 Improvement of National NZEB Framework

This part of the activity involved analysis and improvement proposals of the methodology for verifying the energy performance of NZEBs. For the verification of Minimum requirements of EP, the notional reference building (NRB) approach has been investigated. To date, this methodology has been applied throughout Europe with reference to the steady-state simplified models.

The following suggestions are provided to overcome the limitations of the approach: (1) the thermal bridge effect should be considerate separately from the *U*-value of the building envelope (consideration of reference linear thermal transmittance) (2) the actual technical building system auxiliaries should be attributed to the NRB, so as to easily estimate the electricity energy need by building service; (3) the thermal systems characteristics (except for the thermal system efficiency) of the NRB are assumed the same of the actual building; (4) the mean global seasonal efficiency of a technical building system is expressed as the ratio of the energy need, determinate in reference conditions, to the total primary energy, as to represent the actual system.

In the next years, a gradual transition to the detailed dynamic simulation (or/and simplified hourly simulation) is expected. In the transition there is the question of defining the detail level used for the model description.

The final purpose of the research is to verify if the reference parameters implemented in the current regulation provide adequate information to correctly calculate the *EP* index of the NRB even when a detailed simulation analysis is performed.

The research allowed to reach interesting results both from a procedural and analytical point of view, moreover recommendations to give robustness to the NRB approach are specified. An updating of the methodology is foreseen with reference to the main calculation models in the technical regulations (EN ISO 13790 and in the new EN ISO 52016-1).

5.3 Calculation Models

In the design of NZEBs, the Italian legislation provides the application of quasi-steady-state calculation method. For several case studies the $EP_{\mathrm{C,nd}}$ and $EP_{\mathrm{H,nd}}$ have been calculated with two different approaches: a Quasi-Steady State method and a Detailed Dynamic energy simulation. The analysis has considered a block apartment composed by several building units.

For six levels of thermal insulation of the building envelope and for several locations, the *EP* of each building unit was calculated and analysed.

The main conclusion of this research concerns the limits of the Quasi-Steady State Approach to predict the energy needs of NZEB accurately. Huge deviations appear in warm climates, especially in the heating energy needs.

In any case for each location, there is an existence field for which the Quasi-Steady State Approach offers representative results with a 20% deviation from the results calculated with *EnergyPlus*.

In any case, the more important deviation appears in the assessment of single building units where there are no compensations between energy needs. It follows that the verification of the whole building without adequate attention to the individual building units may involve to significant design errors leading to the failure to build a building consisting of nearly zero-energy building units.

A homogeneity index has also been defined which expresses the variation of the energy performance of building unit respect the energy performance of whole building. In the near future in fact, to obtain good results, greater attention must be paid to the comfort (and energy consumption) of the individual building units.

5.4 Transparent Building Envelope of NZEBs

This part of activity investigates the role of the transparent building envelope in achieving NZEB target and in particular the impact of different orientations' WWR on the *EP* of NZEB in several climatic zones.

To this purpose the energy performance of numerous case-studies (with different level of thermal insulation, windows properties, shading devices, WWR) was assessed. From the analyses appears that the cooling energy needs vary according to the position of the building unit, even if in a less evident way than the heating energy needs. The impact of shading devices is also significant.

In the choosing of the best solution of transparent building envelope plays a fundamental role both the main orientation of the building unit and the extension of the dispersing surface. *For all the case studies and for all the locations, with the only exception of Turin for the northern front (configuration WWR of 10%), the energy need for cooling is higher than the one for heating. For all the analysed locations, the effect of WWR on the East front is very pronounced, followed by that on the West. For Turin the best energy benefits are for WWR between 10 and 20%.* To avoid overheating in the summer it will be good practice to limit the windows on the east side or to use high-performance solar shading devices.

Therefore, in order to achieve the NZEB target it is not a good design practice to increase the WWR ratio. Moreover, the orientation of the windows has a significant impact on the energy performance of the building. Consequently, the weakest link of the NZEBs design concerns the cooling energy performance. In the future it will be necessary to find a good compromise between availability of windows and energy performance, perhaps through the employment of glazing innovative materials.

5.5 Opaque Building Envelope of Low Energy Buildings and NZEBs

The effect of thermal insulation is more visible in the limitation of energy need for heating. The thermal insulation, in contrast, if it is not associated to other design strategies (thermal mass of the building in combination with nocturnal ventilation) could have little influence on cooling energy need. The most effective design solution that shows positive effects on cooling energy performance is the use of shading devices (or external double skins, glazing solar films). Furthermore, the use of thermal insulation in cold and hot locations leads to very different results on energy performance. The use of thermal insulation in cold and hot locations leads to very different results on energy performance. As seen in bibliography ([256], [54]), also aspects like the positioning of the thermal mass layers and the use of natural cooling ventilation by means of the passive techniques shown important effects on the limitation of the energy need of buildings. The importance of thermal insulation in NZEBs depends by the position of the building unit in the whole building and also by the presence of glazing surfaces, and by the performance of solar shading devices. The importance of thermal insulation also increases with decreasing of the internal heat gains. This relationship has been confirmed in some studies ([93],[95],[96]).

The case-studies examined were in fact an Apartment block (high crowded social housing) and an Office building characterized by high internal heat gains. According to the calculations performed with *EnergyPlus*, with the improving of the solar shading efficiency there is a significant increasing of cooling energy performance.

The results of energy simulations of section 3.2 indicate that the increase of the thermal insulation shows different effects which they are not the same for all building units and climatic zones.

For Belluno (HDD 3841) the increasing of thermal insulation has a positive effect on heating energy need for the whole building and for every building unit. Differently, this design choice involves an increase of cooling energy needs for the whole building and related building units. For hot localities like Palermo (HDD 1121), instead, the thermal insulation leads to a reduction of cooling and heating energy needs for all building units except those on the ground floor.

Future researches will enlarge the analysis of energy imbalance by investigating the effects of different degree of thermal insulation on building envelope for more than a few building categories and weather conditions and with the identification of an indicator of thermal imbalance applied also to building units.

5.6 Presence of Thermal Bridges in NZEBs

From the research carried out it results that the individual MS generally don't set minimum requirements or control the constructive quality of junctions. Only some MSs have included in their regulation specific requirements concerning the quality of building junctions (max. linear *U*-value or minimum dimensionless temperature factors). The aim of this activity research is to improve the existing methodological framework concerning the verification of *EP* of NZEB through the methodology of the notional reference building by proposing, in the light of the results obtained, the adaptation of the approach including thermal bridges.

In proposing a solution to the problem, without modifying the verification parameters of the MD 26/06/2015, this activity was carried out to evaluate a possible archive of ψ-values for the most common types of thermal bridges as the climatic zone changes and the insulation techniques.

This research has demonstrated, even for a single location (Turin), that the impact of thermal transmission due to thermal bridges is not negligible and it can even represent about 40% of heating energy need.

5.7 Climatic Data

The last part of my research activity have concerned the construction of TMYs for the verification and design of NZEBs using dynamic simulation program. A new methodology has been proposed which considers the construction of TMYs to determine the sensible and latent energy needs of buildings. Indeed, the outdoor climatic data represent an important factor in the calculations of the EP. With the legislative and normative update in progress the detailed energy simulation will be always more wide used for forthcoming developments in energy design and evaluation of *EP*.

The methodology was applied to five locations and verified on twelve case studies with different characteristics of the building envelope. Therefore, sixty-seven TMYs have been tested. The activity allowed to analyse and develop new procedures for the realization of TMY alternative to the standard methodology contained in EN ISO 15927-4.

Similarly, together with the University of Udine, new methods have been studied for the generation of Moisture Reference Years for Interstitial Condensation Risk Assessment.

With the University of Trieste, a collaboration is underway to define new data for the design of heating and cooling building systems.

This research activity deserves attention because the design of the NZEB depends on the reliability of the data contained in the reference standards.

To investigate this topic, future research will enlarge the analysis of weighting coefficients in the TMY in different climatic zones, with other building types, also investigating the role of the technical building systems. It would also be interesting to investigate different occupancy patterns, bearing in mind that the occupancy *behaviour influences the energy performance but, at the same time, occupancy patterns are influenced by the climatic context.*

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