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A comparison between new European technical standards and dynamic simulation tools for chiller modelling

F. Bianco Mauthe Degerfeld[1], G. De Luca[1], I. Ballarini[1], and V. Corrado[1]
[1]Department of Energy "Galileo Ferraris" Politecnico di Torino, Turin, Italy

Corresponding author: franz.bianco@polito.it

Abstract. In the last years, new technical standards for the assessment of the energy efficiency of technical building systems were developed by the European Committee for Standardization (CEN). These procedures were conceived as to combine the easiness of the calculation methodologies and their related assumptions with a sufficient level of accuracy. While the former objective is often achieved, the latter is a challenging task as the procedures sometimes fail to simulate in a proper way the actual performance of the technical systems. On the other hand, the detailed procedures applied by detailed dynamic energy simulation tools are more precise and complex; however, for their application, they need a wide range of input data that are often hard to collect. For this reason, simplified procedures are now commonly applied, above all in the case of existing buildings. Nevertheless, these procedures need to be deeply analysed and validated. In this paper, the main standard calculation procedures addressed to chillers and specified in EN 16798-13:2017 were analysed, with a focus on the required input data and the calculation procedures. The same approach was then applied to the more detailed calculation methods used in the dynamic tools EnergyPlus and TRNSYS, and the results were compared. The theoretical analysis was then followed by a case study approach. A reference office building, representative of the Italian building stock, was selected and analysed in two different Italian climatic zones. The determination of the thermal energy need for cooling was performed by means of EnergyPlus, while the assessment of the energy demand related to technical building systems was performed both with EnergyPlus and with the standard procedures. This paper is part of a wider research activity finalised to the analysis of the technical building systems calculation procedures, taking into account different generation systems and thermal coupling modes between the technical systems and the building itself.

1. Introduction

Mandate M/480 EN [1] for the development of standards in line with the 2010/31/EU directive [2], published in 2010, started a phase of renovation and improvement of new standard procedures for the assessment of the energy performance of buildings. Compared to the withdrawn ones, the new standards, as presented in Figure 2, are able to offer a not negligible differentiation in the procedures. Some studies were performed on some of the withdrawn framework standard procedures, such as the work on boilers of Mattarelli and Piva [3], and the work on chillers of Hantsch et al. [4]. Since the new procedures were developed and published in a relatively recent period, studies on the accuracy of these methods still need to be performed.

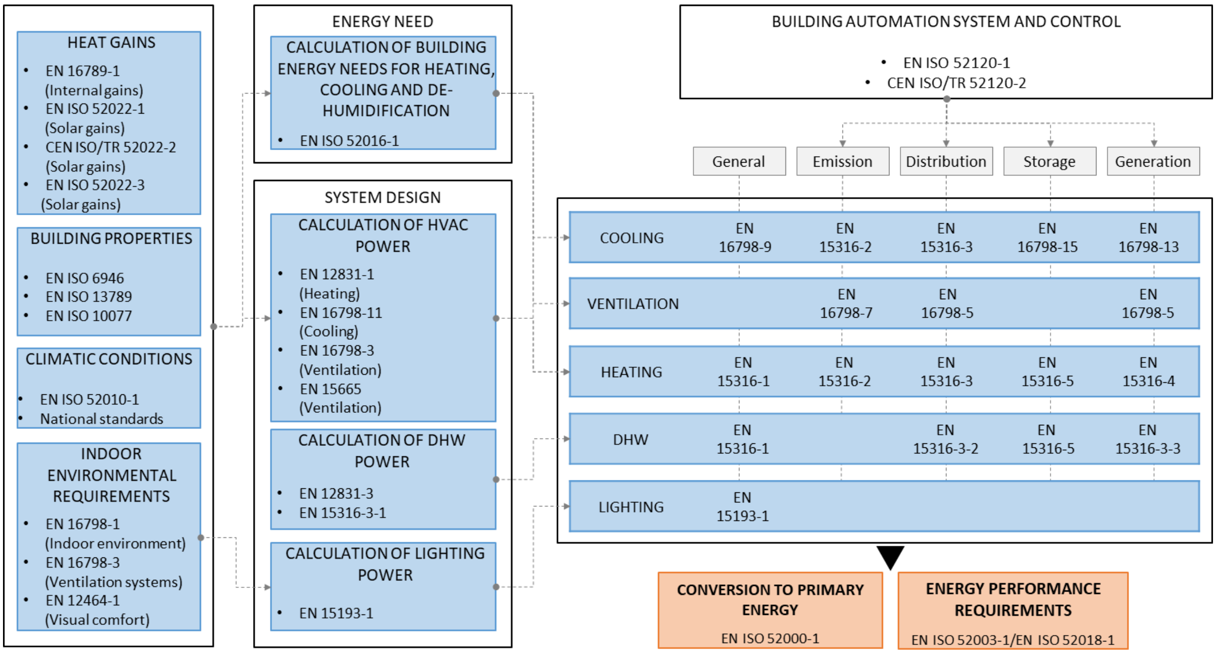


Figure 1. Regulatory framework under Mandate M/480 EN of 2010 [5].

The new standard procedures are a part of a larger group of calculation models that are frequently used to assess the energy performance of buildings; they include both the more complex calculation methods that are frequently found in detailed simulation software and the more straightforward calculation methods that are typically used in standards.

This work is part of a wider study aimed to enhance the simplified calculation procedures for the determination of the energy performances of the technical building systems. This study is a first validation step regarding the calculation procedure of chillers.

The current standard regarding the cooling generators was analysed and its procedures explained as well as the ones deployed in two of the main energy calculation software, i.e., EnergyPlus and TRNSYS, in order to highlight the main differences. Deploying a comparative validation procedure, a case study approach was followed in order to perform a comparison between the standard methods and the EnergyPlus model. An office building, located in two different Italian cities, was analysed and a chiller performance was determined. The results were then compared in terms of both monthly and hourly electrical consumption.

2. Method

In this section, four main calculation procedures to determine the energy performance of refrigeration units were presented, as well as the procedures deployed to compare their calculation results.

Among the different calculation procedures related to cooling generator’s performance determination, the following four were deepened: the two explained in the EN 16798-13 standard [6], the calculation procedure for electric chiller based on condenser entering temperature deployed in EnergyPlus, and the detailed procedure used in TRNSYS.

2.1. The simplified method of EN 16798-13

A simplified calculation method to evaluate the energy performance of refrigeration units for cooling is provided by the EN 16798-13 technical standard [6]. The procedure is applicable to compression or absorption units, and is aimed at assessing their electrical energy input and thermal energy extracted from the cold source, the recoverable thermal energy, and the auxiliary energy consumptions. The EN 16798-13 [6] provides two different calculation methods applicable to compression and absorption chillers (Method 1, Figure 2) and to refrigeration units, splits and multi-splits, and variable refrigerant gas (VRF) systems (Method 2, Figure 3).

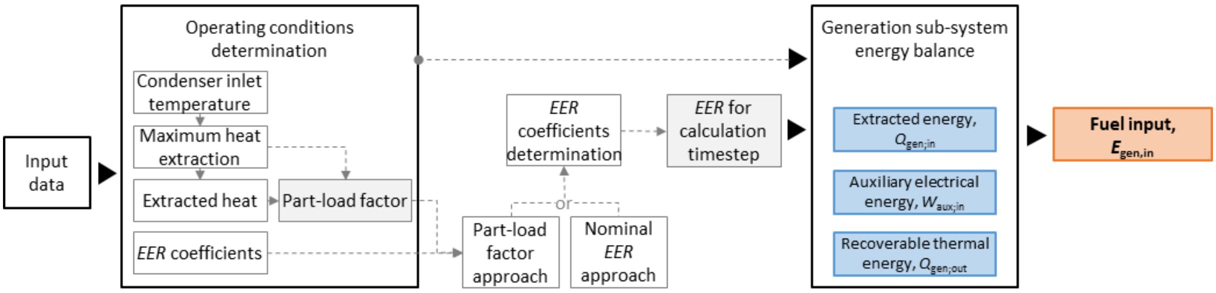


Figure 2. Calculation procedure (Method 1 in EN 16798-13) for chiller generation sub-system [5].

The first method, recommended only if detailed input data related to the machines are available, consists of three main calculation steps (with hourly or per bin calculation intervals):

1. Determination of the operating conditions,
2. Determination of the machine energy efficiency ratio (*EER*) coefficients, and
3. Resolution of the generation sub-system energy balance.

In the first step, the operational boundary conditions for the operation of the generation system are defined, including the condenser inlet and outlet temperatures, and the part load factors (depending on the effective and maximum heat extraction). The effective *EER* coefficients are derived from the *EER*s at reference conditions by means of the correction factor f_{EER}. It is calculated, at each time step, by applying either a part-load factor approach or a nominal *EER* approach. In the former approach, the *EER* is calculated by applying Equation (1) if the effective part-load factor is higher than the minimum factor; otherwise, Equation (2) is used. In the latter approach, based on EN 14825 [7], the effective *EER* is calculated through the use of the nominal *EERs*, as well as four coefficients calculated using the chiller *EER*, the evaporator outlet temperature, and the condenser inlet temperature at five different partial loads conditions, as reported in Equation (3).

Then, the calculation of the heat extracted by the cooling generation system, of the heat recovered or rejected, of the auxiliary system consumption, and of the required energy for the compression chiller is performed.

$$f_{\mathrm{EER};j} = \frac{273{,}15 + \vartheta_{\mathrm{evap;out}}}{\vartheta_{\mathrm{cond;in}} - \vartheta_{\mathrm{evap;out}} + \left(\frac{LR_j}{100}\right)\cdot\Delta\vartheta_{\mathrm{corr};j}} \cdot \left[C_{1;j}\left(\frac{LR_j}{100}\right)^3 + C_{2;j}\left(\frac{LR_j}{100}\right)^2 + C_{3;j}\left(\frac{LR_j}{100}\right) + C_{4;j}\right] \tag{1}$$

$$f_{\mathrm{EER};j} = \frac{273{,}15 + \vartheta_{\mathrm{evap;out}}}{\vartheta_{\mathrm{cond;in}} - \vartheta_{\mathrm{evap;out}} + \left(\frac{LR_{j;\min}}{100}\right)\cdot\Delta\vartheta_{\mathrm{corr};j}} \cdot \left[C_{1;j}\left(\frac{LR_{j;\min}}{100}\right)^3 + C_{2;j}\left(\frac{LR_{j;\min}}{100}\right)^2 + C_{3;j}\left(\frac{LR_{j;\min}}{100}\right) + C_{4;j}\right] \tag{2}$$

$$f_{\mathrm{EER};j} = \frac{\dfrac{273{,}15 + \vartheta_{\mathrm{evap;out}}}{\vartheta_{\mathrm{cond;in}} - \vartheta_{\mathrm{evap;out}}}}{\dfrac{273{,}15 + \vartheta_{\mathrm{evap;out;n}}}{\vartheta_{\mathrm{cond;in;n}} - \vartheta_{\mathrm{evap;out;n}}}} \tag{3}$$

Where $f_{EER;j}$ is the correction factor of the *EER*, $\vartheta_{\mathrm{evap;out}}$ is the evaporator outlet temperature (in °C), $\vartheta_{\mathrm{cond;in}}$ is the condenser inlet temperature (in °C), $\vartheta_{\mathrm{cond;in;n}}$ is the condenser inlet temperature at nominal conditions (in °C), $\Delta\vartheta_{\mathrm{corr};j}$ is the correction temperature difference of the chiller, LR_j is the effective part load ratio, $LR_{j;\mathrm{min}}$ is the minimum effective part load ratio, and $C_{1\text{-}4;j}$ are the chiller's coefficients.

The main issue related to the applicability of this method is related to the calculation of the generator heat extraction and of the *EER*'s correction factor (Equation (1) and (2)); these in fact require the solution of linear systems of different equations, that may lead to increases in the complexity of the calculation procedure as well as in the computational time.

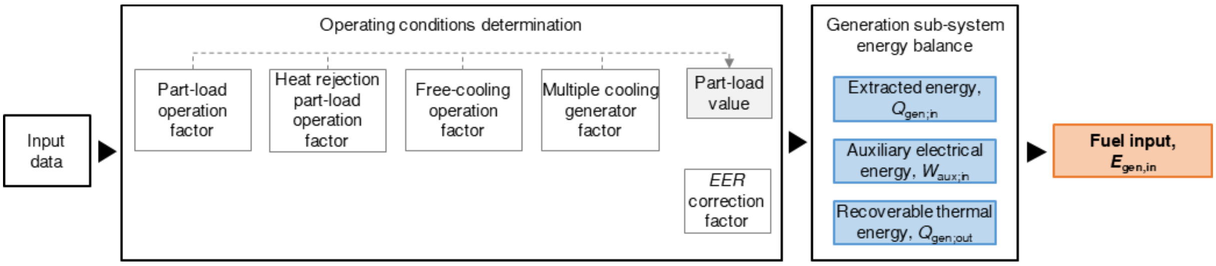


Figure 3. Calculation procedure (Method 2 in EN 16798-13) for chiller generation sub-system [5].

The second method, recommended in absence of detailed information regarding the machines, firstly consists in two main calculation steps (with hourly or monthly calculation intervals):

1. Determination of the operating conditions, and
2. Resolution of the generation sub-system energy balance.

In the first step, the partial load value (*PLV*) and the *EER* correction factor are determined. As for the former, calculated as in Equation (4), four different factors are required, namely the part-load operation factor (Equation (6)), the heat rejection part-load operation factor (Equation (5)), the free-cooling operation factor (derived from tabulated values), and the multiple cooling generator factor (derived from tabulated values).

$$PLV = LR\cdot f_{\mathrm{hr;PL}}\cdot f_{\mathrm{hr;fc}}\cdot f_{\mathrm{C;mult}} \tag{4}$$

$$LR = Q_{\mathrm{C;gen;in;req}}/(t_{\mathrm{C}}\cdot \Phi_{\mathrm{C}}) \tag{5}$$

$$f_{\mathrm{hr;PL}} = a_0 + a_1\cdot\vartheta_{\mathrm{e}} + a_2\cdot\vartheta_{\mathrm{e}}^2 \tag{6}$$

Where *PLV* is the partial load value, *LR* is the effective part load ratio, $f_{\mathrm{hr;PL}}$ is the chiller part load factor of the heat rejection system, $f_{\mathrm{hr;fc}}$ is the chiller free cooling factor, $f_{\mathrm{C;mult}}$ is the factor for multiple refrigeration units, $Q_{\mathrm{C;gen;in;req}}$ is the required thermal energy to be extracted by the refrigeration unit (in kWh), t_{C} is the cooling generation operation time interval, Φ_{C} is the nominal thermal power extracted from the distribution system by the refrigeration system, ϑ_{e} is the outdoor air temperature, and a_0, a_1, and a_2 are tabulated coefficients for the calculation of the heat rejection system part-load factor.

The *EER* correction factor (required for temperatures differing from the reference ones reported in the EN 14511 [8] technical standard) is hence calculated as the ratio between the Carnot *EER*s at working and nominal conditions, according to Equation (7),

$$f_{\mathrm{EER;corr}} = \frac{\dfrac{T_{0;\mathrm{abs}} + \vartheta_{\mathrm{C;gen;req;out}} - \Delta\vartheta_{\mathrm{evap}}}{\left(T_{0;\mathrm{abs}} + \vartheta_{\mathrm{C;gen;hr;req;in;ref}} + \Delta\vartheta_{\mathrm{cond}}\right) - \left(T_{0;\mathrm{abs}} + \vartheta_{\mathrm{C;gen;req;out}} - \Delta\vartheta_{\mathrm{evap}}\right)}}{\dfrac{T_{0;abs} + \vartheta_{\mathrm{C;gen;req;out;n}} - \Delta\vartheta_{\mathrm{evap}}}{\left(T_{0;\mathrm{abs}} + \vartheta_{\mathrm{C;gen;hr;req;in;n}} + \Delta\vartheta_{\mathrm{cond}}\right) - \left(T_{0;\mathrm{abs}} + \vartheta_{\mathrm{C;gen;req;out;n}} - \Delta\vartheta_{\mathrm{evap}}\right)}} \tag{7}$$

where $T_{0;\mathrm{abs}}$ is the absolute reference temperature (in K), $\vartheta_{\mathrm{C;gen;req;out}}$ and $\vartheta_{\mathrm{C;gen;req;out;n}}$ are the required cooling generation output temperatures (in °C), respectively at working and nominal conditions, $\vartheta_{\mathrm{C;gen;hr;req;in;ref}}$ and $\vartheta_{\mathrm{C;gen;hr;req;in;n}}$ are the required heat rejection input temperatures (in °C), respectively at working and nominal conditions, $\Delta\vartheta_{\mathrm{evap}}$ is the temperature difference within the evaporator (in K), and $\Delta\vartheta_{\mathrm{cond}}$ is the temperature difference within the condenser (in K).

Within the generation sub-system energy balance, the calculation of the thermal energy extracted from the machine, the energy input for the operation of the machine, and the calculation of auxiliary energy (considering the contribution of the heat rejection, the control, and the distribution systems) are performed.

2.2. The detailed method of EnergyPlus

The model of electrical chiller available in the EnergyPlus software [9] is closest to the one presented in the EN 16798-13 technical standard [6]. However, the procedure to assess the performance of this component is based on different input data, such as the fluid temperature difference, the condenser outlet temperature, and the condenser inlet temperature.

The calculation procedure related to an inlet temperature based electric chiller is deepened below. The calculation model provided in EnergyPlus, derived from DOE-2.1, simulates the machine thermal performance, and the compressor's and condenser fans' power consumptions, while the associated pumps are not accounted in this model (an additional component needs to be modelled). The procedure is based on user-supplied information on the machine at nominal conditions, while the data at operative conditions are derived by means of the following correction factors:

- Cooling capacity factor (*CC factor*), which is multiplied to the reference capacity to derive the available chiller capacity at operating temperatures. This factor is calculated through a biquadratic performance curve (Equation (8)), depending on the chilled water set-point temperature and the inlet condenser fluid temperature,

  $$\Delta\Phi_{\mathrm{H}} = a+b\cdot(\vartheta_{\mathrm{chw,set}})+c\cdot(\vartheta_{\mathrm{chw,set}})^2+d\cdot(\vartheta_{\mathrm{chw,in}})+e\cdot(\vartheta_{\mathrm{chw,in}})^2+f\cdot(\vartheta_{\mathrm{chw,set}})\cdot(\vartheta_{\mathrm{chw,in}}) \tag{8}$$

  where $\vartheta_{\mathrm{chw,set}}$ is the chilled water set-point temperature (in °C), $\vartheta_{\mathrm{chw,in}}$ is the chilled water inlet temperature (in °C), and *a*, *b*, *c*, *d*, *e*, and *f* are model built-in or user defined factors,
- Temperature-based energy input to cooling output factor (EIR-T factor), which is multiplied to the reference energy input to cooling output ratio (*EIR*) – defined as the inverse of the *EER* – to derive the *EIR* at specific operating temperatures (at full load). This factor is calculated through a biquadratic performance curve, depending on the leaving chilled water temperature and the entering condenser fluid temperature,
- Part-load-based energy input to cooling output factor (EIR-PLR factor), which is multiplied to the reference *EIR* and to the EIR-T factor to determine the *EIR* at specific operating conditions. This factor is a quadratic performance curve, depending on the part-load ratio.

Once these factors are defined, the calculation procedure consists of the following steps (with hourly or sub-hourly calculation intervals):

1. Calculation of the available cooling capacity,
2. Calculation of the evaporator heat transfer rate required for the inlet water to meet the outlet set-point temperature,
3. Comparison of the heat transfer rate (point 2) to the available cooling capacity (point 1), and calculation of the outlet chilled water temperature if the available cooling capacity is not sufficient to meet the set-point temperature (otherwise, the temperature is equal to the set-point temperature),
4. Calculation of the part-load ratio as the ratio between the evaporator heat transfer rate (point 2) and the available chiller capacity (point 1),
5. Resolution of the generation sub-system energy balance, in which the chiller condenser heat transfer energy, the chiller evaporator cooling energy, and the compressor and condenser fan electric energy are calculated.

2.3. The detailed method of TRNSYS

To provide a comprehensive picture of the existing chiller modelling procedure, the TRNSYS model is described as well; however, this will be analysed in a future work.

The procedure requires the input of the *EER* and capacity data for various values of the chilled water set-point temperature and chilled inlet water temperature. Starting from these data, the *EER* at operating conditions is derived through an interpolation. The chiller load is obtained from the chilled water flow rate and the difference between the temperature of the inlet and outlet water, the latter in set-point conditions. The part load ratio is derived from the previously calculated load and limited according to the chiller properties. Using a further interpolation, the fraction of full load capacity for operating condition, at first, and the chiller power consumption, then, are calculated as expressed in Equation (9).

$$E_{\mathrm{C,gen,el,in}} = \Phi_{\mathrm{C}} / EER_{\mathrm{n}} \cdot FFLP \tag{9}$$

3. Application

In this paper, a comparison analysis was performed on the results of different calculation procedures for the assessment of the energy performance of chillers. The case study building, described in Section 3.1., was modelled in EnergyPlus in order to determine the thermal energy needs for cooling related to the two climatic zones analysed. These results were then deployed in order to assess the chiller performance through the use of three different calculation procedures, i.e., the two methods presented in the EN 16798-13 technical standard [6] and the calculation procedure available in EnergyPlus, as described in Sections 2.1. and 2.2.

The main properties of the chiller, such as the *EER* and the nominal power, were defined as input data as well as the correction curves described in Section 2.2., useful for the EnergyPlus calculation procedure. These latter were used to evaluate the *EER* at different part load conditions in accordance with EN 14825 [7] in order to determine the correction factor, as described in Section 2.1.

The results were therefore analysed in terms of monthly electrical energy input for cooling; a characteristic week of July was also deepened, analysing the hourly profiles of electrical energy input for cooling, and partial loads.

3.1. The case study

The considered case study is an office building representative of the Italian existing building stock, built between 1977 and 1990, characterized by five above ground conditioned storeys. For the sake of the present study, a single story was considered (Figure 4); this is characterized by a 512 m^2 conditioned net floor area, and it was assumed to be adjacent to identical stories (geometry, building use, etc.).

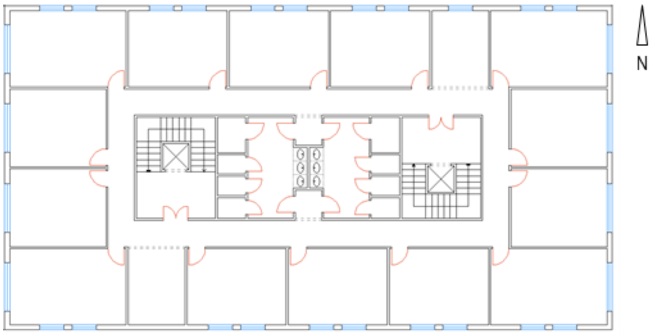


Figure 4. Plan of the analysed storey.

As far as the building envelope is concerned, the external walls are made of hollow brick masonry with interposed low thickness thermal insulation ($U_{\mathrm{wall}} = 0{,}88$ W/m^2K), while the horizontal internal partitions are made of hollow-core concrete slabs (U_{floor} = 0,69 W/m^{2}K). The transparent envelope is characterized by double-glazing windows with metal frame (U_{win} = 2,8 W/m^{2}K, *g*-value = 0,75). For the sake of the present study, the storey is only supplied by a cooling system consisting in an air-to-water electric chiller with fan coil units. The design inlet air dry bulb and the outlet water temperature are 32 °C and 7 °C, respectively. At reference conditions (full load), the *EER* is equal to 4 and the nominal power is 35 kW; to determine the cooling capacity and the *EER* (inverse of *EIR*) at operating conditions, the performance curves reported in Figure 5 were used (see Section 2.2. for a specific description of the curves). Specifically, Figure 5.a and Figure 5.b present, respectively, the cooling capacity factor (*CC factor*) and the temperature-based energy input to cooling output factor (*EIR-T factor*) for different inlet fluid temperatures, while the part-load-based energy input to cooling output factor (*EIR-PLR factor*) is presented in Figure 5.c.

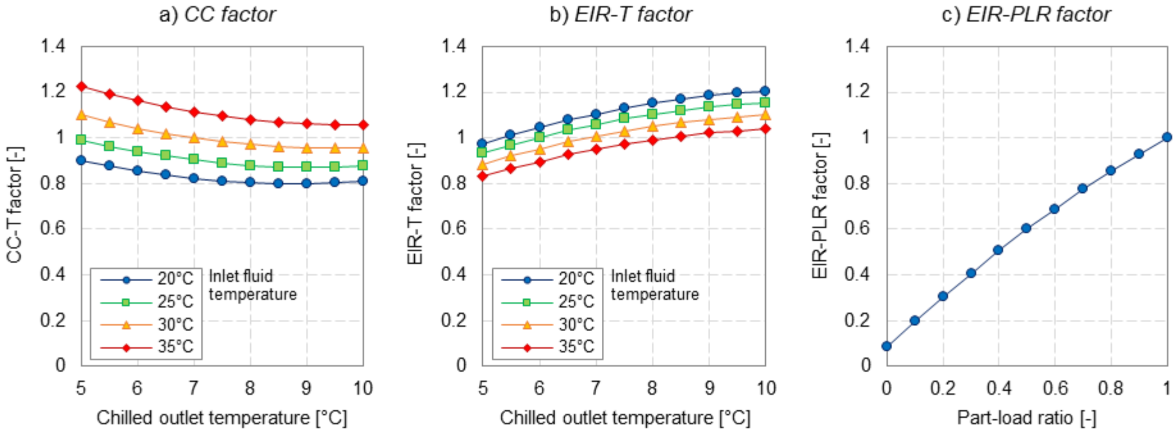


Figure 5. Cooling capacity factor (a), temperature-based energy input to cooling output factor (b), and part-load-based energy input to cooling output factor (c) performance curves.

For the simulation, a standard user behavior was assumed in terms of occupancy profile, internal heat gains, natural ventilation, and HVAC operation. Specifically, the cooling system was assumed to operate from 8 a.m. to 6 p.m. to maintain a 26 °C operative temperature set-point during the weekdays. The evaluations were carried out using the International Weather for Energy Calculations (IWEC) data file [10] for the cities of Milan and Palermo.

4. Results and discussion

The thermal energy need for cooling of the building, presented in Figure 6 on a monthly basis, shows a dependency on the weather data leading to typical differences in the two analysed cities.

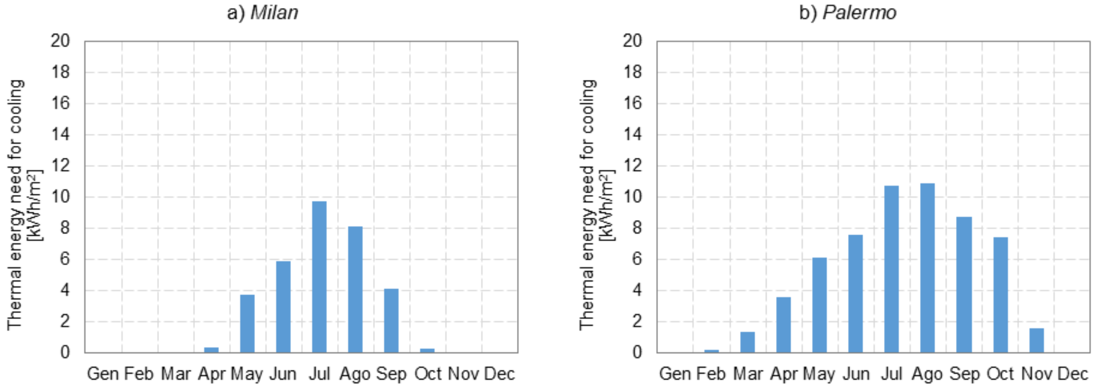


Figure 6. Thermal energy need for cooling of the building in Milan (a), and Palermo (b).

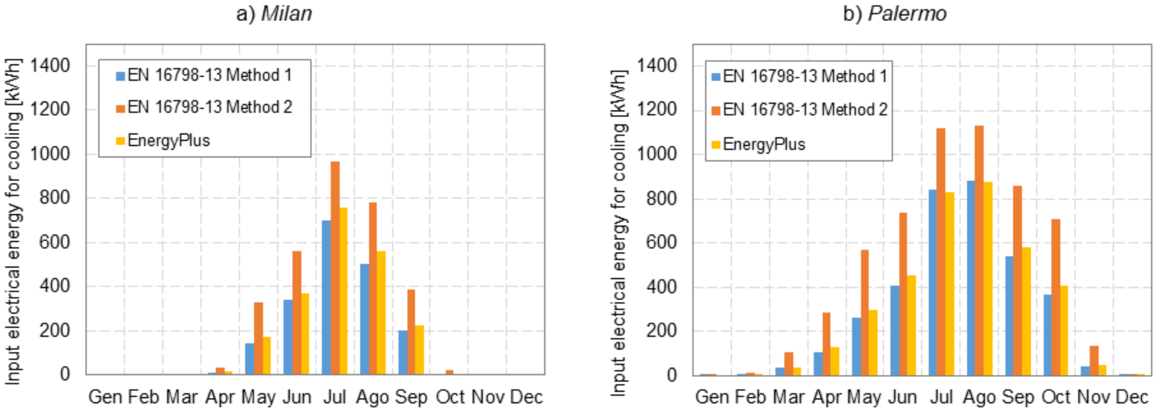


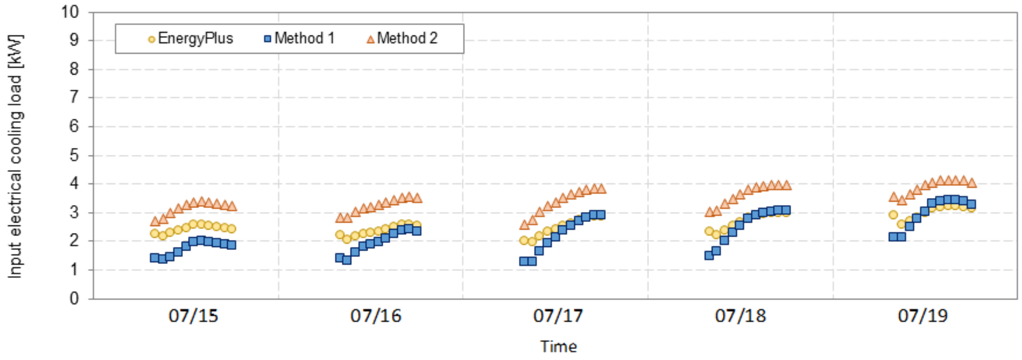
Figure 7. Chiller electrical energy input for cooling in Milan (a), and Palermo (b).

The comparative analysis of the three different methods, presented in Figure 7 on a monthly basis, highlights a strong similarity between the method 1 standard procedure and the detailed calculation used in EnergyPlus, while the method 2 standard procedure shows significant variations. The deviation between the standard methods and the EnergyPlus method results, normalized on the latter, is between −15% and +7% in Milan and between −15% and +1,5% in Palermo, on a monthly basis, for the EN 16798-13 method 1 [6]. The variation for method 2 of the standard, determined with the aforementioned procedure, is between +30% and +90% in both cities. These results are in agreement with the precision of the deployed methods. The similarities derive from the fact that the *EER* determination procedure based on temperatures and partial loads used in method 1 is an interpolation of values derived from the curves used in EnergyPlus. In a similar way method 2 results are severely affected by the use of standard performance tables, with no negligible variation in the results.

The analysis of the hourly electrical load for cooling, presented in Figure 8, shows similar trends in the results, thus underlining the fact that the three methods, at least in the analysed case study, lead mainly to variation in the amplitude of the output consumption.

The results of the part load ratio analysis, performed in a July week and presented in Figure 9, shows again similar trends. These values, since the cooling load is set as input data, are only influenced by the chiller's available cooling capacity. The part load ratio results are strictly linked to the chiller consumption since, as shown in Figure 5, the *EER* increases as the *PL* ratio decreases.

a) *Milan*



b) *Palermo*

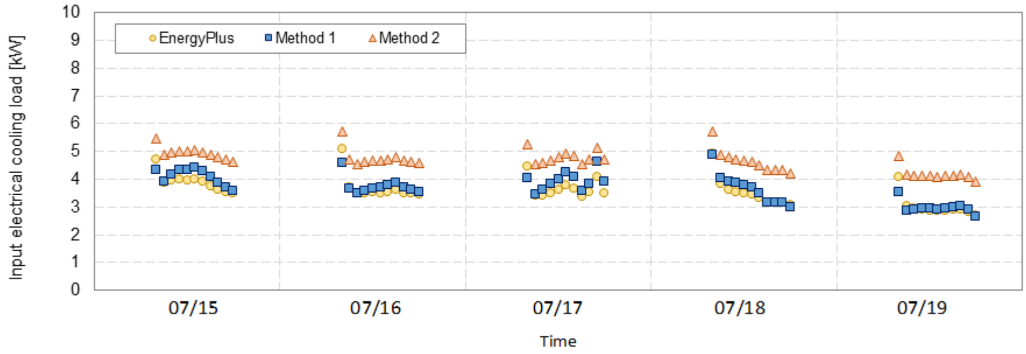
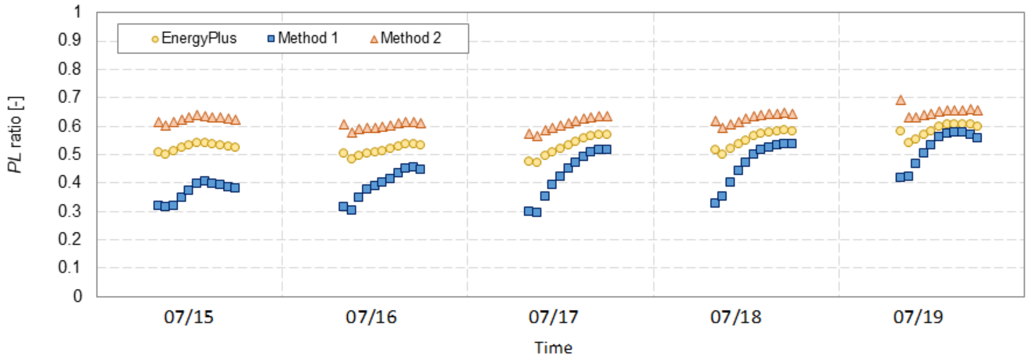


Figure 8. Chiller electrical cooling load in Milan (a), and Palermo (b) on working days of a week in July.

a) *Milan*



b) *Palermo*

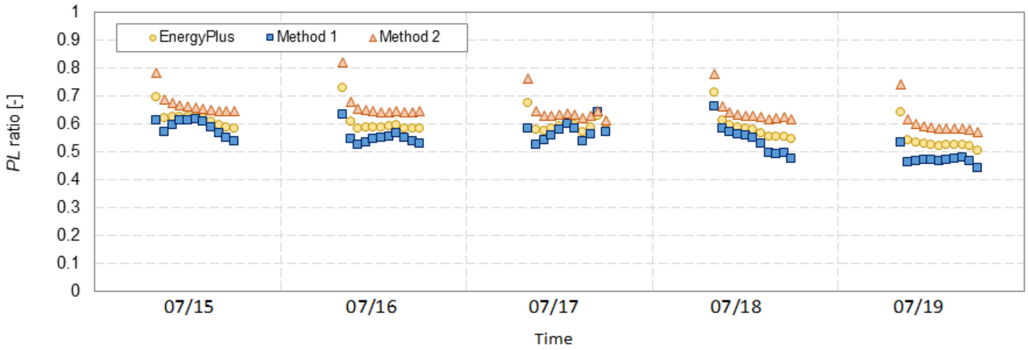


Figure 9. Chiller partial load ratio in Milan (a), and Palermo (b) on working days of a week in July.

5. Conclusion

In the present work, the analysis of four different calculation procedures for the determination of the chiller performance was carried out. The two procedures provided by the EN 16798-13 [6] technical standard, the model implemented in EnergyPlus and that one in TRNSYS were explained in order to highlight the main calculation differences in terms of logical workflow and simplifications. Among the available calculation procedures in EnergyPlus, the one based on condenser entering temperature was deepened due to the input similarities with the standard procedures. The two methods specified in EN 16798-13 [6] were then, through a case study approach, analysed and compared to EnergyPlus. An Italian typical office building was selected and assessed in the cities of Milan and Palermo. The comparative validation with TRNSYS, not covered in this procedure, will be analysed in future works.

The results were analysed in terms of electrical energy input for cooling and part load ratio. Both monthly and hourly results highlighted an optimal coherence between the simplified calculation procedure of EN 16798-13 [6] method 1, which is based on detailed chiller performance parameters, and EnergyPlus calculation procedures with monthly variation between −15% and +7% in the chiller electrical energy input for cooling in both Milan and Palermo. On the other hand, method 2 of the standard, which is based on simplified chiller performance parameters and corrective performance factors, proved to be unreliable with severe deviation in the results. This is strictly related with the precision of the deployed *EER* correction factors that were extremely similar between method 1 and EnergyPlus, while had some differences with method 2. The reliability of the standard calculation procedure is therefore probably strictly linked and influenced by the used input information, especially with regard to the definition of the performance curves. Further work will include other detailed procedures other than EnergyPlus in the comparative testing, as well as the analysis of different case studies with variations in both user profiles and thermal properties of the building envelope.

The results underlined also the importance of an analysis based on the input data; in particular, a sensitivity analysis should be performed to determine the influence of the single input information on the results.

Nomenclature

a, b, c, d, e, f	Model built-in or user defined factors for the cooling capacity factors determination, ND
$a_{0\text{-}2}$	Coefficients for the calculation of the heat rejection system part-load factor, ND
$C_{1\text{-}4;j}$	Coefficient of the chiller *j*, ND
$E_{\mathrm{C,gen,el,in}}$	Cooling generation electrical energy input, kWh
EER_{n}	Nominal energy efficiency ratio, ND
$f_{\mathrm{C;mult}}$	Factor for multiple refrigeration units, ND
$f_{\mathrm{EER};j}$	Correction factor of the *EER* at current calculation interval, ND
$f_{\mathrm{hr;fc}}$	Chiller free cooling factor, ND
$f_{\mathrm{hr;PL}}$	Chiller part load factor of the heat rejection system, ND
$FFLP$	Fraction of full-load power for chiller, ND
LR	Effective part load ratio, ND
$LR_{j;\mathrm{min}}$	Minimum part load ratio of the chiller *j*, ND
PLV	Part load value, ND
$Q_{\mathrm{C;gen;in;req}}$	Required thermal energy to be extracted by the refrigeration unit, kWh
$T_{0;\mathrm{abs}}$	Absolute reference temperature, K
t_{C}	Effective running time for cooling, h
$\Delta\vartheta_{\mathrm{cond}}$	Temperature difference within the condenser, K
$\Delta\vartheta_{\mathrm{corr};j}$	Correction temperature difference of the chiller j, K
$\Delta\vartheta_{\mathrm{evap}}$	Temperature difference within the evaporator, K
$\vartheta_{\mathrm{C;gen;hr;req;in;n}}$	Required heat rejection input temperature at nominal conditions, °C
$\vartheta_{\mathrm{C;gen;hr;req;in;ref}}$	Required heat rejection input temperature at working conditions, °C
$\vartheta_{\mathrm{C;gen;req;out}}$	Required cooling generation output temperature at working conditions, °C

$\vartheta_{\mathrm{C;gen;req;out;n}}$	Required cooling generation output temperature at nominal conditions, °C
$\vartheta_{\mathrm{chw,in}}$	Chilled water inlet temperature, °C
$\vartheta_{\mathrm{chw,set}}$	Chilled water set-point temperature, °C
$\vartheta_{\mathrm{cond;in}}$	Condenser inlet temperature, °C
$\vartheta_{\mathrm{cond;in;n}}$	Condenser inlet temperature at nominal conditions, °C
ϑ_{e}	External air temperature, °C
$\vartheta_{\mathrm{evap;out}}$	Evaporator outer temperature, °C
$\vartheta_{\mathrm{evap;out,n}}$	Evaporator outer temperature at nominal conditions, °C
Φ_{C}	Nominal thermal power, kW

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