CO2 emission reduction, loads analysis, and strategies for new healthcare facilities design – Application on a case study

CO_2 emission reduction, loads analysis, and strategies for new healthcare facilities design – Application on a case study

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Abstract. To understand the "Zero Emission Building" goal introduced by the Energy Performance of Buildings Directive (EPBD) revision, it is certainly important to define its scope, since different considerations must be made for buildings with different uses, characteristics and locations. In this paper, the case study of a new construction hospital building is analysed, bringing attention to two main aspects: the correct identification of energy needs of the Heating, Ventilation and Air Conditioning (HVAC) systems; Mechanical, Electrical and Plumbing (MEP) design strategies aimed at minimizing CO_2 emissions. To pursue these objectives, the hourly trends of energy consumption are examined, focusing on the interpretation of their distribution, the main influencing variables and on the distribution of such energy consumption among the different utilities of the analysed system. It is opinion of the authors that this in-depth study is preparatory to the proper MEP design of the systems: in fact, by knowing the most energy-consuming users and the distribution of heating and cooling loads during the year, it is possible to identify the optimal design strategies and generation technologies to reduce the consumption of Primary Non-Renewable Energy. In this regard, the choice of an ap-propriate calculation model is highlighted as crucial. Possible design strategies related to the case study under consideration are analysed in this paper, ultimately exposing the general considerations regarding the ZEB issue in the hospital setting.

1 Introduction

The building sector is considered by the European Union to be one of the most polluting sectors [1]. For this reason, a new European Directive on the Energy Performance of Buildings (EPBD) [2-3] was issued in 2023, emphasizing the urgent need to implement strategies for the reduction of the construction sector's im-pact on the environment. The EPBD aims to provide new design strategies and encourage EU Member States to set limits on CO_2 production using several benchmarks.

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The newly revised EPBD focuses on both existing and new buildings. For existing structures, it proposes specific thresholds that must be met by the year 2030. For new construction, it requires buildings to achieve zero-emissions and refers to indicators such as the Energy Performance Certificate, which indicates performance in terms of primary energy, final energy and Global Warming Potential (GWP), i.e. the evaluation of the building's entire life cycle. These tools can be used to assess the efficiency of any type of intervention.

To facilitate project evaluation, a clear understanding of the new definition of Zero Emission Building (ZEB) is necessary:

"*High-performance energy building with an energy demand close to zero, producing zero on-site carbon emissions from fossil fuels and minimal to zero operational greenhouse gas emissions, in accordance with specified guidelines*".

This definition highlights the requirement for buildings to achieve zero emissions by having nearly negligible energy demand and minimal operational emissions. Operational emissions refer to the energy demand required for heating and cooling loads, obliging to have zero emissions on-site exclusively [4].

These standards do not differ according to the intended use of the building. As a results, the adopted system "top-down" requires the same requirements for all structures, without taking into account the location, adopted energy system and building typology, which significantly characterize the energy needs [5].

Regarding operational emissions, which depend on the HVAC system, no calculation methods are proposed to assess the performance of an energy generation solution.

Currently, there is increasing evidence of the difficulty of conducting detailed energy assessments using traditional steady-state calculation models. For complex buildings with significant energy inputs, it is more appropriate to adopt calculation methods that allow consideration of the variability of endogenous loads, the energy impact of the air treatment, and the interaction of different and complex generation and distribution systems.

Considering the goal of obtain a detailed and adequate calculation model, and simulated results accurate enough to deduce the best design strategies to achieve a ZEB, this research examines in depth the energy needs of a new large-scale hospital building. An hourly analysis was performed using a dynamic model.

The first stage of the analysis concerns modelling of the building, including building envelope characteristics and endogenous loads for each department. Next, the HVAC system was modelled by detailing each individual component. In this way, energy needs can be analysed by studying the factors influencing them.

2 Case Study description and methodology

2.1 Case Study

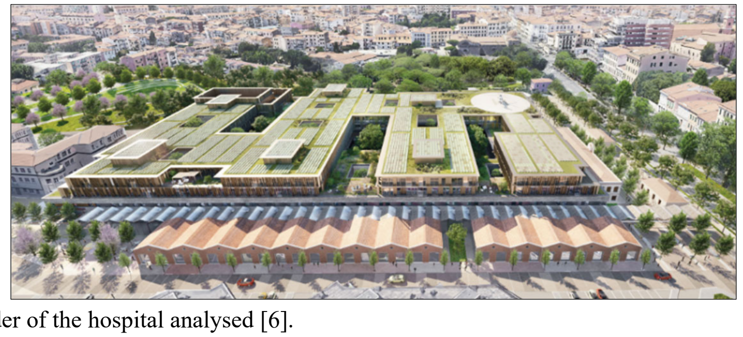


Fig. 1. Render of the hospital analysed [6].

A new hospital, represented in *Figure 1*, was chosen as a case study to perform energy needs analyses. For sake of experimental analysis, it is assumed that the hospital will be built in Turin. This building is characterized by a large gross floor area, (i.e. approximately 89000 m^2) in order to guarantee 490 beds. The entire facility includes five floors with a specific distribution of the departments to ensure regular flow of patients and staff.

The basement floor includes all technology areas, with service areas for staff and logistics departments.

The ground floor consists of two main corridors, which create a division be-tween the external patient area and the emergency department. A central visiting area includes a High Dependency Unit (HDU), an intensive short observation block, and an X-ray room. The southern section is reserved for offices.

The first floor consists of the surgical area with an operating block, a high-care section, a laboratory space, and a designated day surgery area. In addition, each floor includes an office area.

On the second floor is the maternal and child health department, which includes obstetric care units and a paediatric department. Next to these areas are the infectious diseases unit and the surgical suite, followed by offices at the back.

The third floor is dedicated to the ordinary inpatient area organized into specific blocks. The second and third floors include space designed for relatives with an area for meetings with doctors.

The hospital is structured horizontally according to a complex distribution scheme, characterized by large glazed surfaces, stairwells, and lifts. For this reason, it was necessary to optimise the technical choices to mitigate the thermal excursions induced by the architectural design. On the other hand, the complexity of the structure required the selection of a calculation model ensuring reasonable calculation times and result reliability.

2.2 Methodology

In this section, the assumptions concerning the calculation model and the HVAC system were analysed.

As already mentioned in Section 1, it is important to use a dynamic calculation model to ensure a high level of reliability of results. For this reason, Energy Plus® v8.6 software via the Design Builder® v5.5.2 graphic interface was used. This advanced software allows hourly analyses, offering a comprehensive evaluation of the variability in energy requirements over the course of a year. Figure 2 shows the resulting simulation model.

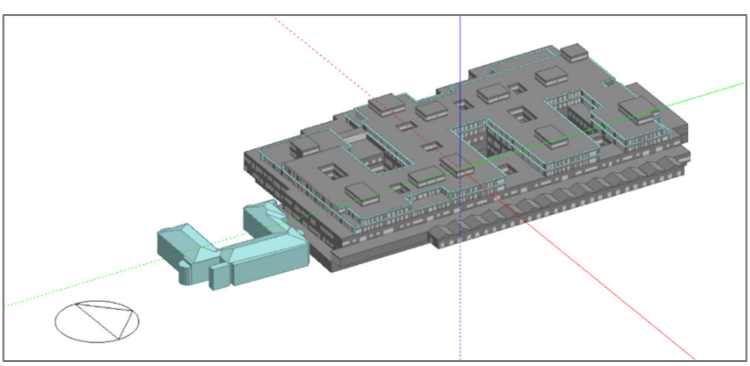


Fig. 2. Simulation Model of the entire hospital analysed.

Concerning boundary conditions, the simulation was carried out over a typical year following the IGDG (Italian Climatic data collection “Gianni De Giorgio”) source located in Caselle-Turin, setting 4-time steps to obtain a high level of performance analysis.

Regarding modelling, the first step concerned the assignment of building envelope characteristics and endogenous loads in each zone; then, also MEP systems and schedules were inserted. For the purpose of better model organization, each zone corresponds to an entire department, which is also characterized by uniform design conditions and type of plants. This choice is also due to the complexity of the building, considering that the greater the level of detail, the greater the computation-al cost.

A focus on detailed modelling of the HVAC system is appropriate. Twenty Air Handling Units (AHUs) connected with seventy departments were inserted in the model. Initially, the total number of AHUs considered was even more than twenty, but the simulation time of such system increased exponentially. For this reason, some AHUs were merged to reduce computational cost. The software also potentially allows the generation and distribution system to be simulated, but the authors experienced that the calculation of complex systems, such as those usually developed for hospitals, must necessarily be approximated. In fact, for this type of application, there are usually several interacting generators that can hardly be reproduced within a software. For this reason, the generation system was simulated separately by using “home-made” models. This point surely represents an obstacle both for the modelling of complex systems, and for the creation of a uniform and reliable standard that can be replicated by anyone.

The resulting AHUs and zones are reported in Table 1, which summarises the specific design condition of each department, opening hours in each zone and the design conditions about the setpoint of relativity humidity and temperature. For each zone, supply air flow rates were calculated according to the activity and the dimension of the department, based on local and international standards [7].

It is important to point out that two main types of HVAC systems are considered: a primary air system (PA) connected with fan coil and radiant panels, and an all-air system (AA) with zone-assigned heating coils (ZA-heating coils) to regulate the temperature of the zone. In the last case we have also distinguished a category with Controlled Contamination Environments (CCE) used in high care departments, and a specific case for Operating Rooms (OR).

In both cases the AHUs include the following devices with specific setpoints:

- Heat recovery unit with double coils, achieving 73% sensible efficiency and 0% latent efficiency;
- Water cooling coil with different outlet setpoints, depending on the design conditions of temperature and relative humidity (RH);
- Water heating coil which is set up to regulate the temperature and to ensure the setpoint at the output of the AHU in case of primary air system or all-air system. In the latter case, in addition to the heating coil inside the AHU, there is a post-heating coil in each zone;
- Steam humidifier to control the RH in each zone;
- Inlet fan and extraction fan with an appropriate air flow rate and head value depending on the served zone. The highest head value is in case of CCE and OR.

Table 1. Summary of the main characteristics of the AHUs, zones and type of plants.

AHUs Code	Departments	Supply air flow [m^3/h]	Return air flow [m^3/h]	Functioning timetable	Winter T [°C]	Winter RH [%]	Summer T [°C]	Summer RH [%]	Type of HVAC system for each department
PA-W	B: Central Beds, Depot, Warehouse 1, Warehouse 2	16632	16632	07:00 -20:00 All days	22	45%	26	50%	Primary air system connected with fan coil
PA-L	B: Medical physics department, clinical engineering	8460	8460	07:00 -19:00 All days	22	45%	26	50%	Primary air system connected with radiant panels
PA-O	B: Offices/PT: Management Area, Offices/ 1F: Men. Areas 1- 2/2F: Men. Areas/ 3F: Men. Areas, Offices	31248	31248	07:00 -19:00 weekdays	22	45%	26	50%	Primary air system connected with radiant panels
PA-S	B: Staff changing room	11520	11520	08:00 -10:00; 12:00-15:00; 18:00-21:00	22	45%	26	50%	Primary air system connected with fan coil
PA-K	B: Kitchen	32800	32800	08:00 -10:00; 12:00-15:00; 18:00-21:00	18	-	28	-	Primary air system connected with fan coil
PA-C	GF: Clinic 1, Clinic 2, Brest unit, Transfusion center, Hemodialysis/ 1F: Chemotherapy, Endoscopy	44352	44352	08:00 -20:00 Mon to Fri	22	45%	26	50%	Primary air system connected with radiant panels
PA-P	GF: Pharmacy	1400	1400	08:00 -19:00 Mon to Fri	22	45%	26	50%	Primary air system connected with fan coil
PA-Cir	GF: Main street/ 2F: Waiting room 1-2-3-4/ 3F: Waiting room 1-2-3-4	44928	44928	09:00 -18:00	22	45%	26	50%	Primary air system connected with radiant panels
PA-SC	GF: Staff canteen, Catering area	24084	24084	08:00 -10:00; 12:00-15:00; 18:00-21:00	22	45%	26	50%	Primary air system connected with fan coil
PA-E	GF: HDU, SOB, Emergency department, X-ray room	48348	48348	06:00-20:00	22	45%	26	50%	Primary air system connected with fan coil
PA-HA	1F: Day Surgery, Oncology Day hospital/ 2F: Hospitalization area 1-2- 3, Pediatrics/ 3F: Medical oncology area 1-2-3-4	94140	94140	h24	22	45%	26	50%	Primary air system connected with radiant panels

CCE-ST	B: Clean wardrobe preparation area, Sterilization	25452	25452	07:00-19:00	24	45%	24	50%	All air system with ZA-heating coils
AA-ST	B: Dirty wardrobe preparation area, Radiotherapy, Dirty sterilization, ADU	47232	47232	07:00-19:00	24	45%	24	50%	All air system with ZA-heating coils
AA-D	GF: Diagnostics area, Nuclear Medicine	59904	59904	07:00-19:00	24	45%	24	50%	All air system with ZA-heating coils
AA-ER	GF: High Intensity Emergency Room	19500	19500	06:00-20:00	24	45%	24	50%	All air system with ZA-heating coils
CCE-OB	1F: Operating Block, Minor Op. Bl., Intensive Care Unit, Hemodynamics	117114	117114	06:00-20:00	24	45%	24	50%	All air system with ZA-heating coils
OR-OB	F1: Minor operating block 1-2, Operating room 1-2	41800	41800	06:00-20:00	24	45%	24	50%	All air system with ZA-heating coils
AA-L	1F: Pathological Anatomy, Lab. Analysis, Endoscopy Room	17208	17208	07:00-19:00	24	45%	24	50%	All air system with ZA-heating coils
CCE-HA	2F: Birthing Block, Infectious Diseases	28044	28044	h24	24	45%	24	50%	All air system with ZA-heating coils

The total supply flow rate in case of a primary air system is 357312 m^3/h, and 356254 m^3/h in case of all-air system.

Table 2 shows the fluid type and temperature values for each system component.

Table 2. Temperature Setpoint of the Heat transfer fluid.

Heat Transfer Fluid				
Device	**Specific component**	**Fluid type**	**Inlet Temperature**	**Outlet Temperature**
			[°C]	**[°C]**
AHUs				
	Humidifier	Steam		
	Cooling Coil	Water	7	12
	Heating Coil	Water	45	38
Zone component				
Radiant surface	Cooling	Water	16	19
	Heating	Water	36	33
Fancoil	Cooling	Water	12	17
	Heating	Water	45	38
ZA-heating Coil		Water	45	38
Domestic Hot Water			65	

The energy need for Domestic Hot Water (DHW) was estimated using the calculation method proposed by the UNI TS 11300 - part 2 Standard [8], considering a daily consumption of 80 l per bed, 490 beds and a water use temperature of 40 °C.

Concerning electric consumption, it was estimated considering the actual values measured for hospitals which are globally similar (modern hospitals with the same offered services, etc.) to the one presented in this research. The measured consumption was parameterized with respect to the gross air-conditioned surface area and readjusted to the surface area of the hospital under study.

3 Energy needs analysis

Starting from the hypothesis indicated in the previous section, the following energy consumptions were modelled:

- Heating and cooling energy needs due to heat transfer through the building envelope;
- Heating and cooling energy needs due to air treatment in each AHU. Every psychrometric transformation was simulated for each time step;
- Steam needs due to humidification;
- Heating needs due to DHW production;
- Electric needs of the entire hospital.

3.1 Heating needs for HVAC system and DHW

Looking Figure 3, it is possible to understand that the heating needs trend is fairly constant throughout the entire year analysed. The reason why this phenomenon occurs is due to the effect of the cooling and dehumidification coil in Summer, which significantly reduces the temperature to dehumidify the airflow. For this reason, the ZA-heating coil is activated to increase temperature and reach the indicated set-point. In the following plot, it is possible to highlight another important characteristic: the peak of thermal power is on the 10th of January (1,7 MW), but most of the high values occur in Summer, because in Winter the heat recovery unit helps to reduce the thermal needs. Thanks to heat recovery unit, 9809 MWh of energy were saved, which compared with the total thermal needs (4411 MWh) is more than double the total demand.

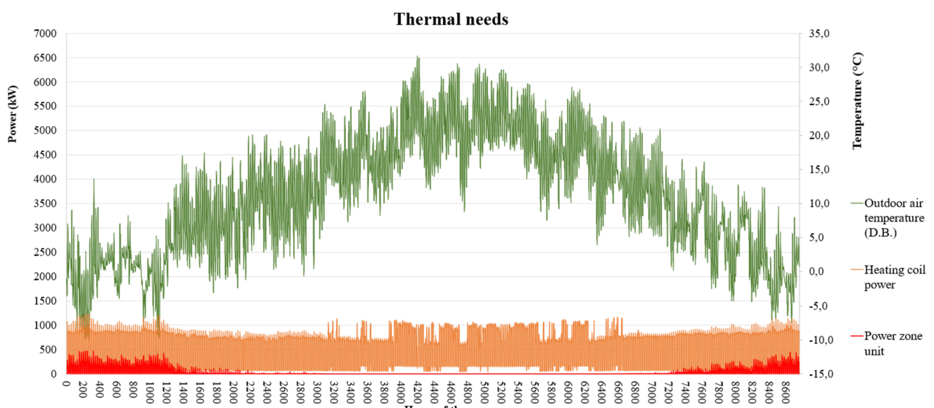


Fig. 3. Thermal needs trend, compared to external air temperature.

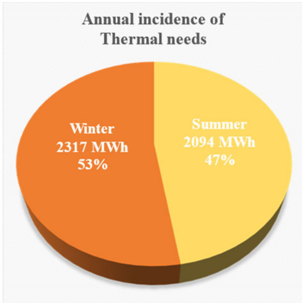


Fig. 4. Annual Incidence of thermal needs in winter and summer.

In Figure 4, a comparison between Summer and Winter thermal needs can be observed. It is clear that the activity of heating coils is almost the same in all months of the year, in particular Winter (intended as the heating season from 15th of October to 15th of April) requirements are slightly higher than Summer (intended as the cooling season from 15th of April to 15th of October) requirements.

The energy need for domestic hot water is estimated to be equal to 513 MWh which corresponds to 10% of the whole thermal needs over one year.

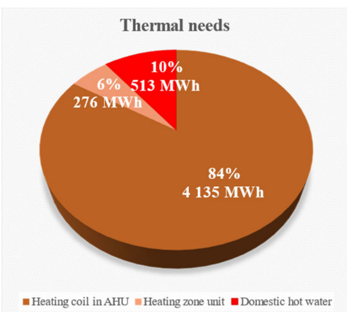


Fig. 5. Distribution of thermal needs.

Figure 5 shows the distribution of the annual thermal needs among the different utilities examined: AHUs heating coils (both internal machines coils and zone post-heating coils), DHW and the contribution of the zone units (radiant panels and fan coils) that balance the heat loss through the envelope in the primary air system. The results clearly show that most of the thermal need, 84%, is due to air treatment.

3.2 Cooling needs for HVAC system

The cooling needs trend was also analysed, and it is shown in Figure 6.

The comparison of the total heating needs (4411 MWh) with total cooling needs (8388 MWh) shows that the cooling components consume much more energy than the others. This result is very significant because it suggests that HVAC system de-sign should maximise the efficiency of cooling generation systems to reduce final consumption.

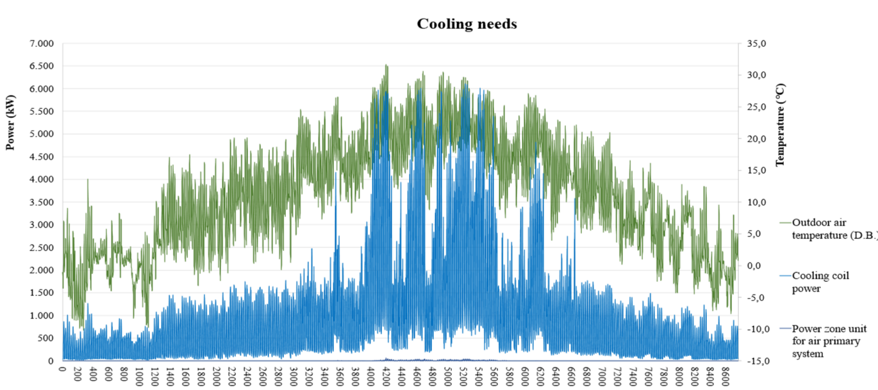


Fig. 6. Cooling needs trend, compared to external air temperature.

Figure 7 represents the incidence of only the sensible fraction in cooling needs. The representation shows that the latent fraction is very significant in the Summer period because of the dehumidification activity of the cooling coils.

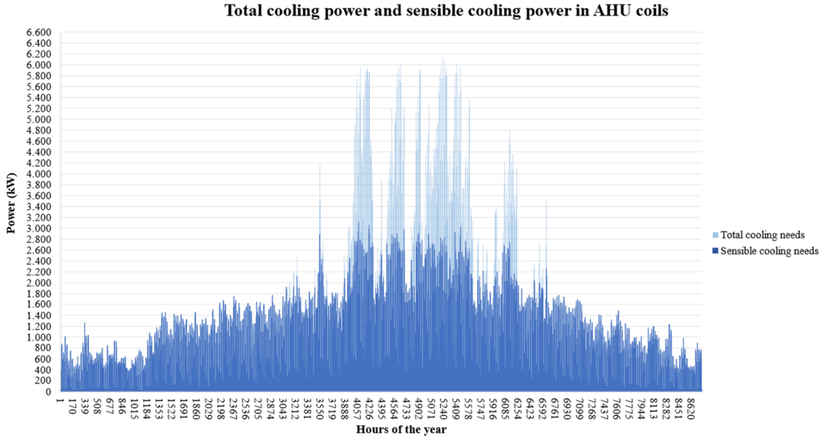
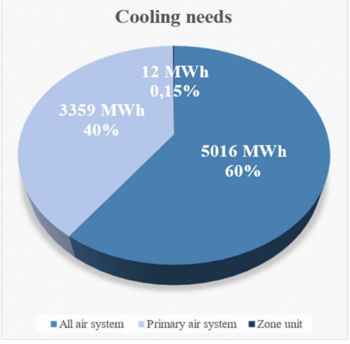


Fig. 7. Incidence of the sensible component in cooling needs.

Table 3 represents a comparison between sensible and latent cooling needs. The percentages show that the sensible contribution is the highest.

Table 3. Percentage of sensible and latent component of cooling needs.

Cooling Needs			
	Sensible	Latent	Total
Energy [MWh]	6523	1852	8375
Percentage	78%	22%	-



Looking at Figure 6 and Figure 8, it appears that the contribution provided by zone units is negligible compared to air treatment, which accounts for almost the entire demand. This is attributed to the huge volume of treated air. It must be considered that results change depending on how endogenous loads are considered, but even if the percentage of zone unit was higher, it would be lower than the contribution given by air treatment.

Fig. 8. Distribution of cooling needs.

The results obtained from the modelling of the cooling needs show that one way to reduce them - before acting on the generation system - could be to suitably modify the internal set point of the environment. In particular, the internal RH set point of 50% could be increased to 55% or 60% where possible (room served by all-air systems or primary air systems + fan coils). In this way, it is possible to increase the specific humidity and temperature set point at the outlet of cooling coils, and consequently to reduce also the heating needs of post heating coils.

The following two examples, applied to AHU- PA-E and AHU-AA-ST, show the impact of changing the RH set point:

• The AHU PA-E is connected to zones with indoor conditions of 26 °C and 50%. If the RH is set to 55%, the annual consumption of the cooling coil drops from

480 MWh to 380 MWh (-21%). Also, the consumption of post heating coil drops from 56,3 MWh to 5 MWh (-91%);

• The AHU AA-ST is connected to zones with indoor conditions of 24 °C and 50%. In this case, the impact of increasing the RH is less because the specific humidity corresponding to the indoor conditions is lower than in the previous case. For appreciable savings, the RH should be increased to 60%. In this case the annual consumption of the cooling coil drops from 602 MWh to 517 MWh (-14%), and the annual consumption of the post heating coils drops from 433 MWh to 394 MWh (-9%).

Thus, the choice of the internal set points must be carefully evaluated balancing the impact on energy consumption and comfort or other specific needs.

3.3 Steam needs for humidification

Figure 9 shows the consumption trend for humidification during the year to meet the environmental set point during the heating season.

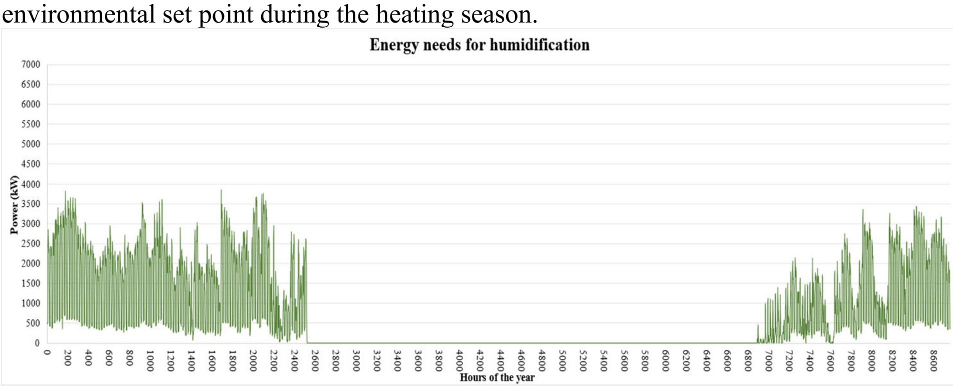


Fig. 9. Energy needs for humidification.

It was supposed to perform humidification through steam as usual in hospital setting. The estimated annual consumption for this service is equal to 5616 MWh, which is more than the energy need for heating.

This is a problem for the ZEB target, since steam for humidification can only be produced using the following options:

• Gas (or diesel) fired boilers, which is non-renewable and results in local emissions;

• Electric devices. This solution results in a rather high increase of electricity consumption, in addition to all the problems related to the huge surplus of electric power installed;

• Combined Heat and Power (CHP) generation. This solution deserves specific considerations involving all the hospital's needs. However, although this solution is the most efficient, the more energy is required for humidification, the more gas is needed to feed the cogenerator and therefore the greater the local emissions.

Considering the impact of this service for the ZEB target, it should be important to evaluate the insertion of humidification only where it is essential and/or the reduction of the internal set point of RH to a minimum acceptable value.

For example, if the internal set point is reduced to 30% (in all the zones) in-stead of 50%, the energy needs is reduced from 5616 MWh to 2046 MWh (-63%), and if only high-care departments are considered (corresponding to AHUs CCE-OB, OR-OB, CCE-HA) the annual consumption is reduced to 790 MWh (-86%).

Thus, the operational set point of RH must be chosen balancing the needs of minimum energy consumption, good comfort and a healthy environment.

Once the energy need is reduced, the option of obtaining humidification by means of other systems using the adiabatic psychrometric transformation could be considered, taking all the necessary precautions to avoid bacteria proliferation. This option must be compatible with national or international standards.

3.4 Electric needs

Figure 10 shows the trend related to electricity consumption over the year.

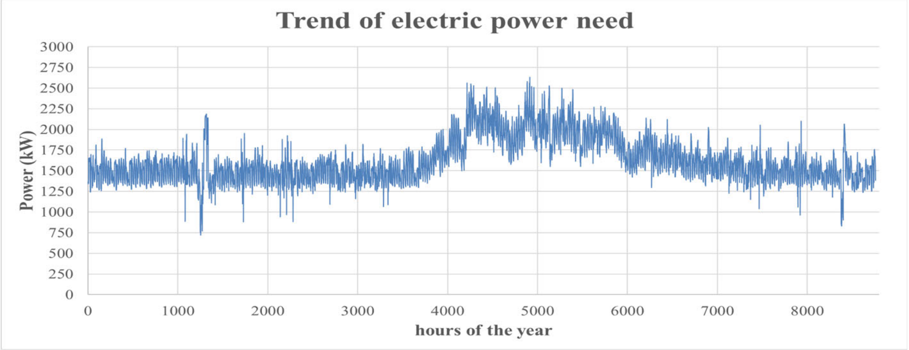


Fig. 10. Trend of electric power need.

The estimated annual electric energy need is equal to 14226 MWh; this value includes all the utilities present in the hospital, i.e. medical equipment, lighting, all process utilities, HVAC equipment etc.

Electricity consumption can be reduced by acting on each determining factor whenever possible. It is important to notice that the HVAC system has a certain impact on electricity consumption, e.g. only the electric energy for all AHUs fans and fan coils has an incidence of 20%. If the future trend is to avoid local emission, most of the consumption for HVAC will be electric and therefore the entire electric need will increase.

4 Design solutions for the generation system

If the definition of ZEB is literally applied, it will not be possible to use generation systems that produce local carbon emissions. This means that, theoretically, boilers should be avoided along with CHP plants, despite the efficiency of the latter. Based on this definition, the only systems that can be used are: heat pumps or district heating for heating, and chillers for cooling.

Solar thermal panels can also be adopted to integrate the production of DHW, while biomass is usually excluded from this type of application. The problem is the production of steam for humidification, as explained in Section 3.2.

The results of the analysis of the energy needs lead to the following considerations:

• It is evident that there is a simultaneous need for heating and cooling throughout the year. This fact encourages the adoption of devices that produce hot and cold water simultaneously. By using the heat pump technology, and employing both the evaporator and the condenser simultaneously with the same electric input, high energy saving can be achieved compared to the separate production of cold and hot water. The coefficient of performance of this type of machine (TER), which is calculated by taking the sum of heating and cooling power as the numerator and the electric input power as the de-nominator, can be greater than 7;

- Since air treatment accounts for most of the heating need, it should be more convenient to size the coils and all the other utilities so that they can operate at low temperature (≤ 45°C); in this way, the efficiency of heat pumps and/or combined heating and cooling production devices can be maximized. On the other hand, DHW must be produced at high temperature, thus only high-temperature heat pumps or high-temperature district heating (if available) may be used. The adoption of district heating must be evaluated taking into account its actual efficiency compared to other possible solutions; it should only be used if it actually allows to reduce the consumption of non-renewable primary energy;
- The results show the 78 % of the cooling need corresponds to the sensible fraction exchanged by the cooling coils. The sensible cooling power can certainly be exchanged using cold sources at higher temperature (10 °C ÷20 °C); therefore, the best way for energy saving is to find (if possible) a free available source of cold water, such as an aquifer, lake, river, sea etc. Energy saving can be achieved by connecting this source to additional coils into AHUs that can cool the air before the normal cooling coils connected to the chiller. Considering the case-study, Figure 11 shows the cumulative distribution of the sensible cooling load. Just to give an example: if free cold-water source of 450 kW or 890 kW or 1400 kW were available, the achievable energy saving would be 10%, 20% and 40% respectively.

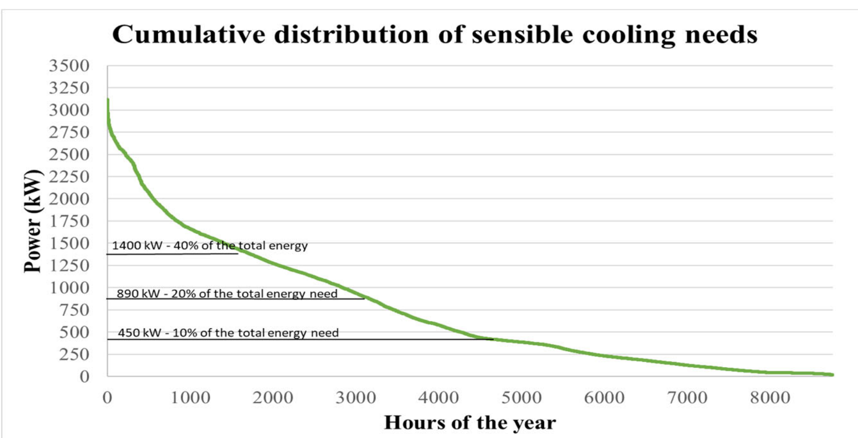


Fig. 11. Cumulative distribution of sensible cooling needs.

In general, the best way to produce cold water (after having used free sources of cold water if possible) is to adopt modern centrifugal chillers that can reach very high levels of efficiency (European Seasonal Energy Efficiency Ratio ESEER > 6).

- Concerning electric consumption, the best way to reduce its impact is to install Photovoltaic panels. The minimum value of the peak power to install is given by Italian Legislative Decree D.Lgs. 199_2021 [9] which states the formula:

$$\textit{Peak Power [kW]} = 0{,}05 \times \textit{ground footprint of the building } [m^2] \qquad (1)$$

For this case-study, this value is equal to 1 MW.

- Trends of electric, heating and cooling needs also suggests the use of CHP plant, which could be cost-effective in hospitals. In fact, in Italy, the use of CHP plant leads to a reduction in the purchase of electric energy from the national grid, thus obtaining an economic saving since electricity is more expensive than gas. Moreover, CHP plants in Italy are subject to economic incentives. The fact that CHP is suitable to minimize emissions must be assessed for each specific case considering, for example, the following factors: the installation context, the interaction with other generation systems, the overall gas and electric energy consumption compared to other solutions, all the energy needs of the hospital considering also the steam production etc.

However, the interaction with this solution and the EPBD will be evaluated in the future.

5 Conclusion

The goal of a Zero Emission Building (ZEB) can be achieved by firstly considering the correct knowledge of energy needs of each utility, thanks to which it is possible to implement all the strategies to minimize them before proceeding to choose the appropriate generation system.

As described in the previous sections, it is important to point out the following issues: the correct evaluation of the internal design conditions that particularly in-fluence cooling and humidification needs; how to reduce sensible cooling needs that account for most of the demand; how to manage humidification; how to reduce the impact of post-heating coils demand.

It is obvious that the higher the performance requirements for hospitals, the higher the energy needs and emissions.

The calculation model must be reliable as much as possible since incorrect evaluation would lead to wrong design strategies. In this regard, as described in Section 2, there are many difficulties in modelling complex systems installed in hospitals, e.g. the high computational cost, the need to simulate the interaction among different generation systems, the impact of the regulation system, etc.

In addition, it should be necessary to have a uniform reliable standard for evaluating energy consumption and making comparisons between different solutions.

The design strategies for generation system must be decided according to the specific situation. In general, for hospitals, the technologies to be used, which are compatible with the need to reduce global emissions and to avoid local emissions, are described in Section 4 of this article. They include: combined hot and cold water production devices, efficient heat pumps and chillers, district heating (or cooling) - if available and efficient, solar thermal panels, free source of cold water and combined heat and power plant if considered appropriate.

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