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Thermal comfort strategies and energy implications in office buildings: a case study

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Abstract. The revised Energy Performance of Buildings Directive (EPBD IV) highlights the importance of ensuring adequate levels of indoor comfort and air quality in the context of energy retrofit, addressing building energy audits toward energy efficiency solutions while enhancing occupants' environmental conditions. In this framework, the present article analyses the energy implications of potential retrofit strategies for a case study building, previously subject to extensive thermal comfort monitoring, by applying the dynamic hourly calculation method given by UNI EN ISO 52016-1:2018. Starting from results of the monitoring campaign, the building energy demand was estimated by modeling different indoor thermal zones, to obtain a more detailed representation of the building thermal behaviour. On this basis, several retrofit scenarios, focused on building envelope and Heating, Ventilation, and Air Conditioning (HVAC) systems, were assessed and compared in terms of their impact on overall energy performance as well as on indoor thermal comfort conditions. The results show that the proposed measures can lead to different impacts on building energy demand, primary energy consumption and thermal comfort conditions. Overall, the study highlights that the integration of comfort analysis into energy audits can support the definition of more balanced and effective retrofit strategies, improving energy performance and occupants' satisfaction.

1 Introduction

The convergence of thermal comfort and energy efficiency in buildings is one of the key points highlighted by the EPBD IV [1], which is currently being transposed at national level. This aspect plays a central role in the design and renovation of buildings, especially in the non-residential sector, which is characterized by high intensity of use, both in winter and summer, with significant internal heat gains and energy consumption for air conditioning. Within the existing building stock, which represents the majority of buildings in Europe, the

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adoption of energy retrofitting interventions offers the opportunity to simultaneously improve energy efficiency, thermal indoor comfort and climate resilience [2].

In this context, the EPBD IV promotes an integrated approach in which energy efficiency and indoor environmental quality are no longer considered as separate objectives, but rather as interdependent aspects of building performance [3].

Actions aimed at improving thermal comfort can involve various building components, starting from both opaque and transparent building envelope to HVAC systems and control strategies. Each measure entails different energy implications, which can significantly affect overall energy consumption by balancing comfort requirements and energy demand.

The effectiveness of these strategies strongly depends on the climate context, building typology and occupancy profile, making a wide-ranging assessment of the overall annual energy balance and microclimatic implications an essential component of the energy audit. In some cases, improving comfort levels in a specific period can lead to increased energy consumption in other seasons: therefore, a holistic strategy involving building envelope, HVAC systems and control technologies enables an improvement in indoor environmental quality and a total reduction in energy demand.

From this perspective, standard calculation methods based on average monthly energy balances according to the UNI TS 11300-1:2014 [4] are often unable to accurately capture thermal discomfort phenomena and to assess the effectiveness of mitigation measures. Conversely, hourly simulation approaches allow for a more detailed assessment of a building energy performance, considering the dynamic interaction between envelope properties, surrounding climate conditions, internal loads and mitigation strategies.

The Italian research work [5] compares the results obtained using the two main calculation methods that analyse building performance under both monthly and hourly conditions. The comparison is carried out considering reference buildings located in the six Italian climate zones (from A to F, the coldest). The results, expressed in terms of the energy demand, show significant discrepancies among the different approaches, highlighting that hourly method provide a more accurate assessment of the energy performance. In particular, for office buildings emerges a difference between monthly method and hourly method ranging from 5% (climate zone F) to 23% (climate zone B) referred to the heating energy demand, overestimated by monthly method. The same trend, but with more relevant differences, was found for the cooling demand: in this case, the values obtained by UNI TS 11300 were considerably higher, ranging between 23% (zone D) and 41% (zone A).

In this study the energy implications of a simple set of energy retrofit scenarios were investigated, starting from the critical issues identified during a previous in-depth thermal comfort analysis of an office building [6], which highlighted significant overheating conditions primarily due to high solar gains from glazing.

In the first phase, a comparative analysis of the building energy needs was carried out considering the monthly method and the hourly method according to the UNI EN ISO 52016-1:2018 [7]; furthermore, different measures aimed at improving thermal indoor comfort were studied. These intervention scenarios are focused on:

1. the application of partial shading devices;
2. the replacement of the existing HVAC systems with Variable Refrigerant Flow (VRF) systems;
3. the combination of scenarios 1 and 2.

Subsequently, the impact of these scenarios was assessed through hourly simulations according to the UNI EN ISO 52016 methodology. The analysis of the alternative strategies considered highlights different impacts on the building overall energy consumption in winter and summer periods, showing how the convergence of improvements in indoor comfort and energy performance can effectively guide energy audits towards optimal retrofit solutions.

2 Case study

For the purposes of this study, a building located at the ENEA Casaccia Research Center in Rome was selected (Fig. 1). It is a three-storey office building, whose main feature is its alignment along the west–east axis; as a result, half of the offices face north and the other half face south. Some rooms have double exposure to the west and east, respectively.

Within this layout, can be identified a “typical floor” (900 m² floor area and 3 m storey height) and a “typical office” (20 m² floor area corresponding to a volume of 60 m³).

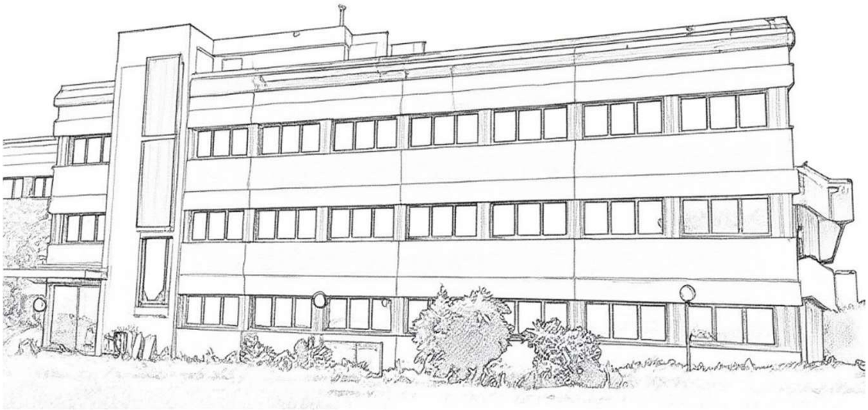

Fig. 1. Case study building.

The main characteristics of the opaque and transparent envelope are reported in Table 1 and Table 2.

Table 1. Opaque envelope details.

Type	s [mm]	U [W/(m²K)]	Ms [kg/m²]	Yie [W/(m²K)]
External wall	300	0.23	0.23	0.09
Partition	104	1.69	1.69	1.52
Basement	300	0.20	0.20	0.60
Slab	300	1.54	1.54	0.62
Roof Slab	610	0.19	0.19	0.01

Table 2. Glazing details.

Type	A [m²]	U_w [W/(m²K)]	$U_{w,shut}$ [W/(m²K)]	g_{gl} [-]
Window	4.24	2.83	2.50	0.75
Door to stairwell	2.78	2.57	2.44	0.75
Door to emergency stairs	4.29	2.86	2.50	0.75

3 Methodology

The building has been modelled with a commercial software that implements both the quasi steady-state method (UNI TS 11300) and the dynamic hourly method (UNI EN ISO 52016). The main differences between the two approaches concern the time scale on which the energy balance steps are based (the quasi-stationary method considers the monthly mean values of physical quantities, for example, temperature, solar radiation, while the ISO 52016 standard considers hourly values) and the different accuracy in calculating of the thermal capacity of the structures that affects the transient heat exchanges of the building. The outcome of the two methods shows significant difference and they have been compared in the following section.

The building model was defined on the basis of a previous study [6] in which an indoor thermal comfort of the same building was carried out. Subsequently, the building's energy demand was evaluated using both monthly and hourly calculation methods, considering different thermal zones.

The model has been set up considering climate data according to UNI 10349-1:2016 [8] and standard occupants' behaviour: in particular, each office can be occupied by one or two workers, and the activity has been scheduled during the working days from 8:00 to 17:00. According to the law, the heating period starts on November 8th and finishes on April 7th, while the cooling period, that is not ruled by law, was considered as the whole year, with the aim of investigating the presence of cooling need beside the summer season. Concerning the thermal zones, the 33 offices of the building have been aggregated into six zones (for each floor, two zones were set, i.e. one for each of the two main exposures - north and south). Moreover, the thermal exchange between such zones and unheated spaces (e.g. corridors, bathrooms, stairwell) has been taken into account.

Finally, three retrofit scenarios involving the building envelope and HVAC systems were studied in terms of energy and comfort implications.

4 Results

The numerical model, characterized by different computational frameworks and specific climatic datasets, made it possible to perform energy-related assessments based on different calculation methods, as well as to examine the implications of various retrofit scenarios on the case study building energy performance, in terms of indoor comfort and primary energy use, with the aim of mitigating the identified thermo-hygrometric critical issues while simultaneously improving the building energy efficiency.

4.1 Comparison between monthly and hourly calculation methods

The model implementation, in the present paper, allows the building energy performance analysis in the baseline condition and the calculation of the energy needs for heating and cooling based on monthly and hourly method to perform a comparative assessment.

For both monthly and hourly method, the energy needs calculated for heating (Fig. 2 and Fig. 3) and cooling (Fig. 4 and Fig. 5) as a function of floor level and building exposure, are shown.

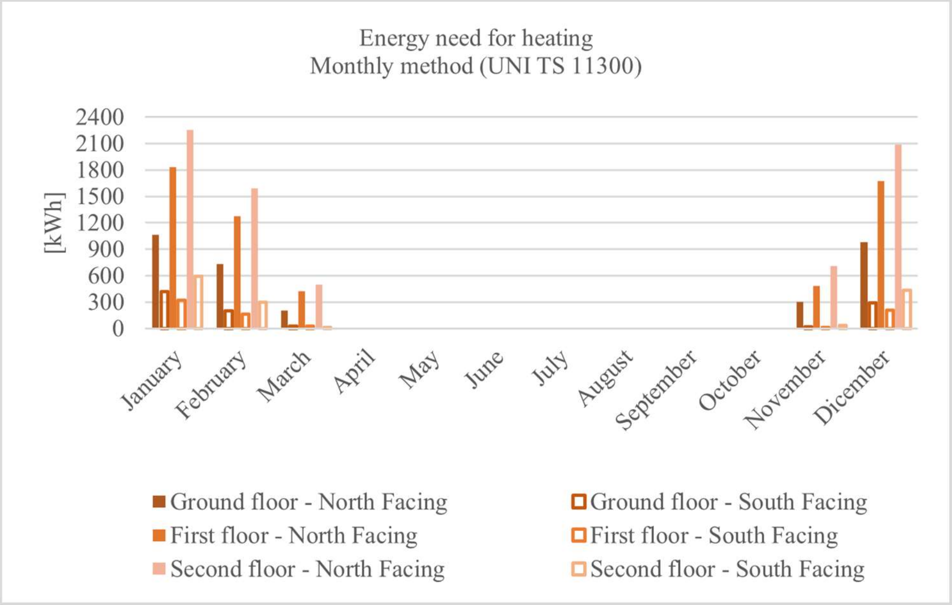

Fig. 2. Energy need for heating (monthly method) by floor level and building exposure.

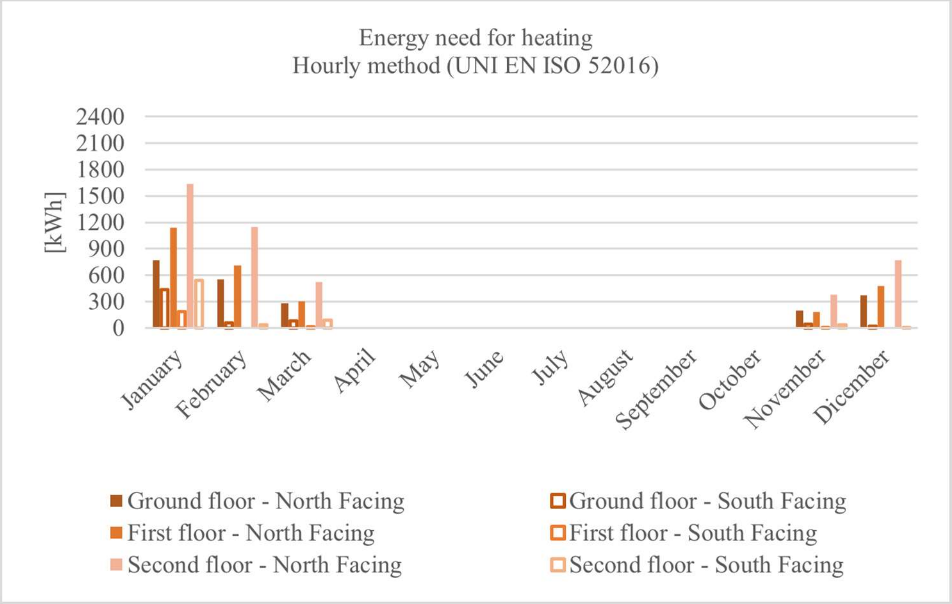

Fig. 3. Energy need for heating (hourly method) by floor level and building exposure.

For both methods, south-facing exposures show lower energy demand during the winter period, while, in most cases, higher energy demand in summer period, mainly due to the incidence of solar gains, which are not adequately shaded. Cooling demand is observed throughout all months of the year and in south-facing offices, the need to offset cooling loads is evident even during the winter season. Although this effect is limited to specific hours, it suggests possible discomfort conditions and highlights a strong thermal asymmetry between spaces with different exposures.

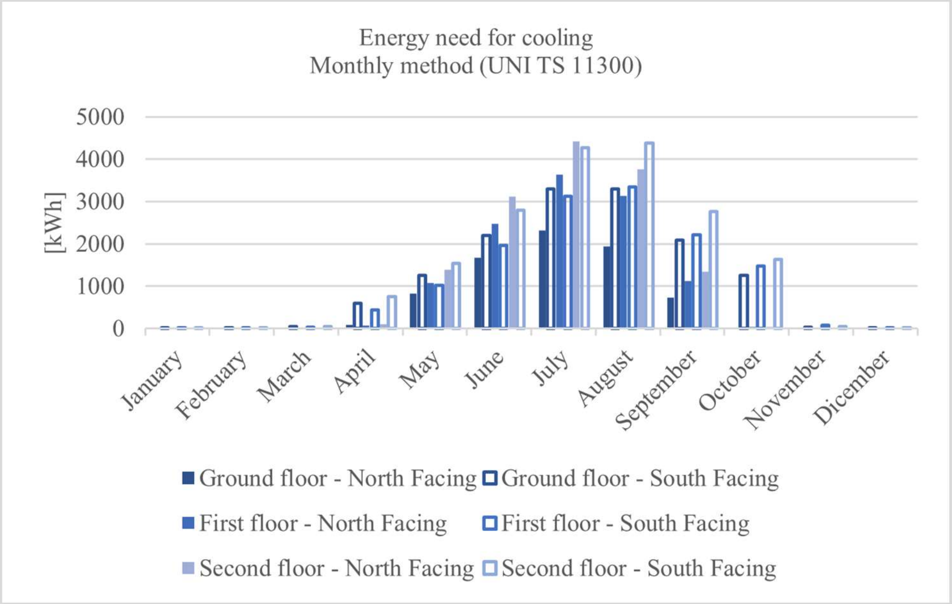

Fig. 4. Energy need for cooling (monthly method) by floor level and building exposure.

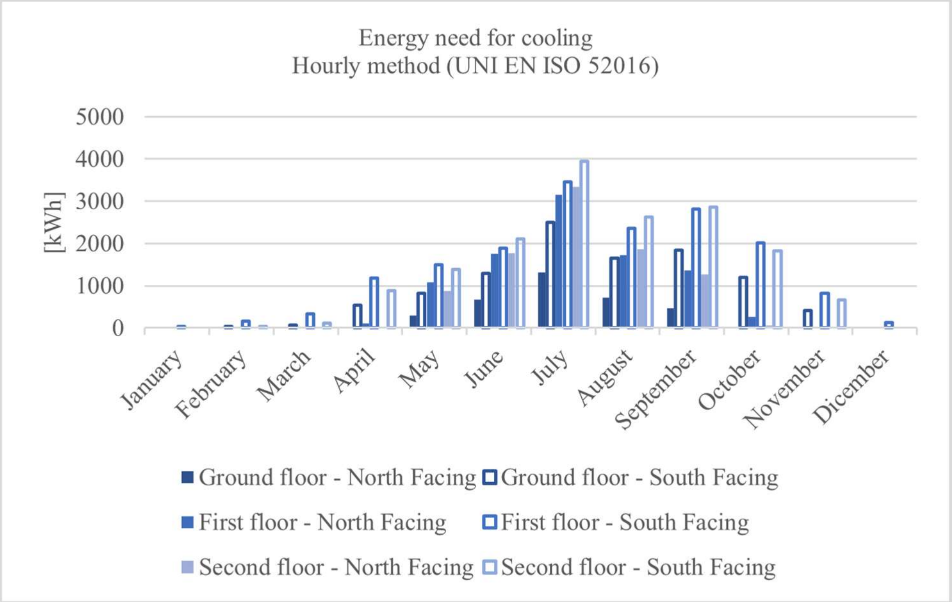

Fig. 5. Energy need for cooling (hourly method) by floor level and building exposure.

The total energy need has been aggregated and presented for heating, cooling and total demand (heating + cooling) for the two calculation methods (Fig. 6).

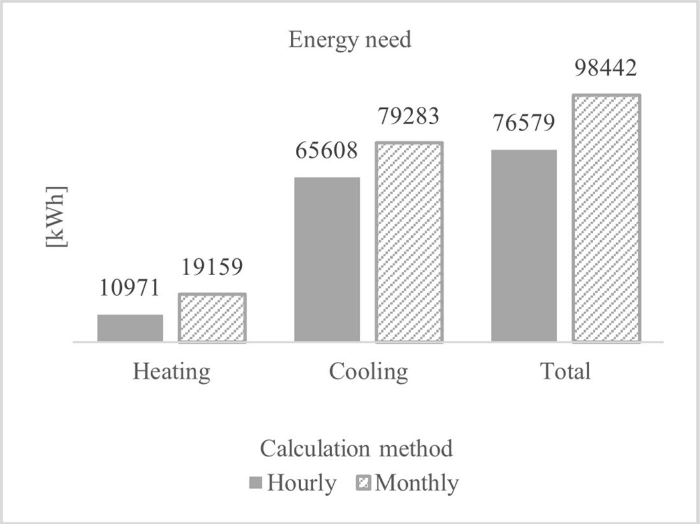

Fig. 6. Building energy need for heating, cooling and total: monthly vs. hourly method.

Considering the total floor area of the case study building (≈1600 m²), the indicators for heating, cooling, and total demand (heating + cooling) are obtained and listed in Table 3. Results show that, for the monthly method, the building overall energy need amounts to 62 kWh/(m²·year), with a predominance of demand during summer period (50 kWh/(m²·year)) compared to winter period (12 kWh/(m²·year)). A similar trend is observed for the hourly method, with a total demand of 48 kWh/(m²·year) and summer and winter demands of 41 and 7 kWh/(m²·year), respectively.

Table 3. Energy need indicators.

Calculation method	kWh/m^2		
	Heating	Cooling	Total
Monthly	12	50	62
Hourly	7	41	48

Finally, a quantitative indication of the difference between the applications of the monthly and hourly calculation methods is provided (Fig. 7). The overall energy need calculated with monthly method is 28.5% higher than hourly method, although with a substantially similar distribution of thermal loads between the zones with different exposures.

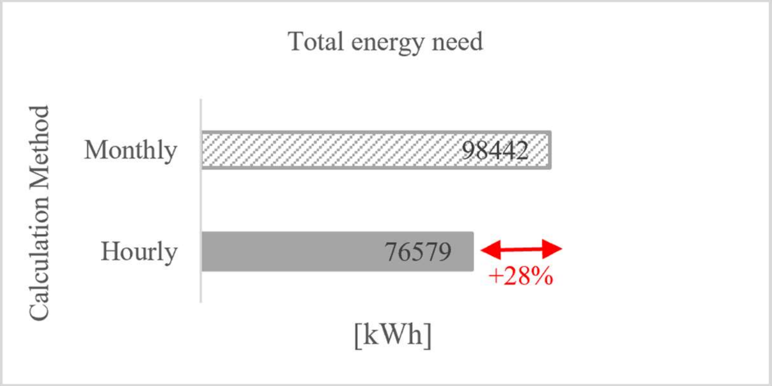

Fig. 7. Total building energy need: monthly vs. hourly method.

Monthly method often overestimates energy demand because it relies on simplified assumptions and average conditions, failing to represent real-world variations in weather, occupancy patterns and systems operation. This can lead to inaccurate predictions of energy retrofits and, consequently, suboptimal investment decisions. On the other hand, the method that uses hourly data to capture the described factors temporal variability, providing a more accurate and realistic representation of building thermal behaviour and energy need.

4.2 Impact of the energy retrofit

Based on the results obtained using the hourly method, it is possible to highlight the different impacts of three proposed intervention scenarios, in terms of the building energy need and indoor comfort improvement, as well as the amount of non-renewable primary energy supplied. In this case, the cooling period has been set from 1st June to 15th September.

Considered scenarios are:

1. the application of partial shading devices.
2. the replacement of the existing HVAC systems with VRF systems;
3. the combination of scenarios 1 and 2.

Scenario 1: the application of partial shading devices

In the present study, the installation of external shading devices is considered covering 55% of glazing area of south-east, south and south-west exposures, in the 8:00-16:00 weekday time slot, in order to reduce the main impact of the direct irradiance on the building surfaces. Fig. 8 presents the heating and cooling energy needs broken down by floor level and exposure. The results show that, with the introduction of the shading devices, the heating need slightly decreases in north-oriented spaces, while it increases significantly in south-oriented zones. Conversely, in summer season, the cooling need increases for north-facing areas and is considerably reduced for south-facing spaces.

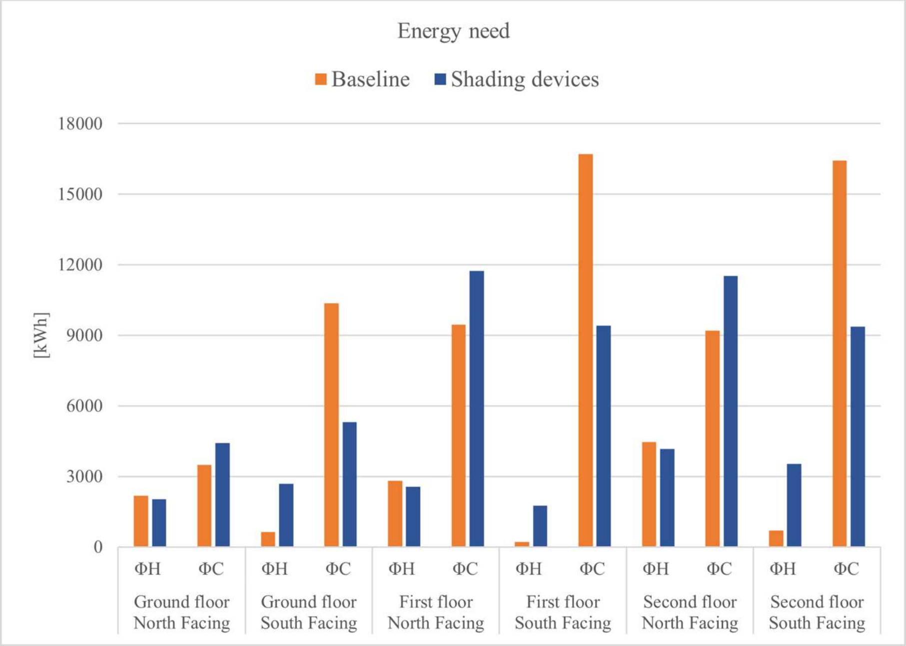

Fig. 8. Energy need for heating and cooling by floor level and building exposure: baseline vs. shading devices.

Fig. 9 shows the total energy needs for the two seasons: the use of shading devices entails a slight increase in heating demand (+5.8 MWh) compared to a significant reduction in cooling demand (-13.9 MWh).

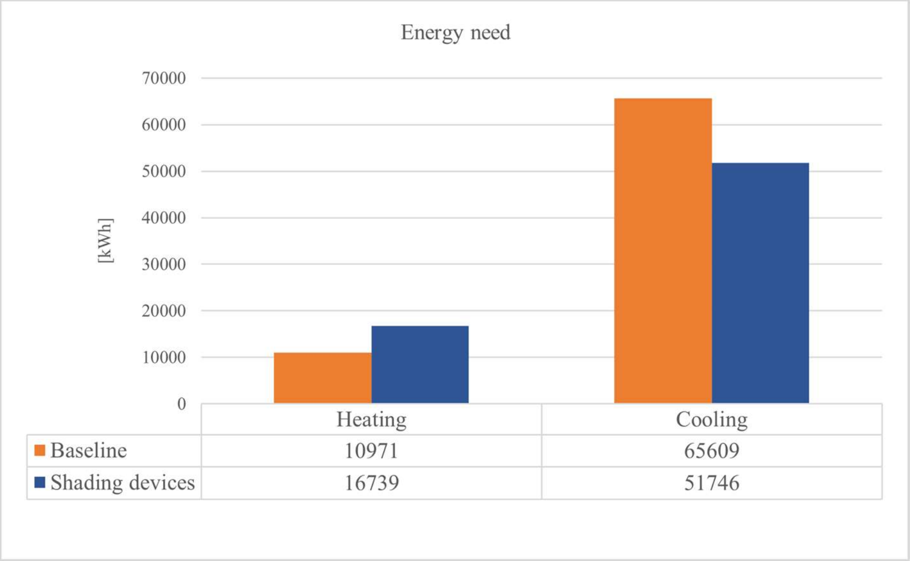

Fig. 9. Energy need for heating and cooling: baseline vs. shading devices.

A particularly relevant comparison can be drawn for the intermediate seasons in which energy systems switched off (April, May, second half of September, October) between the baseline condition and Scenario 1, with respect to thermal comfort, which is assessed based on the ranges defined by UNI EN 16798-1:2019 [9]. Fig. 10 illustrates the percentage distribution of hours across the three comfort categories for the baseline condition and Scenario 1 (dashed borders). The analysis indicates that the increase in comfort hours in south-oriented zones largely overcomes the reduction observed in north-oriented areas, for which the minimum value for Class I nevertheless remains at 60%.

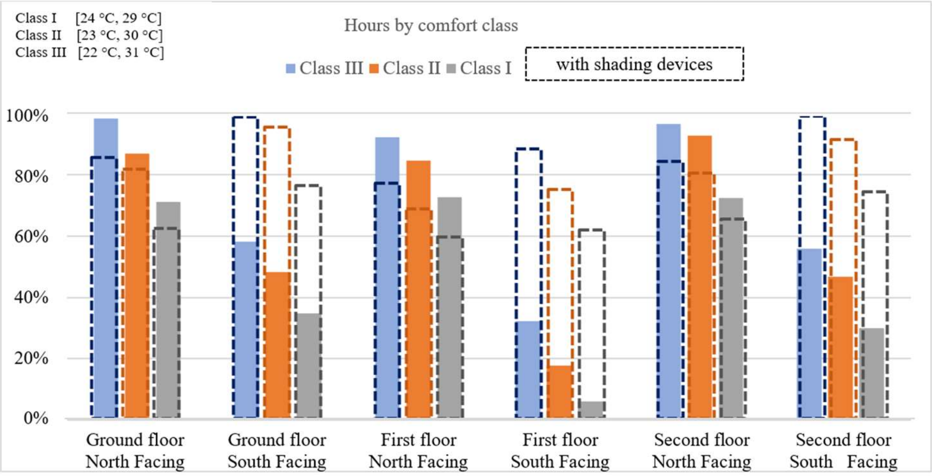

Fig. 10. Distribution of hours in comfort classes by floor level and building exposure.

Scenario 2: the replacement of existing HVAC systems with VRF systems

The second scenario proposed for improving energy performance involves replacing the existing air-conditioning systems with VRF expansion systems that offer a modulation of energy consumption based on real-time occupancy patterns and fluctuating thermal loads, enhancing overall system efficiency in building lifecycle and, consequentially, optimizing operational costs and minimizing environmental impact.

A comprehensive analysis of the energy efficiency and sustainability of VRF systems in a university building shows a significant advantage in energy efficiency for VRF systems, with a reduction of 67% in primary energy consumption per square meter compared to conventional boiler systems [10].

In this paper, the case study building is served by a condensing boiler for heating and by a chiller for cooling. To reduce the primary energy, the installation of three VRF units is planned, each serving a single floor of the building. The operation profile is considered the same of the existing HVAC system (turned on from 6.00 to 19.00 each day) and seasonal performance of VRF units was evaluated taking into account the hourly outdoor temperature profile, starting from manufacturer-provided rated nameplate data, as reported in Table 4:

Table 4. Capacity and efficiency of VRF systems.

	Heating		Cooling	
	Heating	Cooling		Total
Ground floor	50	4	50	3.4
First floor	81.5	4.2	78	3.57
Second floor	76.5	4.12	73	3.52

Furthermore, fan coil units in each office room were replaced by air vents with an emission factor of 92%.

Scenario 3: the combination of scenarios 1 and 2

Finally, the third scenario consists of the combination of the two previous ones. This configuration acts both on the thermal energy demand, through the installation of shading devices as described in Scenario 1, and on primary energy consumption, through the adoption of a VRF system.

Comparison between the three scenarios

The analysis in Fig. 11 shows the non-renewable primary energy of the three scenarios: red and green-hatched areas highlight the differences with respect to the baseline (state-of-the-art).

The installation of shading devices leads to a slight increase in annual non-renewable primary energy consumption, whereas the adoption of VRF systems results in a significant reduction in non-renewable primary energy compared to the baseline condition. The combined scenario, instead, is characterized by a higher non-renewable primary energy consumption than the scenario involving the VRF system alone.

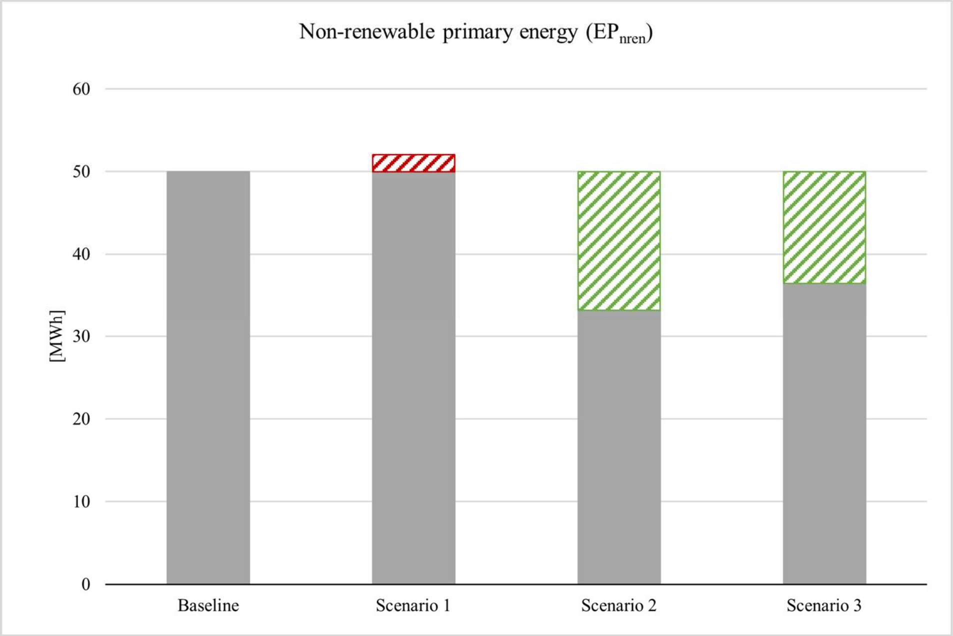

Fig. 11. Deviation of non-renewable primary energy need across scenarios.

Nevertheless, these results should be interpreted in light of the implications for indoor comfort associated with each scenario. The use of shading devices, although penalizes non-renewable primary energy consumption in both Scenario 1 and Scenario 3, is necessary to mitigate overheating during the winter period and to improve thermo-hygrometric comfort during the intermediate seasons.

Overall, the results obtained from the three scenarios analysed can be summarized as follows:

- the implementation of external shading devices (scenario 1), covering 55% of the south-facing glazed surfaces, proves effective in reducing the energy demand and improving indoor conditions; however, it does not necessarily lead to a reduction in primary energy consumption;
- conversely, the adoption of VRF system (scenario 2) does not directly mitigate solar gains at their source but optimizes energy supply according to varying thermal loads, resulting in significant primary energy savings;
- the combined retrofit solution (scenario 3), although yielding slightly lower energy savings compared to the system replacement, emerges as the only strategy enable of reducing thermal loads at their source and consequently enhancing indoor thermo-hygrometric conditions, even during periods when the HVAC systems are switched off.

5 Conclusions

This paper investigates the energy implications of potential retrofit strategies applied to a case study building, previously undergone to extensive thermal comfort monitoring. In the initial phase, the monthly and hourly dynamic calculation approaches were compared to assess the building energy performance. The hourly method, which more accurately accounts for thermal inertia effects, provides more reliable results than the monthly approach, which led to an overestimation of the overall energy demand by 28.5%.

Subsequently, three energy retrofit scenarios were evaluated in terms of primary energy reduction and improvement of indoor thermal comfort.

Overall, the results highlight how the convergence of energy efficiency and indoor environmental quality (IEQ) can represent a key driver in building energy audits and renovation strategies in accordance with the EPBD targets.

References

1. Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast). Official Journal of the European Union
2. W. B. Gillett, S. A. Kalogirou, P. E. Morthorst, B. Norton, M. Ornetzeder. Perspectives on decarbonisation of existing buildings in Europe. Renew Energ, **242**,1-8, (2025).
   https://doi.org/10.1016/j.renene.2025.122490
3. J. Kurnitski. IEQ in the EPBD – How to set national requirements in line with revised EPBD? REHVA Journal, 17–21, (2023)
4. UNI. 2014. Energy performance of buildings - Part 1: Evaluation of energy need for space heating and cooling. UNI/TS 11300-1:2014 Standard. Milan: Italian National Unification Body
5. D. Palladino, D. Iatauro, P. Signoretti. Application of hourly dynamic method for nZEB buildings in Italian context: analysis and comparisons in national calculation procedure framework. E3S Web of Conferences, **312**, 02006, (2021).
   https://doi.org/10.1051/e3sconf/202131202006
6. D. Iatauro, C. Lavinia, I. Nardi, R. Sannino. Thermal comfort monitoring in office buildings: a case study. E3S Web of Conferences, **523**,1-14, (2024).
   https://doi.org/10.1051/e3sconf/202452306006
7. UNI. 2018. Energy performance of buildings - Energy needs for heating and cooling, in-ternal temperatures and sensible and latent heat loads – Part 1: Calculation procedures. UNI EN ISO 52016-1:2018 Standard. Milan: Italian National Unification Body
8. UNI. 2016. Heating and cooling of buildings - Climatic data - Part 1: Monthly means for evaluation of energy need for space heating and cooling and methods for splitting glob-al solar irradiance into the direct and diffuse parts and for calculate the solar irradiance on tilted planes. UNI 10349-1:2016 Standard. Milan: Italian National Unification Body
9. UNI. 2019. Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. UNI EN 16798-1:2019 Standard. Milan: Italian National Unification Body
10. Y. Arroyo Gómez, J.F. San José-Alonso, L.J. San José-Gallego, J.M. Rey-Hernández, A. Sanz-Tejedor, F.J. Rey-Martínez. Optimizing Energy Efficiency and Sustainability in Winter Climate Control: Innovative Use of Variable Refrigerant Flow (VRF) Systems in University Buildings. Appl Sci, **15**, 1-21, (2025).
    https://doi.org/10.3390/app15052374

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