Towards environmental sustainability of non-residential buildings: an integrated approach to combine thermal comfort of people with energy saving strategies for heating system management

Maria Giulia Proietti[1], *Marco* Elefante[1], *Luca* Proietti[2], *Francesco* Longhi[2] and *Elisa* Moretti[1*]

[1]Ciriaf – University of Perugia, Via G. Duranti 63, Perugia, Italy
[2]Arpa Umbria – Agenzia Regionale per la Protezione Ambientale, Via Carlo Alberto Dalla Chiesa 32, Terni, Italy

Abstract. Buildings are constructed and operated to satisfy human needs and improve quality of life. Good indoor air quality and thermal comfort are prerequisites for human health and well-being. At the same time, these aspects are strictly linked to the buildings' energy consumption, with a direct impact on energy efficiency global goals and climate changes. Global technical regulations and guidelines aim at increasing the energy performance of buildings, with targets of NZEB and ZEB, both for new and existing buildings. In this context the research was carried out in order to investigate energy saving strategies related to heating systems, combining with indoor comfort analyses. The case study is an existing building, located in Perugia (Italy), which is the main seat of Arpa Umbria. The recent energy crisis has imposed strict measures to contain energy consumption, especially for heating; for this reason, the study aims to identify optimal management of the heating, based on a thermal calibrated model of the building and thermo-hygrometric monitoring. With the model, different management strategies were defined and simulated in order to develop schedules to set switch-on/off systems based on indoor and outdoor weather conditions. The results are presented in an integrated approach, combining the estimated reduction of energy consumption with human well-being.

1 Introduction

Government buildings are built to satisfy the well-being of employees, to improve the local quality of life and to help protecting the environment. In order to achieve these goals, it is necessary near-complete elimination of greenhouse gas emissions from the building sector and the introduction of energy efficiency measures to reassess the needs of heating, cooling,

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* Corresponding author: elisa.moretti@unipg.it

and ventilation (HVAC). Essentially, these needs stem from human requirements for healthy, productive and comfortable lives. Great thermal comfort is a prerequisite for people's health and well-being. For its provision, buildings often rely on HVAC systems, which may lead to higher energy consumption [1]. These aspects directly have effects upon energy efficiency goals and climate change matters. The balance between energy use, optimal thermal comfort and legal obligations requires scientifically sound and well-established exposure limits for indoor building occupants, including homes, schools, and offices. In Europe, the revised Energy Performance of Buildings Directive (EPBD) sets out how a zero-emission and fully de-carbonized building stock can be achieved by 2050 [2]. The directive enables more targeted financing of investments in the building sector, complements other European Union (EU) instruments and supports vulnerable consumers. In Italy, national regulations regarding these parameters are given in relation to human requirements and take into account the use within buildings and energy saving aspects. The challenges concerning the energy sector are becoming more critical day-to-day. Nowadays, new methods and energy-saving measures are well-known and applied, so it's critical to identify which ones are more dependable and effective over time [3] Building Automation and Control System (BACS) are the most known and used. They automatically control and regulate the technological systems in-side a building, such as lighting, heating, ventilation, air conditioning (HVAC), security systems, plumbing systems, etc. BACS aim to automate and control individual subsystems in a building. The Building Management Systems (BMS) are more advanced and integrated systems. They enable centralized and intelligent management of all aspects of a building, including BACS. They offer broader features such as monitoring, control-ling, optimizing, and managing the subsystems (such as HVAC, lighting, security, etc.) in a single platform. Smart systems and Internet of Things (IoT) technologies, which are used for energy-efficient buildings and environments, also have a rising impact on reduce energy consumption, cost, simplify asset management and offers greater flexibility through remote access - anytime, any-where and enhance environment-related comfort in buildings [4].Most of the current conventional building automation and control (BAC) or building management system (BMS) are not as responsive as energy-efficient systems, according to the studies. Moreover, problems such as overheating or overcooling that negatively impact indoor thermal environments, have been observed in most buildings because of inappropriately designed BAC systems. However, BMSs are getting more and more critical for sustainable building performance [5]. Right now, one of the best models known according to related literature, is the “model Predictive Control” (MPC), that represents the performance of complex and simple thermal dynamical systems [6]. Optimizing the building control systems is a priority, especially in public administration. Therefore, the paper aims to build a model of predictive control (MPC) for the main seat of Arpa Umbria (Perugia, Italy) that takes into account a variety of elements, including occupancy and predicted outdoor conditions, by investigating and optimizing energy usage and workers' thermal comfort indoor [7]. The study originates from the need for users to investigate the critical aspects related to the building’s envelope and HVAC in order to define a guideline, in which energy saving measurements are combined with human comfort. Therefore, based on a validated thermal model of the building and thermo-hygrometric monitoring, different optimal management strategies for heating were set up.

2 Case study

The building [8] is located in Perugia, it is the operational seat of Arpa Umbria. “Arpa” is the organization responsible for the environmental prevention and protection in Umbria. The building hosts offices and research laboratories; it covers a floor area of about 1082 m² and spans across five floors, whose one is under-ground. Moreover, it is composed by two sections, which were built in different periods: the original one, referred to as the "old part" (OP) dating back to the 1970's, and the earliest one, known as the "new part" (NP), added in 2015 (which is smaller than the first one). They own different types of heating and cooling methods, as described below. The heating of the old section is powered by two traditional natural gas boilers. In-stead, the cooling is powered by two hydronic heat pumps, placed outdoors on the ground floor, equipped with a 2000 l inertial tank to store chilled water. The distribution system consists of fan coil (FC) of different power ranges. Eventually, on the first floor, where there are the laboratories, an air handling unit (AHU) has been installed. In the new section, there is a direct expansion air conditioning system with a variable refrigerant flow rate (VRF), powered by a modular external unit: an air-condensed heat pump and ducted indoor units that deliver air through circular diffusers. Air exchange is ensured by enthalpic heat recovery fans installed on each floor. In this paper attention was paid to the old section of the building, to evaluate the effects of the new plant's system control in terms of human comfort and energy consumption (natural gas).

3 Material and methods

3.1 Methodology

On October 6th, 2022, the Ministry of Ecological Transition issued D.M. n. 383 of 2022 to promote energy conservation and to counter the increasing prices of energy. In particular, this Decree revised the indoor temperature limits and the operating hours of heating during the winter season of 2022/2023. Specifically, the indoor temperatures decreased by 1°C, from 20°C to 19°C and the heating was to be operational from October 22nd to April 7th (according to the classification of the Italian territory). In this context, the attention to energy saving led users towards optimization and control strategies, setting new heating schedules. The control strategies implemented by the user concern: on the one hand the weekly working time was regulated for all workers, on the other hand a digital time switch was installed to manage the plant's operating of the old section. So, it allows to set up daily and weekly schedules based on the real occupancy of the building and on the outdoor conditions (on weekends the boilers are partially switched off during daytime and the circulation pumps are switched off at nights). In this way, the heating schedule for the 2022/2023 season was modified as reported in Table 1.

Table 1. Heating schedule setting for 2022/2023 season.

Periods	Schedules		Daily hours	Weekly hours
from Nov. (start-up) to 20/12	Mon/Wed/Fri	7:00-15:00	8:00	43:00
	Tue/Thu	7:00-13:00/14:00-17:30	9:30	
from 21/12 to 23/01	Mon/Wed/Fri	5:00-15:00	10:00	53:00
	Tue/Thu	5:00-13:00/14:00-17:30	11:30	
from 24/01 to 14/02	Mon/Wed/Fri	5:00-15:00	10:00	58:00
	Tue/Thu	5:00-19:00	14:00	
from 15/02 to 20/03	Mon/Wed/Fri	5:00-15:00	10:00	57:00
	Tue/Thu	5:00-18:30	13:30	
from 21/03 to 16/04	All workdays	7:00-10:00	3:00	15:00

In this context, an integrated approach, combining the estimated reduction of energy consumption with human well-being was proposed in order to set-up an optimal management of the heating, based on a thermal calibrated model of the building and thermo-hygrometric monitoring. This approach, depicted in the flowchart of Figure 1, harmonizes comfort with eco-efficiency, a fundamental principle of modern, environmentally conscious architectural practices. With the thermal model, different management strategies were defined and simulated in order to develop algorithms to set switch-on/off system based on indoor and outdoor weather conditions.

In particular, according to the procedure for microclimatic parameters measurement, a preliminary survey [8] was carried out by using portable sensors (Tinytag Plus 2-TGU-4500) for measuring indoor air temperature and relative humidity; this preliminary monitoring campaign concerns the heating period, between October 2022 and April 2023, in which the sensors were installed in different spaces of the building's old part, with a recording setting of 10 minutes. The monitoring campaign has two purposes: the former aims at investigating the effects of the new heating sched-ule on human comfort, verifying that the acceptable temperature set-point (19°C) is guaranteed during the occupancy, instead, the second aims at collecting temperature data for the calibrating phase of the thermo-energetic model. In particular, the development of the building's model encompasses several stages, beginning with the implementation of new schedules for thermal comfort regulation. The system constantly monitors temperature and humidity, essential to maintain human comfort; for this rea-son, outdoor and indoor conditions are continuously assessed in order to meet comfort standards. Simultaneously, energy simulations are conducted to predict the system's efficiency. These elements are integrated into a validation model, which verifies the accuracy of simulated comfort and energy data against actual conditions. Eventually, the model goes through the final stage: optimizing energy consumption to enhance efficiency while maintaining comfort levels.

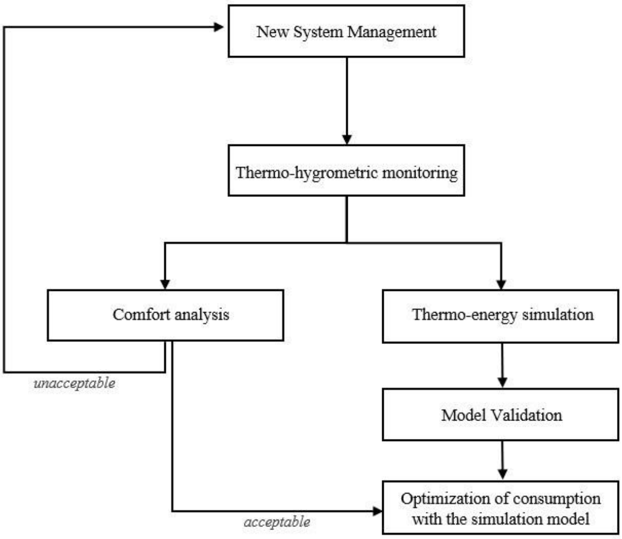


Fig. 1. Flow diagram of the methodology.

The results of the monitoring campaign are presented in [8]; however, the principal outcomes can be summarized as follows:

- the comfort temperature was guaranteed for more hours over the occupancy period, especially in the offices (due to the small size and different occupancy compared to

laboratories) and in the spaces West oriented (due to direct solar contribution in the afternoon);
- the heating start-up transient for the first weekday is slower than the others, based on the outdoor conditions; so, an early heating ignition is reasonable for this day (of at least an hour).

3.2 Energy calibrated modelling of the building

The virtual model of the building was evaluated by means of EnergyPlus v.8.9 dynamic energy simulation software, in order to predict hourly indoor temperature in the most representative spaces [9]. The first step was to create a geometric 3D model: the geometry of the building was analysed using documents and CAD plans, combined with on-site survey. The CAD plans were transferred to the software DesignBuilder, appropriately scaled and oriented, to create the volumes of the various zones (Figure 2).

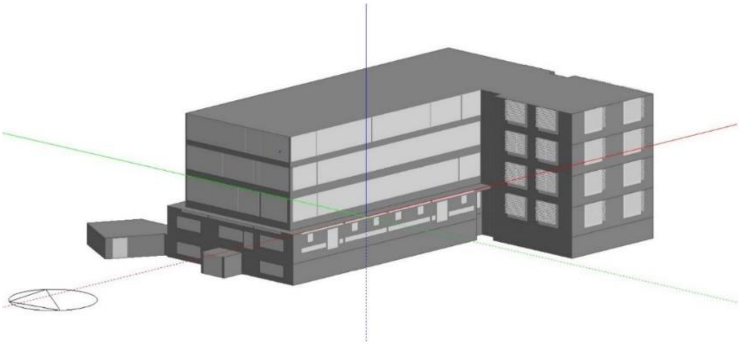


Fig. 2. Building model geometry (from DesignBuilder software).

To create the model, in addition to the thermophysical properties of the building envelope, even thermal loads and HVAC system characteristics have been set. In particular, as internal gains, human occupancy, lights and office equipment were considered. Another essential step was the definition of weather data file for the simulation, since the energy balance is mostly influenced by external inputs; for this reason, a weather file was created based on the data collected from a weather station (dry bulb temperature, relative humidity, wind speed, solar radiation), which is located in the roof of the university building, not away from the seat of Arpa Umbria. To validate the energy model, a calibration process was followed: this was an important phase, to allow a reliable simulation model. The energy model was calibrated to consider only two spaces, one office and one laboratory, both located in the original part of the building:
- Office, located on the third floor and East oriented;
- Laboratory, located on the first floor and West oriented.

The quality of the model was assessed by adopting indoor temperature as the calibration control variable. In particular, hourly values of indoor air temperature collected during the monitoring campaign were compared with simulated values, by means of three indices: mean bias error (MBE), coefficient of variation of root means square error (Cv(RMSE)) and Pearson's index (r). The first two indices are suggested by ASHRAE Guideline 14-2002 [10], while the third one (r) is a typical statistical coefficient of linear correlation between the two variables of simulated and measured data. In this study, it was considered the Cv(RMSE) index, the normalized mean bias error (NMBE) and the determination coefficient (R^2), that is the square of Pearson's index (r) [11]. The model is considered calibrated when the mentioned indices matched the values reported in Table 2.

During the iterative simulation phase, the model was optimized, varying the values attributed to the infiltration air change rate and the air mixing between adjacent zones, which were regarded as the uncertain parameters mostly influential on simulation results.

Table 2. Indices and threshold values for thermal model calibration.

Index	Acceptable value [%]
MBE monthly	-5% ≤ NMBE ≤ +5%
Cv(RMSE) monthly	≤ 15%
MBE hourly	-10% ≤ NMBE ≤ +10%
Cv(RMSE) hourly	≤ 30%
R^2	≥ 0.75

4 Material and methods

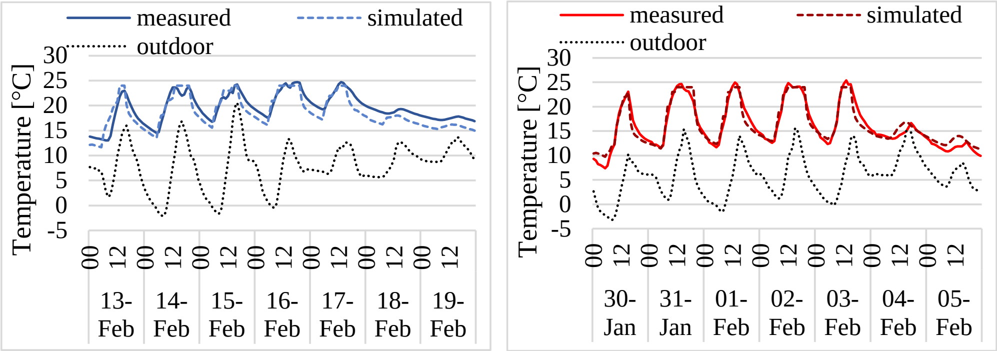
4.1 Energy model: validation phase

For the validation of the model, the average hourly indoor temperature of the rooms was considered as the variable of interest. The two rooms selected for the validation were strategically chosen to represent the different zones within the building: the East Office, located on the third floor, and the West Laboratory, situated on the first floor, both of which are part of the old section. Given the complexity of the case study, the validation process was carried out on both a monthly and weekly basis during the monitoring period, which spanned from January 24th to February 24th, 2023. The validation was performed using an iterative procedure, involving periodic adjustments to various parameters of the model, in particular the building’s air permeability and the convective exchanges between adjoining rooms. However, a significant discrepancy is observed in the simulation of the start-up transient, due to simplified modelling of the heating in the software (Simplified HVAC). The simulated data reached the set-point temperature faster than the actual measured trend. This was attributed to the real system's use of fan coil units as terminal elements, whereas the simplified model treated them as an air-based system. This simplification was necessitated due to the building's system's complexity and the lack of detailed technical data. This modelling approach particularly impacted the R^2 index, one of the three validation parameters specified by ASHRAE. The values of the validation parameters are reported in the following Table 3.

Table 3. Values of the indices for the chosen spaces.

	East Office-Floor 3		West Laboratory-Floor 1	
	Monthly values	Hourly values	Monthly values	Hourly values
MBE	-2%	-5%	-1%	-1%
Cv(RMSE)	7%	9%	14%	7%
R^2	0.79	0.82	0.73	0.93

The trend of the indoor temperatures (measured and simulated) is illustrated in Figure 3.



(a) (b)

Fig. 3. Validation model of a week, hourly averaged data, fort the Office East-3 (a) and Laboratory west-1 (b).

In the East Office, the comparison between the measured and simulated temperatures for the investigated period indicates a correctly simulated trend, even at night, with a maximum deviation of less than 2°C. The discrepancy between the measured and simulated temperatures on the morning of Monday, February 13th, is attributable to a malfunction of the system, which started operating later than scheduled. A more pronounced difference is observed over the weekend, likely due to a different response of the model concerning the building's thermal inertia. Greater focus was placed on the behaviour during weekdays since, on holidays, the system is turned off, contributing no energy. In the West Laboratory as well, the experimental data were compared with the simulated temperatures for the period under consideration. In this case too, the graph shows a temperature trend that follows the pattern of the data measured by the sensor. The primary differences between the measured and simulated temperatures are record-ed over the weekend, with a maximum difference of about 1°C.

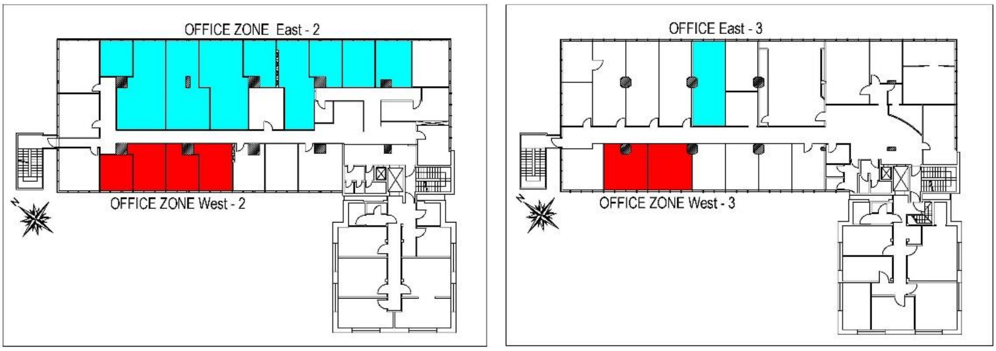
4.2 Heating schedule comparison and selection

The dynamic energy model was employed to hypothesize new heating schedules for the old part of the building, different from those adopted during the last winter. Analysing the results of the thermo-hygrometric monitoring and observing the trend of the outdoor temperature throughout the entire winter season, several start-up and shutdown schedules were proposed, varying both on a monthly basis (to take into account different outdoor climatic conditions) and on a daily basis (based on the current occupancy of the building). A greater number of operating hours were anticipated during the colder periods and, conversely, fewer in the warmer months. As it was described, the model doesn’t well simulate the transient time of switching on, for this reason the time constant *(τ)* was calculated. This parameter, expressed in hours, represents the response time of the building to reach a new thermal balance after a variation of indoor or outdoor conditions (in this case the switch-on and off of the heating). Preliminarily, it was calculated considering only the external surface [12], as a ratio between the areic thermal capacity and the thermal transmittance of the surface (1).

$$\tau = C / U \tag{1}$$

These thermophysical properties of the envelope components were defined by inspections and techniques. The parameter thus calculated results about 3 hours, in accordance with the monitoring results. The value of the time constant allowed to set the switch-on time of the new simulated heating schedules, especially for the first weekday.

All the proposals were tested in some areas of the second and third floors of the old section, specifically where the office spaces are located (Figure 4). The simulation of the new operating schedules was carried out on an annual basis using the statistically significant climatic file created by the Italian Thermotechnical Committee (CTI), avail-able within DesignBuilder. It has also been hypothesized for the next winter season that the indoor temperature set-point will be 21°C, a value that falls within the range pre-scribed by the regulation (20°C ± 2°C). In order to evaluate the effects of the proposals, the percentage of discomfort hours during working hours was calculated. Specifically, the percentage of the hours in which the indoor temperature falls outside the comfort conditions prescribed by the regulation (21°C) was determined. Furthermore, for a more comprehensive overview, the same 'discomfort index' was also calculated as a total per-centage value, taking into account the entire period. The discomfort indices (%) have been calculated for the simulation of the current state (c.s.), related to the operating hours of the heating during the 2022/2023 season and for the proposed schedules.



(a) (b)

Fig. 4. New tested spaces for the simulation of the schedules, for the second (a) and the third floor (b).

According to simulation results, two new heating schedules were chosen as the most suitable in terms of energy savings and people's comfort (proposal n. 1 and proposal n. 2), described in Table 4.

Table 4. New monthly heating schedules for the old section.

Periods	**Proposal 1**				**Proposal 2**			
	Schedules		**Daily hours**	**Weekly hours**	**Schedules**		**Daily hours**	**Weekly hours**
from 15/10 to 15/11	Mon	7:00-10:00	3:00	19:00	Mon	7:00-10:00	3:00	11:00
	Tue/Thu	7:00-10:00 14:00-16:00	5:00		Tue/Thu	8:00-10:00	2:00	
	Wed/Fri	7:00-10:00	3:00		Wed/Fr	8:00-10:00	2:00	
from 16/11 to 7/01	Mon	6:00-14:00	8:00	39:00	Mon	6:00-13:00	7:00	35:00
	Tue/Thu	7:00-12:00 14:00-17:30	8:30		Tue/Thu	7:00-12:00 14:00-17:00	8:00	
	Wed/Fri	7:00-14:00	7:00		Wed/Fr	7:00-13:00	6:00	
from 8/01 to 15/02	Mon	5:00-14:00	9:00	45:00	Mon	5:00-14:00	9:00	43:00
	Tue/Thu	6:00-12:00 14:00-18:00	10:00		Tue/Thu	6:00-12:00 14:00-18:00	10:00	
	Wed/Fri	6:00-14:00	8:00		Wed/Fr	7:00-14:00	7:00	
from 16/02 to 17/03	Mon	6:00-14:00	8:00	38:00	Mon	6:00-14:00	8:00	36:00
	Tue/Thu	7:00-12:00 14:30-17:30	8:00		Tue/Thu	7:00-12:00 14:00-17:00	8:00	
	Wed/Fri	7:00-14:00	7:00		Wed/Fr	7:00-13:00	6:00	
from 18/03 to 15/04	Mon	6:00-12:00	6:00	28:00	Mon	7:00-10:00	3:00	15:00
	Tue/Thu	8:00-12:00 15:30-17:30	6:00		Tue/Thu	8:00-10:00 15:00-17:00	4:00	
	Wed/Fri	7:00-12:00	5:00		Wed/Fr	8:00-10:00	2:00	

The proposal n. 1 is more cautious, ensuring a greater number of operating hours for the system in every period. In contrast, the second, which envisages fewer operating hours, could cause discomfort to the occupants in extremely cold climatic conditions. The discomfort indices (%) calculated for the proposed sched-ules are reported in Table 5.

From the data analysis, it is observed that schedule n. 2 results in higher discomfort index values, especially during the two coldest periods of the year (16/11-07/01 and 08/01-15/02).

In some cases, the values settle between 10% and 15%, with a peak of 20% in the East Office macro-area of the second floor, on Mondays between 16/11 and 07/01. Overall, the values of schedule n. 2 consistently remain below 15%, thus ensuring a prolonged sensation of comfort in the rooms during the building's occupancy period.

The schedule n. 1 is certainly more cautious, as the total values of the discomfort index never exceed 10%.

Table 5. The discomfort indices (%) calculated for the simulations of the current state (c.s.) and the two proposed schedules (n.1 and n.2).

Periods		**Off. Zone East-2**			**Off. Zone West-2**			**Off. Zone West-3**			**Office East-3**		
		c.s.	**n.1**	**n.2**	**c.s.**	**n.1**	**n.2**	**c.s.**	**n.1**	**n.2**	**c.s.**	**n.1**	**n.2**
from 16/10 to 15/11	Mon	0	0	0	0	0	0	0	0	0	0	0	0
	Tue/Thu	0	1	2	0	0	0	0	1	1	0	0	2
	Wed/Fri	0	0	0	0	0	0	0	0	0	0	0	0
	Tot.	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
from 16/11 to 07/01	Mon	4	10	20	4	8	14	12	10	16	4	0	6
	Tue/Thu	7	11	14	3	5	6	3	7	11	4	8	8
	Wed/Fri	0	0	8	0	0	1	0	0	4	0	0	0
	Tot.	**4**	**7**	**13**	**2**	**4**	**6**	**4**	**5**	**10**	**3**	**4**	**5**
from 08/01 to 15/02	Mon	2	10	12	5	7	10	12	14	17	0	2	2
	Tue/Thu	5	11	13	2	5	5	4	8	9	5	6	7
	Wed/Fri	0	1	1	0	0	0	0	1	3	0	0	0
	Tot.	**3**	**8**	**9**	**2**	**4**	**4**	**4**	**7**	**8**	**2**	**4**	**4**
from 16/02 to 17/03	Mon	0	0	0	0	0	0	0	0	0	0	0	0
	Tue/Thu	0	6	6	0	1	1	0	2	3	0	3	3
	Wed/Fri	0	0	0	0	0	0	0	0	0	0	0	0
	Tot.	**0**	**3**	**3**	**0**	**1**	**1**	**0**	**1**	**2**	**0**	**2**	**2**
from 18/03 to 15/04	Mon	0	0	0	0	0	4	11	11	11	0	0	0
	Tue/Thu	0	0	0	0	0	0	0	0	0	0	0	0
	Wed/Fri	0	0	0	0	0	0	0	0	0	0	0	0
	Tot.	**0**	**0**	**0**	**0**	**0**	**1**	**2**	**2**	**2**	**0**	**0**	**0**

In the following graphs, the average hourly trend of the indoor temperature (East Office on the third floor) during the three different heating periods is represented, compared with the outdoor trend (Figure 5). The daily occupancy of the office is highlighted in orange, while the two red lines indicate the comfort range prescribed by the regulations.

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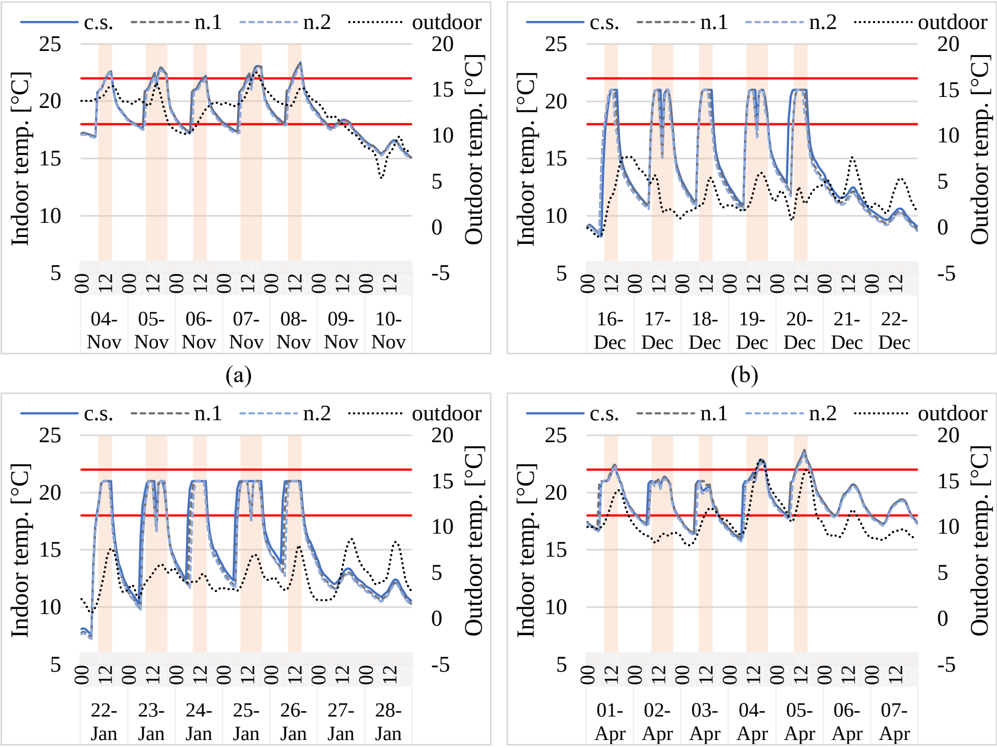
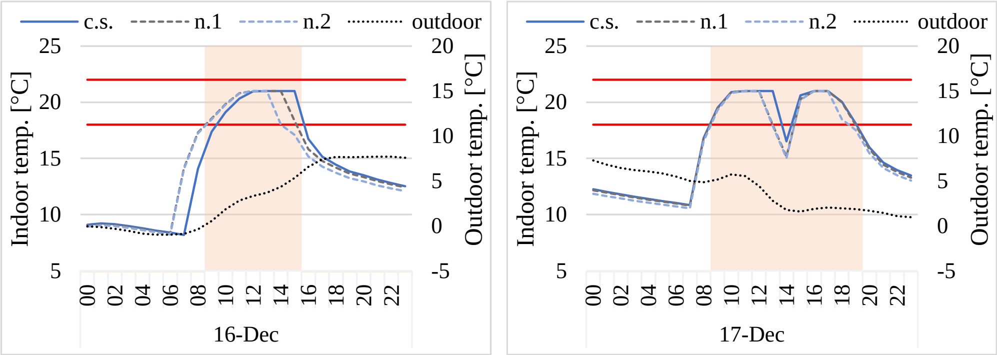


(a) (b)

(c) (d)

Fig. 5. Simulated trends of the indoor temperature for the Office East-3, referred to the current state (c.s.) and the two management systems proposed (n.1 and n.2), in four representative weeks of the heating period.

The Figure 6 focuses on the two days of the heating period in which the discomfort index is higher: on Monday and on Tuesday. The former is characterized by an early temperature decrease of the two proposed schedules, which reaches values less than 18 °C before the end of the daily occupancy. The same situation applies in the second graph, during the lunch break.



(a) (b)

Fig. 6. Simulated trends of the indoor temperature for the Office East-3 in particular weekdays, on Monday (a) and on Tuesday (b).

Finally, thanks to the real hourly gas consumption data, directly detected, an estimation of the natural gas consumption for the two proposed heating schedules was carried out, and they were compared with the estimated consumption for the next season, if the schedules of 2022/2023 heating season are used. Overall, a reduction in seasonal consumption is achieved by adopting the new proposals; in particular, by adopting the proposal n. 1, a reduction in gas consumption of 23% could be achieved, while adopting the second one would result in a 35% savings. The methodological approach is based on the real hourly consumption of natural gas (directly detected) and it is well explained in [8, 13].

4.3 The implementation for the heating season 2023/2024

In the winter season of 2023/2024, the startup of the heating was postponed until Tuesday, November 14th, due to mild weather conditions, and the decision to partially implement operating proposal n. 2 for the systems was made, as shown in Table 6. The operating hours for the heating used in the current season are influenced by different factors such as achieving indoor comfort temperatures, weather conditions and the simulations described in the preceding section. The operating hours are reviewed and, if necessary, adjusted every two weeks, while also ensuring that comfort temperatures in the offices are achieved simultaneously.

Table 6. Heating schedules setting for 2023/2024 season.

Periods	**Schedules**		**Daily hours**	**Weekly hours**
from 13/11/ to 08/12	Mon	7:00-12:00	5:00	26:00
	Tue/Thu	7:00-11:30 15:30-17:00	6:00	
	Wed/Fri	7:00-11.30	4:30	
On weekends the boilers are partially switched off during daytime, while the circulation pumps are switched off at nights. During special weekdays (holidays) the heating is off.				

The following graph (Figure 7) shows the indoor temperature trend, compared with the outdoor one, of a specify week, in which the daily occupancy period is highlighted by orange while the green and red arrows indicate respectively the time of switch-on and off the heating.

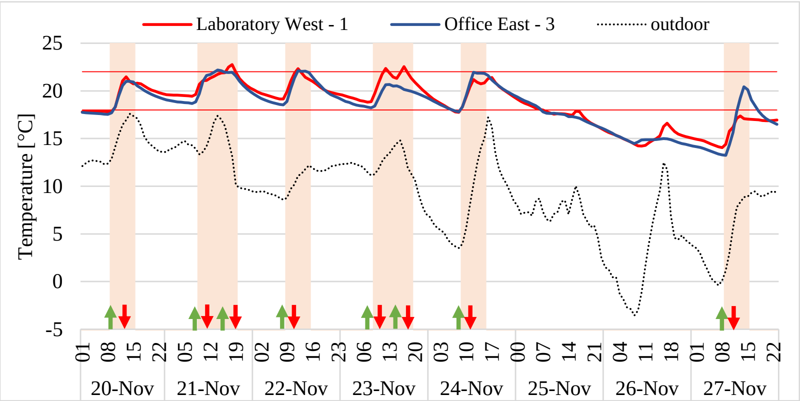


Fig. 7. Hourly fluctuations of indoor and outdoor temperatures during a typical week (November 2023).

As shown in Table 7, a significant reduction in gas consumption was observed in the current heating management, compared to the same period of previous years. In particular, a reduction of 43% in consumption compared to the 2022/2023 season and reduction of 75% compared to the 2021/2022 season have been recorded.

Table 7. Monthly gas consumption for the three heating seasons.

Periods	**2021/2022 season [Sm^3]**	**2022/2023 season [Sm^3]**	**2023/2024 season**		
			Consumption [Sm^3]	**Variation from 2021/2022**	**Variation from 2022/2023**
October	5699	880	838	-85%	-5%
November	7870	4996	2520	-68%	-50%
Total	13569	5876	3358	-75%	-43%

5 Conclusions

A methodology suited for the management and control of the heating of the seat of Arpa Umbria in Perugia (old part of the building) was set up, in order to optimize gas consumption and to achieve indoor comfort.

Based on the indoor temperature monitoring and a calibrated thermal model of the building, different schedules were simulated, in order to optimize and to improve those already implemented following the D.M. n. 383 of 2022, taking into account the mutual outdoor conditions by the cold season and the occupancy of the building (variable in weekdays). Then, the two best were proposed in terms of guaranteed human comfort during the daily occupancy of the building (proposal n. 1 and n. 2). The proposal n. 1 is more cautious, ensuring a greater number of operating hours for the system in every period. In contrast, the second, which envisages fewer operating hours, with higher discomfort index values, especially during the coldest periods of the year (from December to February). With schedule n. 1, the reduction in gas consumption was estimated at 23%, while adopting the second one would result in 35% savings.

This research lays the foundation for the scheduling of the heating season in progress: the schedule n. 2 was implemented, adapting it to real outdoor conditions characterized by milder temperatures than the simulated one. So, a significant reduction in gas consumption in the first two months of the heating season was achieved thanks also to the delayed ignition of the heating. The integrated approach, thanks to a calibrated thermal model and experimental monitoring, combines the estimated reduction of energy consumption with human comfort and could lead non-residential buildings towards environmental sustainability.

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