



Original Research Article

Impact of Office Dress Code on Building Cooling Energy Demand: A Dynamic Sensitivity Analysis for Italian Weather Zones

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ABSTRACT

One of the key factors affecting both the energy consumption of Heating, Ventilation, and Air Conditioning (HVAC) systems and the indoor thermal comfort of inhabitants is the indoor air temperature in buildings. A primary parameter that significantly influences HVAC energy demand and thermal comfort is the clothing insulation of the users. Although clothing insulation is carefully selected according to well-known standards, its value depends on various factors: i) gender, as males tend to feel warmer than females in cool conditions; ii) metabolic heat production; and iii) the performed activity. Consequently, building occupants can adjust their thermal comfort by modifying clothing insulation values based on outdoor temperature variations. Additionally, the indoor set-point temperature values in a building also depend on its weather zone, which is influenced by outdoor air relative humidity and outdoor air temperature. This work presents a dynamic simulation model for analyzing comfort conditions and energy consumption for space cooling and heating, taking into account changes in clothing insulation values for a specific user. A particular office room was considered for the study. The space heating and cooling energy demand of the office was calculated using a suitable thermal zone modelled by Type 56 of TRNSYS, coupled with the Google SketchUp TRNSYS3d plug-in. The selected case study is an office room located at the University of Federico II in Naples, Southern Italy. To evaluate both comfort conditions and energy demands, several sensitivity analyses were conducted by varying the clothing insulation and office set-point temperature. A sensitivity analysis on the weather zone of the office building was also performed to assess the dependency of clothing insulation values on weather parameters. The presented model serves as a suitable and general tool to propose simple clothing variation behaviors, aiming to achieve a trade-off among dress code, energy saving, and thermal comfort.

KEYWORDS:

Thermal comfort, Dynamic simulation model, Clothing insulation, Building energy saving.

INTRODUCTION

The adoption of energy efficiency strategies and renewable energy technologies is becoming increasingly crucial to achieve a decarbonized future and reduce greenhouse gas emissions by 80–95% by 2050. Given the significant impact of the building sector on global energy consumption and CO₂ emissions, an impact that has increased in recent years, particularly in the residential sector [1], [2], many countries have recognized the need to develop regulations, policies, and committees to address this issue [3], [4]. To decrease the building energy demand for space heating and cooling purposes, households and policymakers must implement suitable strategies to reduce related carbon emissions [5], especially considering the ongoing global warming issues.

In this framework, it is estimated that 80% of the existing building stock will still be in use by 2050, and current renovation rates of 1% are too low to meet the Green Deal objectives [6]. To reduce energy consumption in the building sector, energy-efficiency strategies for building stock and advancements in heating, ventilation, and air conditioning (HVAC) systems, are feasible solutions.

Currently, over 75 % of existing European buildings feature inadequately insulated thermal envelopes, low airtightness levels, and uncontrolled ventilation rates [7], often resulting in indoor thermal conditions that fall short of minimum requirements [8]. Researchers are focused on the renovation of existing buildings [9], improving building envelopes [10], building structures and advanced insulation [11], and employing innovative materials [12] or reused materials within the framework of the circular economy [13] (the principle of “Reduce, Reuse, and Recycle (3R) [14]). Passive energy measures [15], such as environmentally friendly end-use behaviours [16], are also a potential approach, providing both a fast improvement in indoor thermal conditions and a reduction in energy demand [17]. Passive energy strategies increase occupants adaptive opportunities, thereby enhancing the level of thermal comfort [8].

To control indoor humidity and air temperature – key factors in indoor thermal comfort [18] – various HVAC systems can be adopted for both non-residential and residential buildings

Thermal comfort can be evaluated using different modelling approaches. The most widely adopted framework for mechanically conditioned buildings is the steady-state model developed by Fanger, expressed through the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) indices, and standardized in ISO 7730 and ASHRAE Standard 55 [19], [20]. This model relates occupants thermal sensation to environmental parameters (air temperature, mean radiant temperature, relative humidity, and air velocity) and personal factors such as metabolic rate and clothing insulation. Alternative approaches include adaptive thermal comfort models, such as those proposed in ASHRAE Standard 55 and EN 16798, which link acceptable indoor temperatures to outdoor climatic conditions [21]. However, these models are primarily intended for naturally ventilated buildings and for occupants who can freely adapt their behaviour and environment, and are therefore less suitable for office buildings characterized by centralized HVAC systems and fixed temperature set-points [22]. However, is one the most diffused accepted and used method for assessing thermal comfort [19], [23], [24].

The thermal energy consumption of these systems also depends on the occupants thermal comfort levels. As indoor thermal comfort levels rise, the energy consumption of HVAC systems significantly increases [25], a situation further exacerbated by the climatic severity of the building location.

Most energy refurbishment actions for advanced HVAC systems improvements to building envelopes, such as increased thermal insulation [26] and window retrofit [27], involve high capital costs and result in long payback periods. However, by simply adjusting resident behaviours, considerable cost and energy savings can be achieved without expensive refurbishment actions [28]. Resident behaviours are crucial for achieving high energy efficiency in buildings [29]. Incorrect user habits can negatively affect both comfort conditions and building energy demand, leading to significant energy dissipation. This issue is particularly prevalent in office settings where users often overlook the impact of energy dissipation on operating energy costs. Several types of incentives, such as monetary rewards and interactive games designed to increase awareness of energy-saving strategies [30], can be implemented to encourage residents to adopt positive energy behaviours [31].

The dress-code plays a key role in energy consumption and user thermal comfort [32]. Additionally, dress-code is pivotal in certain workplaces (such as universities, banks, and other formal offices) as it symbolizes worker credibility [33]. In some cases, a more formal corporate dress code prevents clothing adaptation [34], leading to irrational thermoregulatory behaviour. For example, wearing a multi-layer wool suit during hot weather conditions leads to significantly higher cooling energy consumption during the summer than would occur with a

more casual and relaxed dress code. Conversely, an outfit without a tie can considerably improve thermal comfort and lower the energy demand for space cooling.

For metabolic rates around 1.2 met, typical of sedentary activities in office settings, variations in dress code and clothing insulation affect the optimal operating temperature by approximately 6 °C per clo (where 1 clo equals 0.155 m² K/W). Consequently, removing a thin, long-sleeve sweater decreases the clothing insulation by about 0.25 clo, leading to an increase in optimal operating temperature of approximately 6 °C/clo × 0.25 clo = 1.5 °C [35]. According to the ASHRAE chart, achieving comfort at around 25.6 °C, requires a clothing factor lowered to about 0.1-0.6 clo, preferably 0.3 clo [36]. For a clothing insulation value of 1 clo, comfort is reached at approximately 21.5 °C, assuming a relative humidity of 50%, an air velocity lower than 0.1 m/s, a standard office activity of 1.2 met, a Predicted Percentage of Dissatisfied (PPD) equal to 5%, a Predict Mean Vote (PMV) equal to 0, and the air temperature equal to the mean radiant temperature. A temperature variation of 1 °C in a conventional office building is associated with a change in clothing insulation of just 0.2 clo [37].

Several studies confirm that adjusting clothing to adapt to weather conditions is an effective and helpful approach to achieve thermal comfort [35], [38]. For example, the influence of clothing on thermal comfort in a call center and a suburban shopping mall located in Sydney, Australia, is analyzed in ref. [35]. The call center follows a strict dress code, allowing casual attire only on Fridays. For all workers, the daily values of the clothing factors on Fridays were notably higher than those for other weekdays in winter and lower in summer. This indicates that workers prefer dressing without the constraints of formal codes.

The influence of clothing factors on energy consumption and thermal comfort is studied by Newsham [39]. In this study, a model is developed and applied to an office in Toronto. To determine the suitable values of the clothing factor to ensure a PPD index of about 5%, the author varied the set-point temperatures during the summer and winter seasons. Specifically, the study used low heating set-point temperatures during winter and high cooling set-point temperatures during summer. For more adaptable and flexible clothing, the detected cooling set-point value was 25.55 °C. For a clothing factor value of 0.75 clo, the cooling set-point temperature decreased to 24.35 °C. These set-point temperatures are lower than those associated with the classic formal dress code of 1 clo. It is important to note that the energy demand for space cooling significantly depends on these set-point temperatures. The yearly energy consumption decreased from 275 kWh to 218 kWh, resulting in a saving of about 21%.

Lakeridou et al. [40] conducted a statistical study on office buildings in United Kingdom, increasing the current set-point temperature of 22 ± 2 °C by 2 °C. The study included 129 participants and applied the increased set-point temperature only to one floor of the building. Indoor air temperatures across several locations were measured. The results showed that the suggested increase made participants feel considerably warmer without causing discomfort. The increase to 24 °C in open-plan areas did not lead to discomfort, although the actual percentage dissatisfied (APD) was about 20%, close to the maximum acceptable value. Wu et al. [41] studied the thermal comfort of an office building in Guangzhou, characterized by warm winters and hot summers. To conduct the analysis, the physical environmental parameters of the office were continuously recorded, and different clothing factors were considered. Workers completed a weekly questionnaire regarding their comfort conditions. The study found that increasing the set-point temperature from 26 °C to 29 °C could save around 60% of the energy consumption for space cooling without causing thermal discomfort. Schiavon and Lee [42] developed two multivariable linear mixed models evaluating clothing as a function of indoor operative temperature and outdoor air temperature. The outdoor air temperature values were measured at 6 PM. These models provide precise estimations of thermal comfort and appropriately size HVAC units, considering typical clothing factors of 1 clo during winter and 0.5 clo during summer. For a case study in Canada, they found that when the median outdoor air temperature at 6 PM was -7.5 °C, the median clothing factor was 0.8 clo.

Aim of the Work

Despite the extensive literature on thermal comfort and energy consumption in office buildings, few studies have explicitly investigated the dynamic interplay between clothing insulation, dress code policies, and HVAC energy demand using time-resolved simulation models. This work introduces a novel dynamic simulation framework that evaluates occupant thermal comfort hour by hour, linking clothing behavior adjustments to space heating and cooling energy requirements under varying weather conditions. Unlike previous approaches that rely on static set-points or simplified comfort indices, the proposed model integrates detailed building-plant interactions, occupant behavior, and localized climatic variables. Furthermore, it provides actionable insights for energy-efficient dress code policies, quantifying the trade-off between occupant comfort, HVAC energy use, and dress code formality. To the authors' knowledge, this is the first study to couple a dynamic building simulation with sensitivity analyses on clothing insulation and office dress code relaxation, offering a practical tool for both researchers and facility managers to optimize thermal comfort and energy performance simultaneously.

METHOD

The section presents the approach used to perform the analysis and calculations for the considered case study. Section 2.1 describes the dynamic simulation model and the energy, economic and environmental analyses. Section 2.2 details the case study selected for the dynamic simulations.

Model

The well-known tool TRNSYS is used to perform the dynamic simulations and develop the model of the building-plant system. TRNSYS includes a comprehensive library of energy components, capable of in-depth simulation of the performance of the energy components involved in this work. The energy components of the TRNSYS tool are validated [43] and considered accurate and reliable by the scientific community. Within the framework of building simulation, TRNSYS is regarded as a benchmark software for validating in-house building simulation models [44-46] and estimating the energy demand of buildings [47].

To dynamically simulate the selected office room, Type 56 was chosen. The validation of the Type 56 is demonstrated in ref. [48]. Using Type 56, the dynamic energy demand is evaluated by considering the envelope thermophysical properties, the effects of the weather conditions (e.g., solar radiation, ambient temperature, and humidity), ventilation and infiltration rates, and internal gains (machineries, lights, and people). Additionally, the 3D geometry of the building is modelled as specified in the Google SketchUp TRNSYS3d plug-in [49]. **Figure 1** illustrates the geometry of the office room investigated in this study. Details concerning the office geometry are provided in the Case Study section. As shown in **Figure 1** (a), the room features external overhangs, which are simulated using the "Trnsys3d Shading Group" tool.

All data regarding heating and cooling schedules, ventilation and infiltration profiles, heat gains, and the thermophysical properties of materials, layers, and walls can be defined by Type 56. An important capability of Type 56 is its mathematic modelling for evaluating the comfort of building residents according to ASHRAE Standard 55-2013 [50]. It is also notable that in TRNSYS 18 release, Type 56 can model radiative heat exchange in the thermal zone, using a complex model for estimating view factors and the radiative properties of surfaces as a function of wavelength. This enables the model to calculate the radiative flows transmitted by glazing surfaces and emitted by walls, along with wall temperatures. This feature is particularly useful for comfort analysis, as the model provides both the mean radiant temperature and the operative temperature, which directly influence comfort index values. According to Fanger's theory [51], the model calculates the most significant comfort parameters: the Predicted

Percentage of Dissatisfied (PPD) and the Predicted Mean Vote (PMV), evaluated according to the UNI EN ISO 7730 regulation [52]. Using the dynamic approach in this study, the discomfort hours of the residents – defined as the number of operating hours when comfort parameters are outside the acceptability range – are detected.

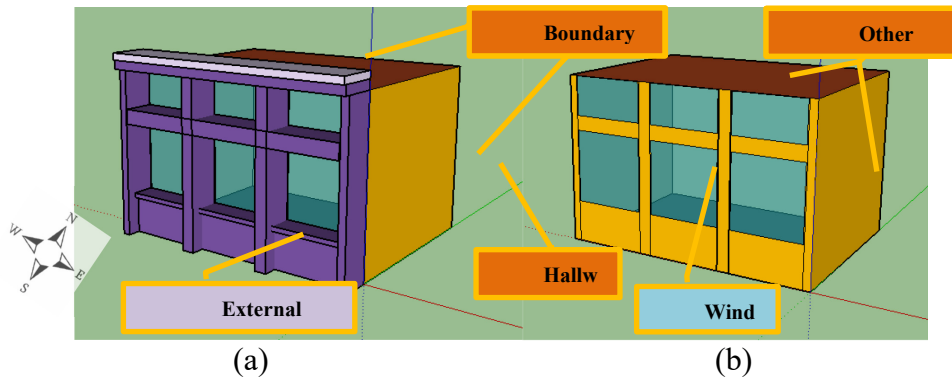


Figure 1. Sketchup 3D model of the office, with (a) and without (b) external overhangs

To simulate the climate conditions of the locality where the selected office is located, TRNSYS Type 15 and 109 were used. These types utilize hourly weather data files provided by the Meteorom database. The cooling and heating energy needed to maintain the office at the required set-point temperature in the summer and winter seasons is provided by a fan coil unit, simulated by TRNSYS Type 600. A suitable variable speed pump, simulated by Type 110, supplies the fan coil unit with chilled water or hot water depending on the season. To manage the water flow rate through the pump, a control strategy is implemented using the proportional controller Type 1669. This controller adjusts the water flow supplied to the fan coil based on the indoor air temperature of the office room. For instance, during the summer, when the indoor air temperature exceeds a set limit, the pump supplies the maximum flow rate to the fan coil unit. As the indoor air temperature decreases, the flow rate is proportionally reduced. The fan coil air flow is considered constant and is based on the fan coil nominal capacity.

CASE STUDY

A 22.3 m² office room located on the 10th floor of the University of Federico II in Naples, Italy, is considered as the case study. **Figure 2** and **Figure 3** show pictures of the investigated office room and the University of Federico II, respectively. The office room features three internal adjacent vertical walls and one external vertical wall. The internal adjacent vertical walls border a hallway and other similar office rooms. The external wall, which faces south, includes three double-glazed windows and three skylights with an air gap and aluminium frame. The office has a volume of 80.95 m³.



Figure 2. Investigated office room



Figure 3. University of Federico II, Piazzale Tecchio in Naples (Southern Italy)

As can be seen, three skylights ($1.52 \text{ m} \times 0.85 \text{ m}$) are located on the upper side of the wall, and three windows ($1.52 \text{ m} \times 1.56 \text{ m}$) are located on the lower side of the wall. For the lower side windows, 35% of the total glazed area is covered by an aluminium frame, whereas for the upper side windows, the aluminium frame covers 40% of the whole glazed area. All lower side windows are equipped with Venetian blinds, which play a key role in reducing incoming solar radiation. To control the opening and closing of the shading device, a control strategy based on incoming solar radiation is implemented in the model. This strategy relies on the total horizontal radiation value: if it exceeds a specific limit, the shading device closes; otherwise, it remains fully open.

The thermophysical proprieties of the office room are defined according to the construction period of the building. Therefore, the proprieties typical of buildings constructed from 1955 to 1970 are assumed. **Table 1** lists the thermophysical proprieties of the internal floor/ceiling, external wall, outer pillar, and windows of the lower and upper walls.

Table 1. Thermophysical proprieties of the considered office room

| Component | U [$\text{W}/\text{m}^2\text{K}$] | Thickness [mm] |
|-------------------------------------|-------------------------------------|------------------------|
| Internal floor/ceiling | 0.347 | 0.350 |
| External wall | 0.326 | 0.340 |
| Outer pillar | 1.899 | 0.470 |
| Window glass (lower and upper wall) | 2.89 | 0.004/0.016(air)/0.004 |

In **Table 2**, the heat gains from machinery, lighting systems, and occupants are defined according to the ASHRAE Handbook Fundamentals [6]. On weekdays, the office room is occupied from 9:00 am to 6:00 pm. The summer vacation period, when the office is assumed to be closed, is from August 8th to 22nd. During the winter season, it is assumed that the heating system is operational from November 22nd to March 23rd, based on to the weather zone of Naples. The summer season is considered to be from May 1st to September 30th. The cooling/heating system operates only during occupancy hours. Regarding the switching on and off of artificial lights, an appropriate control strategy is implemented. Specifically, when the

total horizontal radiation is lower than a fixed limit of 120 W/m², the lights are switched on. Conversely, the lights are switched off when the total horizontal radiation exceeds an upper limit of 200 W/m². The infiltration rate is set at 0.6 air changes per hour.

Table 2. Heat gains of the considered office room [53]

| Mode | Total heat [W] | Radiative heat [W] | Convective heat [W] |
|--|-------------------|--------------------|-----------------------------|
| Two computers | | | |
| Continuous operating | 65 | 6.5 | 58.5 |
| Energy saving | 25 | 2.5 | 22.5 |
| Four Monitors, 48 cm each one | | | |
| Continuous operating | 80 | 8 | 72 |
| Energy saving | | 0 | |
| Lights: 2 LED panels [60cmx60cm] 48W | | | |
| Switching on | 31.2 | 8.4 | 22.8 |
| Two women Activity: Light office work | | | |
| Total heat [W] | Sensible heat [W] | Latent heat [W] | Radiative Sensible heat [%] |
| 115 | 70 | 45 | 60 |

To analyze the comfort conditions of the users inside the office, three different combinations, namely C1, C2, and C3, were taken into account. In each combination, the clothing factor affecting thermal comfort was varied to simulate a specific outfit of the user. According to EN ISO 7730, the considered clothing factors are reported in [Table 3](#)

Table 3. Clothing factors, selected according to Ref. [53]

| Clothing factor [clo] | Description | Comfort condition |
|-----------------------|--|-------------------|
| 1 | typical of the classic formal dress (trousers, jacket and tie, and long-sleeved shirt) | C1 |
| 0.5 | typical of the generic light summer clothing (unbuttoned short-sleeved shirt and light trousers) | C2 |
| 0.3 | typical of the "tropical" outfit (unbuttoned short-sleeved shirt and light trousers) | C3 |

For all the combinations, the values related to air velocity and metabolic activity were considered constant and equal 0.1 m/s and 1.2 met (reliable values for the simulated office room environment). The metabolic activity value corresponds to light metabolic activity typical of sedentary office work, and the air velocity value is consistent with the fact that the investigated office room is a closed environment without significant infiltration phenomena.

To perform the economic, energy, and environmental analysis, the following parameters were considered:

- i) A constant coefficient of performance (COP) equal to 3 [54] for the conversion of the cooling energy demand of the office into electric energy;
- ii) An electric efficiency of national power plants equal to 0.46 [47], [55], [56];
- iii) A specific electric unit cost of 0.53 €/kWhel to estimate the operating cost of the office;
- iv) An equivalent emission factor of 0.48 kgCO₂/ kWhel [55], [56]; [57] to estimate the total CO₂ emissions due to the electric energy demand of the office.

Note that in this study, a constant COP of 3 was assumed for the fan coil system. Although this is a simplification, the system belongs to a large building where each office fan coil is fed by the same central thermal plant. Simulating the entire plant, including interactions with other fan coils, is highly complex and beyond the scope of the present work. Therefore, a conservative constant COP was adopted for the analysis.

RESULTS

In this section, the key results detected by the dynamic simulations are presented. Special attention is given to the comfort analysis during summer operation. Specifically, a discussion of the following results is provided as follows:

- The hourly trends in terms of indoor air temperature, mean radiant temperature, relative humidity, thermal flow rates humidity over a particular summer day (**Figure 4** and **Figure 5**);
- The hourly trends of relative humidity and radiant mean temperature for a typical summer day for different set-point temperatures (ranging from 24 °C to 28 °C) of the cooling plant (**Figure 6** and **Figure 7**).

As well as the monthly energy trends throughout the summer operation. Additionally, a sensitivity analysis on the users clothing factor and the cooling plant set-point temperature is performed. The results of a further comfort analysis during the winter season are also discussed. This analysis varies the clothing factor and the heating plant set-point temperature values of 19 °C and 20 °C to evaluate the number of comfort hours for the users.

To estimate the effect of dress code variation on user thermal comfort under different outdoor relative humidity and outdoor air temperature conditions, a sensitivity analysis on the weather zone where the office room is located is also presented.

It is assumed that occupants perceive comfort according to the PMV values: specifically, users perceive comfort if $-1 < PMV < +1$. According to Italian regulations (UNI EN ISO 7730:2006) for evaluating thermal comfort, the main thermophysical parameters for user comfort must be within the following ranges: i) indoor air temperature, 10 °C – 30 °C; ii) relative humidity, 30% - 70%; iii) mean radiant temperature, 10°C - 40°C; iv) air velocity, 0 m/s - 1 m/s.

Comfort Analysis: Summer Operation

The above-mentioned thermophysical parameters are reported in the following figures (**Figure 4** and **Figure 5**) to show their values for the selected case study as a function of the assumed set-point temperature of the cooling plant. In **Figure 4**, the results for indoor air temperature T_{inAir} , mean radiant temperature T_{mr} and relative humidity U_{rel} are presented for a typical day in July when the set-point temperature is 24 °C. For the same day, the thermal

flow rate related to the cooling demand of the office and the internal gains (lights, auxiliary devices, and people) are reported in **Figure 5**.

The indoor air temperature is particularly high (about 27 °C) during the early hours of the day. This temperature significantly decreases when the cooling system is switched on. Once the set-point temperature of 24 °C is reached, the temperature remains almost constant until 6:00 pm, the office closing time, which also marks the switching off of the cooling system. Subsequently, the temperature shows a significant increase, due to both the solar radiation absorbed during daylight hours and released during the evening hours, as well as the heat gains from computers. Even though the office is closed, these devices continue to operate in energy saving mode.

The mean radiant temperature remains almost constant at a value higher than 26 °C during all daylight hours, with peak values exceeding 27 °C from midnight to 10:00 am. During office hours, the relative humidity is about 60%, showing a significant increase during the early morning and late evening hours.

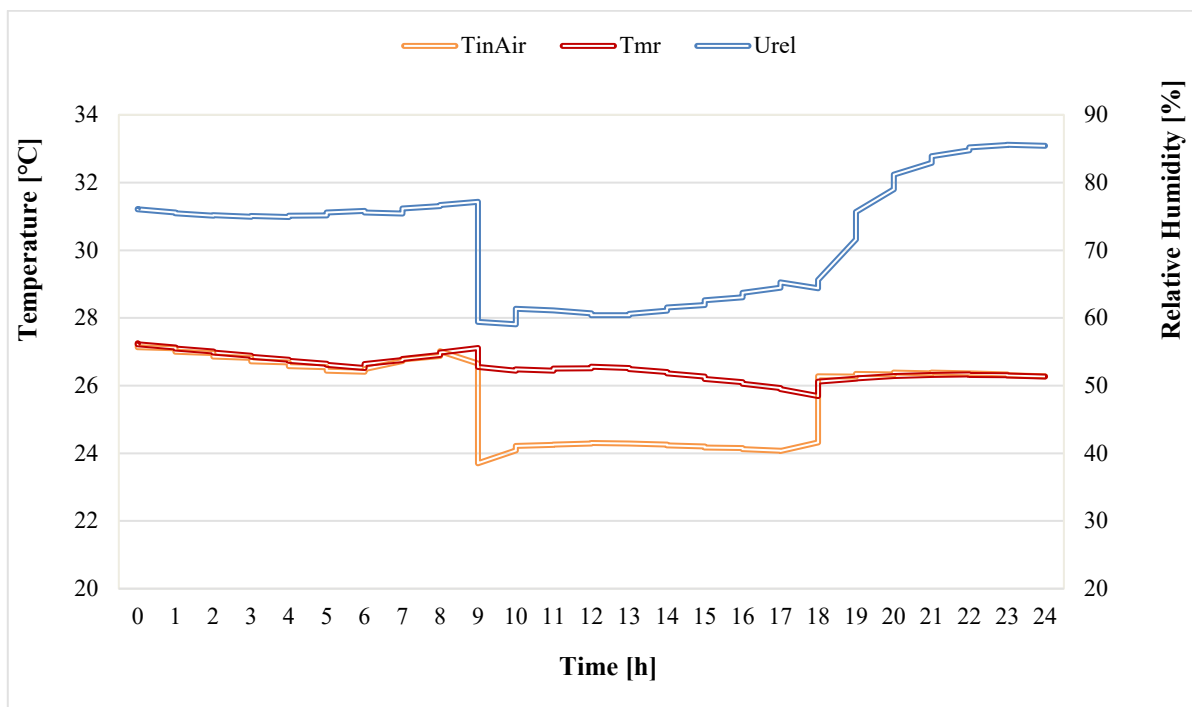


Figure 4. Temperature and relative humidity for a typical day in July

In **Figure 5**, the indoor air temperature T_{inAir} of the office and the ambient temperature (on the left axis) T_{amb} as well as the the thermal flow rate of the cooling system Q_{cool} and the thermal flow rates due to lights Q_{light} , machinaries Q_{aux} , and people Q_{people} are shown. It is interesting to observe how the cooling thermal flow rate peaks at the opening hour of the office, as a high cooling capacity is needed to decrease the indoor temperature. Subsequently, the thermal flow rate follows a more regular trend until the cooling plant is switched off. The thermal flow rates due to lights and people are zero during the office closing time. The thermal flow rate due to the computers is never zero for the reasons mentioned above. This last thermal flow rate is 450 W during office hours and 50 W during the office closing time in energy-saving mode. It is noteworthy that the lights are switched on only for one hour, from 5:00 pm to 6:00 pm, due to the implemented control strategy monitoring the value of the incoming solar radiation.

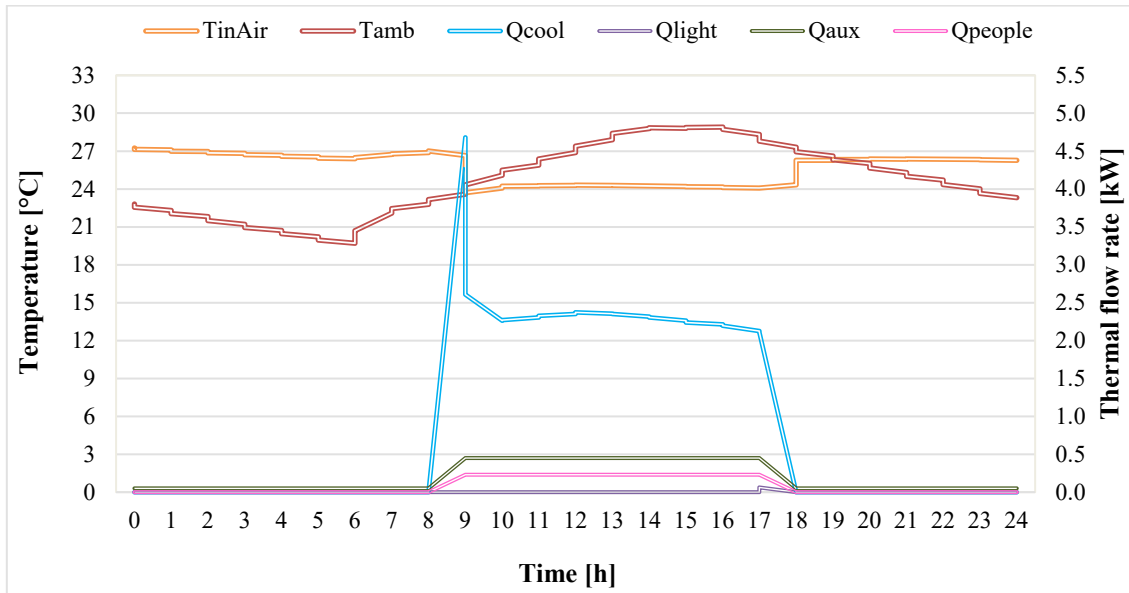


Figure 5. Temperature and thermal flow rates for a typical day in July (set-point temperature of 24 °C)

In **Figure 6** and **Figure 7**, the hourly trends of relative humidity and radiant mean temperature for a typical summer day are reported for different set-point temperatures of the cooling plant (ranging from 24 °C to 28 °C). Note that according to the UNI EN ISO 7730, both parameters (relative humidity and radiant mean temperature) affect the thermal comfort of the building residents.

In **Figure 6**, similar trends in relative humidity can be detected for all set-point temperatures. During office hours, the relative humidity is generally lower than 70%, whereas significant increases are observed in the early morning and late evening hours. It should be noted that the cooling plant in this case study is not designed for regular control of relative humidity. Therefore, for a typical sunny and humid day, the relative humidity remains high during operation hours. However, when the cooling plant is switched on, the relative humidity in the investigated office decreases and falls within the range suggested by the UNI EN ISO 7730, which is between 30% and 70%.

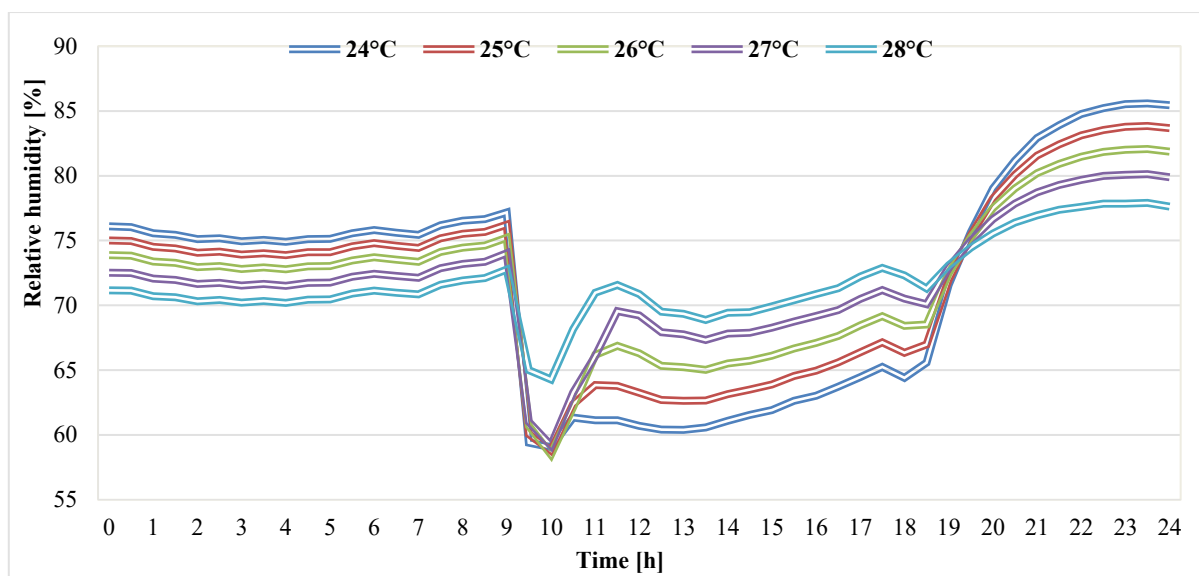


Figure 6. Hourly relative humidity vs different set-point temperatures for a typical summer day

Similar trends in the mean radiant temperature values are noted for all the set-point temperatures (Figure 7). From midnight to 6:00 am, the mean radiant temperature decreases following the trend of the outdoor air temperature. When the sun rises and solar radiation impacts the external wall of the office, the mean radiant temperature increases, occurring from 6:00 am to 9:00 am. The mean radiant temperature then decreases at 9:00 am, coinciding with the activation of the cooling plant. This drop is more evident for the set-point temperature of 24 °C.

It is noteworthy that the office room features a south-facing wall. Due to the high solar radiation incident on the office, the mean radiant temperatures rise, reaching their maximum value at around 12:30 pm, despite the indoor air temperature having reached the set-point value. Even with the cooling plant operating, the mean radiant temperatures still reach values of 29 °C and 26.5 °C, for the set-point temperatures of 28 °C and 24 °C, respectively.

At the closing time of the office, at 6:00 pm, the cooling plant is switched off, and the mean radiant temperatures reach their lowest peak values. Subsequently, a further increase in the mean radiant temperature is noted. This increase is due to the following reasons: i) the solar heat absorbed during the day is released during the evening hours, and ii) the convective and radiative fluxes emitted by the computers, which remain in energy-saving mode even during the office closing hours. During the late afternoon and evening hours, as the outdoor air temperature decreases and the solar radiation ceases, a small decrease in mean radiant temperatures occurs.

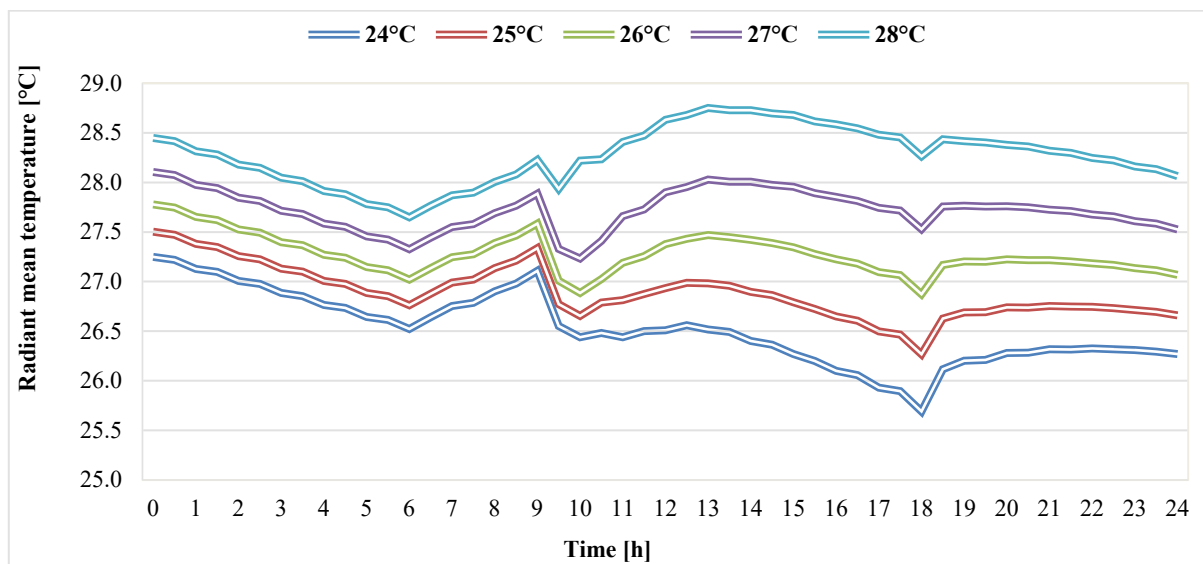


Figure 7. Hourly mean radiant temperature vs different set-point temperatures for a typical summer day

For all the investigated cooling set-point temperatures, the monthly cooling energy consumption during the summer months, from May to September, is reported in Figure 8. According to the weather data for Naples, the hottest month is July. During this month, for a set-point temperature of 28 °C, the lowest energy consumption for space cooling is detected, equal to 12.80 kWh/m² per month, that is 33% lower than the energy consumption related to the set-point temperature of 24 °C, which is 18.18 kWh/m² per month. The low peak values observed in August are due to the two-week closure of the university for the summer vacation.

Figure 9 compares the hours of comfort for the three scenarios of clothing factors (1 clo, 0.5 clo, and 0.3 clo) and the hours of plant operation. Note that the hours of plant operation progressively decrease from 865 to 713 as the set-point temperature rises. For the CLO 1 scenario (classic formal dress), the number of comfort hours of the plant is 24 and 0 at set-point temperatures of 27 °C and 28 °C, respectively. For CLO 1 scenario, the number of comfort

hours is high only at 24 °C. For the CLO 2 scenario (light summer dress), the number of comfort hours is 758 at 27 °C, decreasing to 308 when the setpoint temperature rises to 28°C. For the CLO 3 scenario (tropical outfit), the number of comfort hours is 707, a reasonable value even for the cooling set-point temperature of 28 °C. For clothing factors equal to 1 and 0.5, the cooling set-point temperature of 28 °C is not appropriate.

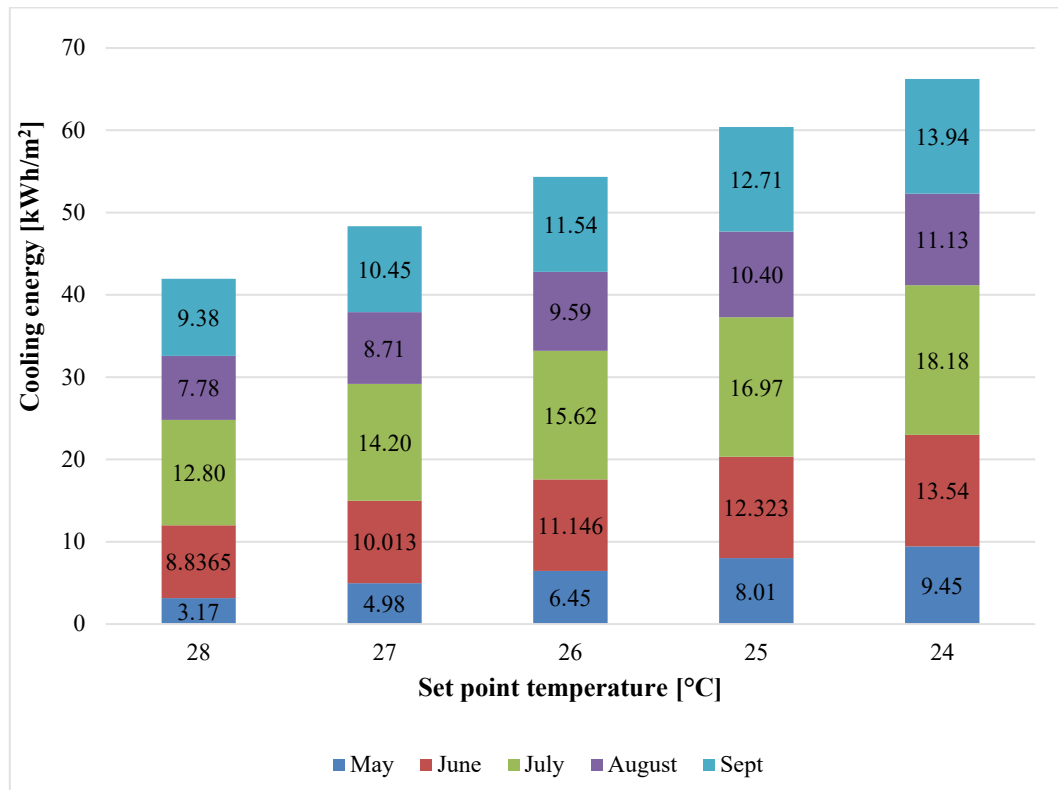


Figure 8. Monthly cooling energy vs cooling set-point temperatures

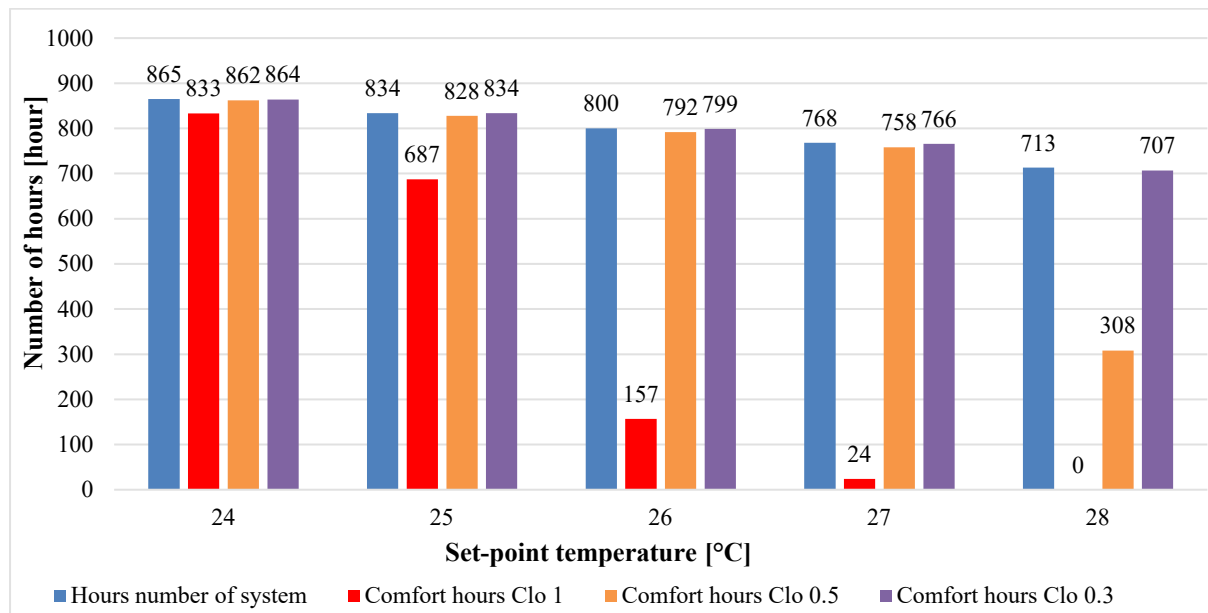


Figure 9. Hours of comfort and hours of plant operation for different values of clothing factor

The distribution of PMV frequency versus PMV ranges (from [-1; -0.75] to [1.5; 1.75]) for the investigated cooling set-point temperatures and clothing factors is reported in [Figure 10](#).

For a set-point temperature of 24°C and a clothing factor of 0.3, the PMV values are below 0 for about 850 hours. A cooling perception, corresponding to $-1 < PMV < -0.75$, occurs for about 100 hours. Only a very small number of hours correspond to PMV values higher than 1 in the case of classic formal dress (1 clo). When the set-point temperature is 25 °C with classic formal dress, PMV values exceed 1 for more than 150 hours. Conversely, a significant increase in discomfort hours, rising from about 150 to 650 hours, is detected with just a 1°C increase in the set-point temperature. In the case of light summer dress (0.5 clo) and a set-point temperature of 27 °C, almost all PMV values are below 1 during operation hours. However, when the set-point temperature increases to 28 °C, PMV values exceed 1 for about 400 hours. For a clothing factor of 0.3 (summer light dress), all the PMV values are below 1 for all operation hours. This indicates that dress code relaxation leads to a reduction in energy consumption for space cooling purposes. Due to the cooling perception associated with wearing summer light dresses, office users are likely to set a higher cooling temperature, thereby reducing the cooling demand.

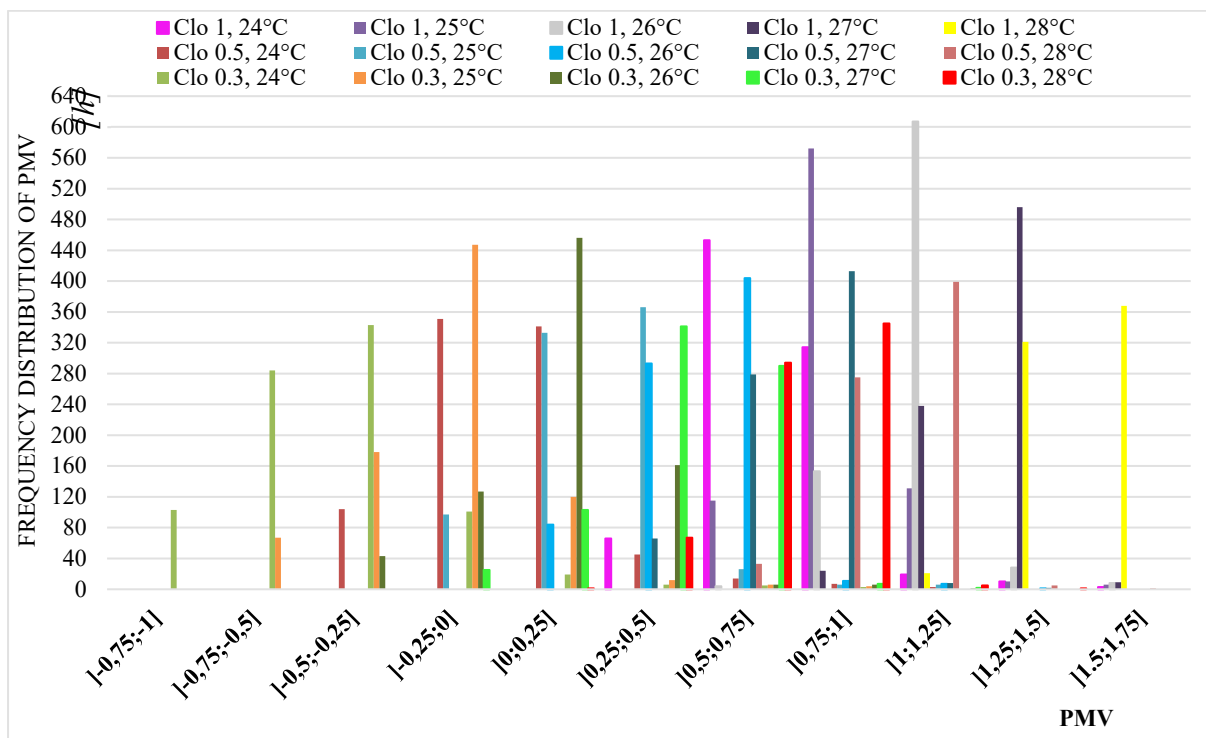


Figure 10 PMV indices frequency distribution as a function of cooling set-point temperature values.

For all the investigated set-point temperatures, ranging from 24 °C to 28 °C, the results of the environmental, energy, and economic analyses are reported in **Table 3**. The cooling energy demand for the most commonly adopted set-point temperature of 26 °C is about 54 kWh/m². The cooling energy demand for a set-point temperature of 24 °C is 66 kWh/m², which is higher than the 42 kWh/m² associated to a set-point temperature of 28 °C.

Primary energy savings of over 32% are obtained when using set-point temperatures of 28 °C and 27 °C compared to the cooler set-point temperature of 24 °C. A reduction in total CO₂ emissions of 108 kgCO₂/year is achieved when comparing the CO₂ emissions for set-point temperature of 28 °C and 24 °C. With a set-point temperature of 24 °C, the operating cost for space cooling in the considered office room is 376 €/year. This decreases to 252 €/year for a set-point temperature of 28 °C. Therefore, wearing tropical or light summers dresses is a feasible and easy method for achieving significant environmental, energy, and economic savings without any capital cost. It is important to highlight that the savings in emissions, primary energy, and operating costs reported in **Table 4** are related only to the considered

office room of 22 m². The achievable results could be more significative and advantageous if the analysis were extended to other offices of the university.

Table 4. Energy, economic, and environmental analysis results

| Set-point temperature | 24 [°C] | 25 [°C] | 26 [°C] | 27 [°C] | 28 [°C] |
|--|---------|---------|---------|---------|---------|
| Cooling energy [kWh/m ² y] | 66.24 | 60.41 | 54.35 | 48.36 | 41.98 |
| Increase of cooling energy [%] | 57.80 | 43.92 | 29.47 | 15.21 | - |
| Cost for space cooling [€/y] | 376 | 347 | 316 | 285 | 252 |
| Primary energy [kWh/m ² y] | 67.60 | 62.34 | 56.81 | 51.24 | 45.32 |
| Total CO ₂ emissions [kgCO ₂ /y] | 332 | 306 | 297 | 252 | 224 |

Comfort Analysis: Winter Operation

During the winter season, the heating plant is in operation from November 22nd to March 23rd, in compliance with the regulations for the weather zone of Naples. Two set-point temperature values were considered: 19 °C (as suggested by the Italian legislative decree of March 1st, 2022, n°17) and 20 °C. Two alternatives for the clothing factor were assumed: 1 clo and 1.5 clo, corresponding to classic formal dress and classic winter dress, respectively. The following figures report the main parameters related to the comfort condition, for a typical winter workday, given the selected set-point temperatures.

The obtained results confirm that the investigated office maintains high temperatures even during the heating season. For the considered clothing factors, the number of operating hours for the heating plant is not particularly high, with 176 hours and 253 hours for set-point temperatures of 19 °C and 20 °C, respectively (**Table 5**).

Table 5. Number of operating hours of plant and number of comfort hours as a function of the clothing factor and set-point temperature

| Set-point temperature [°C] | Number of operating hours of plant [-] | Number of comfort hours for Clothing Factor=1 clo [-] | Number of comfort hours for Clothing Factor= 1.5 clo [-] |
|----------------------------|--|---|--|
| 19 | 176 | 157 | 176 |
| 20 | 253 | 247 | 253 |

The number of comfort hours mainly depends on the set-point temperature. For the same set-point temperature, the variation in the number of comfort hours is less than 20% when the clothing factor increases from 1 clo to 1.5 clo.

Figure 11 shows the duration curves of PMV values as a function of the clothing factor and the set-point temperature for the heating plant, 19 °C (above) e 20 °C (below).

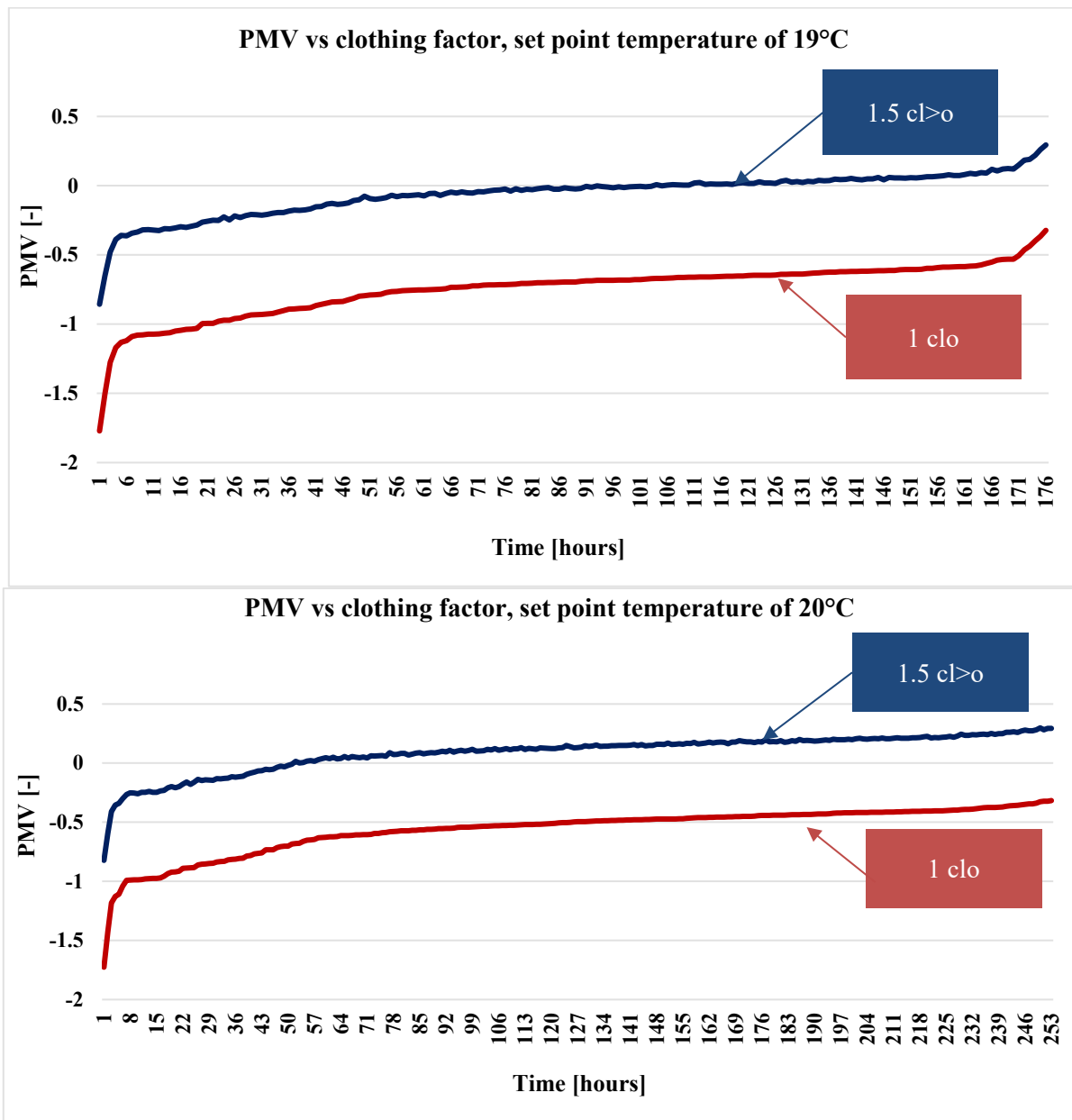


Figure 11. Duration curve of PMV vs clothing factor for the set-point temperature of 19 °C (above) e 20 °C (below)

Considering the number of operating hours of the plant, which is 176 for a set-point temperature of 19 °C, about 11% of these hours result in the user with a clothing factor of 1 clo perceiving a discomfort condition. Specifically, the case with a clothing factor of 1 clo features 19 PMVs lower than -1, indicating a cold perception due to clothing that is not suitable for the low temperatures perceived. Conversely, with a clothing factor of 1.5 clo, such discomfort does not occur at any hour of plant operation. This is notable in [Figure 11](#) (above), where the blue curve, related to PMVs for the clothing factor of 1.5, remains within the range [-0.9; 0.3].

For the set-point temperature of 20 °C, only 2% of the total number of operating hours of the plant result in the user with a clothing factor equal to 1 clo perceiving discomfort. Conversely, with a clothing factor of 1.5 clo, discomfort does not occur, as all PMVs are within the range [-0.8; 0.3]. For a clothing factor 1 clo, only 6 PMVs are lower than -1, indicating a cold perception due to unsuitable clothing for the low temperatures perceived.

The monthly thermal energy demands from November 22nd to March 23rd, according to the weather zone of Naples, for both set-point temperatures, are reported in [Table 6](#).

Table 6. Monthly thermal energy demand vs set-point temperature

| Month | Thermal energy, set-point temperature 19°C [Wh/m ²] | Thermal energy, set-point temperature 20°C [Wh/m ²] |
|----------------------------|---|---|
| November | 26.59 | 79.51 |
| December | 348.06 | 666.45 |
| January | 911.51 | 1399.69 |
| February | 644.29 | 1091.66 |
| March | 146.33 | 342.60 |
| November- March | 2076.61 | 3579.90 |

The total thermal energy demand increases by nearly 72% when the set-point temperature increases from 19 °C to 20 °C.

Comfort Analysis: Weather Zone Sensitivity Analysis

In this subsection, a sensitivity analysis on the weather zone location is performed to detect a correlation between the main weather parameters and the comfort conditions, as measured by the number of comfort hours. The analysis is conducted for ten weather zones, considering the clothing factors (0.3 clo, 0.5 clo, and 1 clo) and the set-point temperature values of the cooling plant ranging from 24 °C to 28 °C. Consequently, the analysis is performed only during the cooling season.

For the sake of brevity, the results will be discussed only for the set-point temperatures of 24 °C and 28 °C to evaluate whether increasing the set-point temperature from the minimum of 24 °C is feasible for user comfort in different weather zones. **Table 7** reports the yearly average values of relative humidity, horizontal solar radiation, and ambient temperature for the ten Italian weather zones.

Table 7. Investigated weather zones

| Weather zone | Relative humidity [%] | Horizontal solar radiation [kWh/m ²] | Ambient temperature [°C] |
|-----------------|-----------------------|--|--------------------------|
| Bologna | 73.6 | 1420 | 14.5 |
| Bolzano | 68.7 | 1301 | 13.0 |
| Cagliari | 72.9 | 1618 | 17.5 |
| Croton | 69.3 | 1632 | 17.4 |
| Genoa | 67.0 | 1425 | 16.5 |
| Milan | 75.5 | 1345 | 14.3 |
| Naples | 73.0 | 1589 | 17.0 |
| Turin | 73.8 | 1353 | 13.2 |
| Trapani | 77.5 | 1755 | 18.0 |
| Venice | 75.8 | 1356 | 14.0 |

In **Table 8**, the results of the sensitivity analysis in terms of the number of comfort hours for different clothing factors and set-point temperatures of 24 °C and 28 °C are summarized. Note the cooling period for each location was determined based on the Italian regulation specifying city-specific cooling periods [58]. Observing the values of the comfort number hours, it is evident that a clothing factor of 0.3 clo is the best value in almost all the weather zones, except for the less warm weather zones. In these zones, a set-point temperature of 24 °C causes a cold perception when tropical clothing is used. Summer clothing (0.5 clo) could be

classified as the optimal solution in terms of balancing user comfort and dress code. In most cases, a clothing factor of 0.5 clo offers a comfort condition comparable to that of tropical clothing but provides greater elegance to the office user. For a set-point temperature of 28 °C, the only clothing factor suitable for maintaining thermal comfort is 0.3 clo, even though it may not be appropriate for most work environments. It is also noted that the two weather parameters significantly affecting user comfort are the average values of horizontal solar radiation and ambient temperature of the weather zone. The outdoor relative humidity does not significantly impact user comfort, according to the assumption concerning ventilation and infiltration in this case study.

Table 8. Results of the sensitivity analysis in terms of the number of comfort hours for different clothing factors

| Weather zone | Set-point temperature of 24°C | | | | Set-point temperature of 28°C | | | |
|-----------------|--|-----------------------------------|-------------------------------------|-------------------------------------|--|-----------------------------------|-------------------------------------|-------------------------------------|
| | Number of operating hours of plant [-] | Number of comfort hours 1 clo [-] | Number of comfort hours 0.5 clo [-] | Number of comfort hours 0.3 clo [-] | Number of operating hours of plant [-] | Number of comfort hours 1 clo [-] | Number of comfort hours 0.5 clo [-] | Number of comfort hours 0.3 clo [-] |
| Bologna | 863 | 824 | 860 | 863 | 756 | 0 | 361 | 751 |
| Bolzano | 800 | 791 | 800 | 780 | 597 | 0 | 418 | 597 |
| Cagliari | 848 | 812 | 845 | 844 | 684 | 0 | 277 | 679 |
| Croton | 855 | 805 | 848 | 841 | 708 | 0 | 337 | 691 |
| Genoa | 851 | 818 | 848 | 848 | 681 | 0 | 347 | 677 |
| Milan | 795 | 786 | 795 | 775 | 549 | 0 | 319 | 549 |
| Naples | 865 | 833 | 862 | 864 | 713 | 0 | 308 | 707 |
| Turin | 803 | 796 | 803 | 792 | 584 | 0 | 328 | 584 |
| Trapani | 869 | 810 | 860 | 864 | 749 | 0 | 241 | 726 |
| Venice | 837 | 821 | 836 | 836 | 653 | 0 | 383 | 652 |

The considered office is characterized by three double-glazed windows and three skylights on the single south-facing external wall. Therefore, despite the control strategy implemented for shading, these weather parameters have a greater impact on the indoor comfort conditions of the office.

CONCLUSION

In this work, the perceived comfort and the space cooling and space heating energy demand for a typical university office room under various dress codes were evaluated. Three clothing factors were considered, corresponding to light summer, tropical, and classic clothing. Special attention was paid to the evaluation of energy demand during the cooling season. The analysis was conducted using the TRNSYS tool through a dynamic simulation model, allowing for the assessment of office energy demand and the most used indexes for comfort analysis. The office room analyzed is located in Naples, at the University of Naples Federico II (considering the authors office). Additionally, a sensitivity analysis on the weather zone was conducted to estimate the effect of dress code variation on hourly comfort conditions, considering different outdoor relative humidity, air temperature, and solar radiation levels.

The results of the analysis highlighted that during the summer season, relaxing the dress code while increasing the air set-point temperature leads to a reduction in primary energy use, total CO₂ equivalent emissions, and operating costs. The energy consumption and comfort indexes are primarily dependent on the set-point temperature and clothing factor values.

According to the simulation results, if users wear short-sleeved shirts and shorts during the summer months, the set-point temperature of the cooling plant can be raised to 28 °C without causing discomfort. The set-point temperature of 28 °C is compatible only with tropical dress and corresponds to a reduction in cooling and primary energy consumption by over 50%. However, if this attire is deemed improper or extreme for the office environment, wearing trousers, a short-sleeved shirt, and closed shoes is recommended, with the set-point temperature decreased to 27 °C. A set-point temperature of 27 °C, compatible with light summer dress, results in cooling energy savings of over 37%. If a classic formal dress code is essential and no relaxation is allowed, acceptable comfort index values are only obtained with an air set-point temperature of 24 °C, which is lower than the summer air conditioning temperature set by Italian regulations (DL 1 March 2022, N. 17). This lower set-point temperature corresponds to very high cooling energy demand, as well as significant environmental and economic impacts.

Regarding the sensitivity analysis on weather zones, the two weather parameters affecting user comfort are the average values of horizontal solar radiation and ambient temperature, while outdoor relative humidity does not significantly impact comfort under the case study assumptions.

Although this analysis was conducted on a small scale, it demonstrated significant reductions in energy consumption, costs, and emissions when variable set-point temperatures and flexible dress codes are applied in office settings. However, several critical issues may limit the implementation of the proposed initiative:

- The traditional belief that in a professional context, attire reflects reliability, seriousness, competence, and professionalism, which may make implementing this simple energy-saving measure challenging.
- Workers accustomed to a formal dress code as part of company policy may not feel comfortable with a more flexible dress code.

Future developments of this work will focus on the integration of a controller capable of dynamically assessing indoor comfort and adjusting the partial load operation of the fan coil according to the occupants' thermal perception. Additionally, the analysis will be extended to other locations outside Italy, considering, for example, more tropical and humid climatic conditions.

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