Indoor comfort conditions assessment in educational buildings with respect to adaptive comfort standards in European climate zones

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Abstract. Educational buildings across Europe refer to a large amount of structures for which critical interventions are necessary. Particularly, for old buildings, comprehensive refurbishment efforts are essential, in order to enhance the indoor comfort conditions and establish the best possible settings for students and users. Evidently, the above issue is decisive to stimulate and support students with reference to the learning process and aims of the educational system (superior learning performance); this has also a positive effect on users’ interaction with the nearby environment, in terms of social adaptability and health for children and adults. In this context, the main goal is to transform entirely the design of educational building spaces with respect to the initial conditions. To this end, governments often set targets on upgrading and utilizing school infrastructure in the urban district (mostly, for school classes situated in the urban core of the social and local communities). As is well known, the improvement of a building from a building physics point of view is fundamentally related to the attainment of acceptable hygrothermal, visual and acoustic comfort conditions. On the other hand, limiting the heat flux through the buildings’ envelope and restricting CO$_2$ emissions, is of great importance, from an environmental point of view. However, the complexity and significance to assess educational facilities mostly relies on the use of heating in winter and the absence of cooling systems during summer. In addition, climate change, which results into growing values of the air temperature, makes it difficult to attain acceptable indoor comfort conditions with natural ventilation. To reduce this effect, especially in the southern part of Europe, shading devices, as well as ventilation and cooling systems offer rational approaches to scrutinize the indoor environment. The central points of the present investigation, with respect to the indoor comfort conditions of educational buildings in different climate zones, during the cooling season, are as follows: (a) the retrofit measures to improve the thermal performance during heat waves; (b) how to gain tolerable indoor comfort conditions with or without a cooling; (c) the implementation of adaptive thermal comfort models. A dynamic thermal simulation on three levels (envelope, classroom, school building) has been carried out in order to assess the school building stock and investigate possibilities of improvements. For three different locations several retrofit scenarios have been evaluated by considering adaptive comfort standards (for typical users, as well as for children). Furthermore, to stretch the impact of this investigation, the analysis has been extended for a real case study: the "Modulo Didattico" building in the Smart Campus of the University of Brescia. At last, the integrated workflow of the design process is presented, considering both BIM and BEM data, and demonstrating an interesting application of visualization techniques for assessment of the comfort conditions in the different thermal zones. The study is the outcome of a collaborative workplan between the University of Brescia (unibs, Italy) and the Aristotle University of Thessaloniki (A.U.Th., Greece).
1. Introduction

In the last decades, according to the scientific community, our planet is experiencing the effects of climate change as a result of human activities with severe consequences on the environment. Since the industrial revolution, and mainly in the last 250 years, the increase of global temperatures was unrestrainable and the primary source of this increase has been ascribed to the fossil fuel-based energy emissions. The scientists theorized that overcoming the “tipping point” could lead to a radical change in the global climate causing a new “hotter and wetter” age similar to the Earth’s environment before the appearance of human beings, or a new ice age [1]. The reduction of the environmental impact due to human activities is thus globally recognized as crucial and several governmental initiatives have been boost; among these, the decrease of the emissions generated by the building stock is one of the fundamental ones as in the industrialized countries, it represents an important share. In parallel, the changing of environmental conditions is affecting thermal comfort in the buildings since the outdated building stock constructed around ’70s, without any concern about the issue, as well as energy saving and emissions, strongly disturb the users wellbeing and productivity. Among the most impactful buildings in the European cities it is common to identify the school facilities, realized after World War II during the reconstruction phase of the cities and the development of new settlements. The need of an increased thermal comfort, the poor performance of the public buildings and the high prominence of the education sector turn the school facilities and university campuses into hot spots for investigation. The two main topics working on the school building stock are: (a) the evaluation and possible upgrade of energy performances; (b) the comfort level appropriate for children and school users. As first, the educational buildings have a huge potential of loads reduction for both heating and cooling. About the latter, the indoor comfort conditions affect the learning performance of the users and thus optimal temperature and comfort should be guaranteed to promote social improvement. Moreover, the school facilities are gaining a role as civic centre of the cities and an extended schedule of use for the citizens could be visualised and supported with energy policies. For this reasons, the summer behaviour of the educational buildings opens a new field of investigation, considering that usually these buildings are considered as unoccupied during the cooling period.

The present research focuses on thermal comfort in school buildings, employing the model of adaptive thermal comfort particularly considering children’s experience that is different from their adult tutors. School buildings are usually designed on adults-based models and this can lead to a discrepancy of perception and thermal needs. To bridge this gap, some strategies and a design workflow are tested through building energy simulation tools and some retrofit options are proposed, considering the highly critical school building stock energy performance and comfort conditions. The aim of this paper is also to demonstrate an interoperability path between geometrical modelling software and simulation software to exchange data and improve the information chain, increasing accuracy in system setting and switch in a IoTed scenario (Internet of Things) of thermal zone comfort control.

2. Methodology

2.1. Research phases and methods

The research has three levels of in-depth investigation aiming at evaluating the energy performance and the thermal comfort improvement in the cooling season into the school building spaces. As first step the building quality to promote energy saving and mitigate the indoor condition in summer without thermal plant have been evaluated considering the envelope components that are commonly used in the school building stock of the experimental field of investigation; for this step the software Comsol Multiphysics has been adopted. As a second step the classroom or the simple thermal zone has been adopted to calculate, with free running dynamic regime simulation, in the summer season, the indoor comfort
conditions, in three different climate zones, representing the European context, by using the EnergyPlus software. As a third step a whole educational building has been considered and calculated, evaluating the comfort conditions in the different classrooms and proposing a comfort data mapping into the Building Information Model (BIM), from the Building Energy Model (BEM) that could be the informative and actuation tool in the IoTed scenario, in which sensors can communicate the temperature inside the spaces and controllers can actuate ventilation systems to mitigate the indoor conditions.

2.2. Thermal comfort models
The core parameter of the research is the thermal comfort of the users. Thus, a brief excursus on thermal comfort models is given. Thermal comfort became a topic with the studies of Fanger, in the 70s as the energy crisis was unfolding. The experiments led to the well known PMV (Predicted Mean Vote) comfort model, widely adopted in the following decades but with some important limits to be underlined. The PMV model is static and based on survey steered in laboratories, without considering the actual conditions and the user is assumed with a passive behaviour. It is worthy to note also that these studies involved only adults working on school facilities. Therefore, it is important to include and prioritize the preferences and needs of the children and young users. For these reasons the Adaptive Comfort Model was developed promoting new possibilities in the buildings design. The fundamental change is the main principle: the user has an active role and he/she takes decisions to change and adapt the indoor environment to enhance the comfort conditions. The result is a dynamic model in which also the climate conditions are involved and the range of temperatures is wider.

2.2.1. Standards
In the last developments, concerning buildings’ comfort studies, the analysis of the most recent regulations confirms the importance of the adaptive thermal comfort model. This model was included both in the American norm (ASHRAE55)[2] and the European norm (EN15251)[3] for buildings with natural ventilation. This is considered as more reliable than the PMV Model in the case of school buildings, during the cooling season. The equation of comfort temperature, as defined in the European norm, is as follows:

\[ T_{\text{comf}} = 0.33\cdot T_{\text{rm}} + 18.8 \]  \hspace{1cm} (1)

2.2.2. Previous studies on school buildings
Nowadays, the interest in the study of school buildings and the awareness that a specific norm is compulsory to meet the thermal comfort of children are growing. In fact, many researchers started to propose and perform surveys in schools, finding in a lot of cases, that the responses between adults and students are actually different. The most important issues, renowned as concerns about educational buildings are:

- Difference in thermal perception between children and adults [4].
- Impact of temperature and relative humidity on learning performances [5].
- Children neglecting to adapt their clothes or wearing uniforms [6].
- Important urban heat island phenomenon in the cities with increase of cooling needs [7].

Among the others, a relevant research of the University of Southampton [8] in UK schools investigated the perception of children and the energy efficiency in different type of schools. The research proposed a new adaptive thermal comfort model for children based in the following equation:

\[ T_{\text{comf,child}} = 0.26\cdot T_{\text{rm}} + 18.2 \]  \hspace{1cm} (2)

The results of this new model have been compared with the adults’ model finding that usually the thermal comfort temperature during the summer season is about 2°C lower for children’s comfort. The two adaptive comfort models have been applied for the second level analyses to evaluate the percentage of discomfort hours that can be calculated and the difference of suitability of the conditions for adults and children.
3. Case Studies
In order to evaluate the performance of classrooms, representative of the school building stock, a standard classroom, with a basic dimensional configuration, has been set for three different envelope configurations and three climates (Italy, Greece and United Kingdom), were tested. The indoor temperature in summer season has been simulated in a free running building considering that the majority of the schools have no mechanical systems. The operative temperatures obtained from the simulations have been compared with comfort temperatures proposed using the adaptive thermal comfort model and the children adaptive model that was proposed in the studies by the University of Southampton [8]. In this research, the standard European norm EN15251 [3] has been used as reference. A further achievement has been to propose retrofit strategies to increase the comfort hours in the adaptive comfort model that is with passive strategies.

3.1. Envelope typologies
Three different opaque envelope configurations based on the commonly adopted typologies in the case study countries have been considered. The most frequent typologies identified are: Envelope 1. A solid brick masonry; Envelope 2. A hollow brick masonry with cavity; Envelope 3. A hollow brick masonry with a thin insulation layer. The above three typologies were analysed in terms of thermal transmittance $U$ [W/m$^2$K], thermal mass $M_s$ [kg/m$^2$] and periodic thermal transmittance $Y_{ie}$ [W/m$^2$K] that are included in the national regulation (Figure 1). The analysis was carried on in steady state conditions in the heat transfer module of Comsol Multiphysics software. For this purpose, a 3D test portion of 1m x 1m of the envelope has been modelled. The external temperature was set at 35°C and the internal temperature was 26°C, hypnotizing the activation of a mechanical system. The results of the investigation are evaluated on the boundary surface, as inward heat flux: Envelope 1: 10.862 W/m$^2$; Envelope 2: 7.188 W/m$^2$; Envelope 3: 2.779 W/m$^2$. Looking at the distribution of temperatures and the inward heat fluxes it is clear that the insulated envelope performs the best however variations could occur during the different seasons and thus a dynamic simulation is required. Furthermore, to evaluate the indoor thermal comfort, the calculation of the variation of the indoor operative temperature in the occupied hours is needed.

![Figure 1. Envelope Typologies and simulations with Comsol Multiphysics.](image)

3.2. Climate for different locations
Three different climates have been analysed, namely the cities of: Brescia (Italy), Thessaloniki (Greece) and Southampton (United Kingdom). The three cities are representative of the climate distribution across Europe and adopting the internationally recognized Koppen-Geiger [9] classification system it is possible to define: Southampton (United Kingdom) as temperate oceanic climate; Brescia (Italy) as warm temperate climate and Thessaloniki (Greece) as warm Mediterranean climate. The climate conditions have been evaluated considering the temperature variation in the summer period and the extreme conditions, as defined in EN 15251 standard, in order to evaluate the correct comfort
temperatures by using the Adaptive Comfort Model. In particular, it is important to take into consideration the following parameters:

- External temperature, daily mean (T_{ed}): average of the hourly mean external air temperature for one day (24-h).
- External temperature (running mean): exponentially weighted running mean of the daily mean external air temperature (T_{ed-n}) is calculated from the formula: 
  \[ T_{rm} = (1 - \alpha) \cdot [T_{ed-1} + \alpha \cdot T_{ed-2} + \alpha^2 \cdot T_{ed-3} + \ldots] \]
  where \( \alpha \) is a constant between 0 and 1 (based on regulations, the recommended value is 0.80).

3.3. Dynamic energy simulation

The dynamic simulation procedure has been applied to the second and third step of the analyses, considering the single classroom and the whole experimental building (Figure 2). For the evaluation of the operative temperature, calculated with the software EnergyPlus, the following equation was used:

\[ T_{op} = \frac{h_r T_{mr} + h_c T_a}{h_{cr}} \]  

Where: \( T_{mr} \) is the mean radiant temperature; \( T_a \) is the air temperature; \( h_c \) is the convective heat exchange coefficient for human; \( h_r \) is the radiative heat exchange coefficient for humans; \( h_{cr} = h_c + h_r \) and \( T_{rm} = (1 - \alpha) \{T_1 + \alpha T_2 + \alpha^2 T_3 + \ldots\} \) is the running mean external temperature.

The simulation period goes from 15th of May to 13th of September which is historically the most critical period for overheating risk, in the three cities selected for the aim of this study.

3.3.1. Single classroom

After the analysis of the classrooms geometry across Europe, the measure of the base case classroom were set as 8.50 m x 7.30 m resulting in 62.05 m\(^2\) of floor area, with three south oriented windows which measure are 1.50 m x 2.25 m, establishing a total fenestrations area of 10.11 m\(^2\) as required by the regulations (aero-illuminance ratio between the floor area and windows are between 1/5 and 1/7). The model has been defined through a 3D interface communicating with the EnergyPlus calculation engine to perform the analysis of the classroom without considering the thermal plant. The classroom has been oriented in the four directions (south, east, west and north) with only one external side and with the following setup: Ventilation rate = 2.5 h\(^{-1}\); Occupancy levels = 0.56 pers/m\(^2\); Internal Gains = 4 W/m\(^2\); Internal Gains = 4 W/m\(^2\); Activity level = 108 W/person.

Figure 2. Building Energy Model of the standard classroom and of the “Modulo Didattico” building.

3.3.2. Educational building

Applying the same methodology to the educational building, the analysis was set for the three storey “Modulo Didattico” building, located in the Smart Campus of the University of Brescia. The building also hosts lessons and graduation ceremonies with a significant occupancy level, during the summer period. The building is equipped with a mechanical system to provide heating and cooling into the learning spaces. The analysis has been performed with the aim to calculate the energy saving that could be achieved by reducing the operating hours of the mechanical system and the number of days that could be managed with the adaptive thermal comfort approach. The building that dates ‘90s, it is symmetrical...
with the main north-south axis. The south-east façade is almost totally glazed and closes a wide atrium used to distribute the classrooms, as well as for free space for students group activities. Two laboratories and technical rooms are located on the underground floor, two classrooms are located at the ground floor and one main hall is located at the first floor. The atrium has the widest window while the classrooms have small windows. Two vertical portions, made with glass-bricks are the main source of daylighting of the classrooms and they are equipped with internal curtains. Monitoring the users’ behaviour informed about the use of the classrooms doors to promote cross ventilation, when high occupancy, growing CO\textsubscript{2} and indoor temperature occur during the summer season, spring and autumn. The performance evaluation of this building has been carried out by the University of Brescia, in the frame of the SCUOLA project [10]. These investigations aimed to evaluate daylight conditions, internal air quality and energy management of the educational building and they are an interesting source for the thermal comfort analysis.

3.4. Simulations setup

The building has been simulated with EnergyPlus software with all the information about the educational spaces (Table 1) and the envelope information coming from the previous analyses [10].

| Location Floor | Zone Name | Space Typology | Dimensions [m\textsuperscript{2}] | Maximum Occupancy [m\textsuperscript{2}] | Occupancy Rate [-] |
|----------------|-----------|----------------|-----------------------------------|------------------------------------------|-------------------|
| Underground    | Mlab1     | PC Lab         | 151.8                             | 40                                       | 0.19              |
| Underground    | Mlab2     | PC Lab         | 207.9                             | 27                                       | 0.19              |
| Ground         | MTA       | Classroom      | 178.3                             | 168                                      | 0.94              |
| Ground         | MTB       | Classroom      | 177.5                             | 168                                      | 0.94              |
| Ground         | Atrium    | Common area    | 180.8                             | 56                                       | 0.31              |
| First          | M1        | Aula Magna     | 337.5                             | 262                                      | 0.77              |

The occupancy in the different classrooms has been defined by realizing a schedule based on the actual courses that are carried out using as internal gains = 4 W/m\textsuperscript{2} and metabolic activity level = 108 W/person and the assumptions adopted for the educational spaces.

4. Results and possible retrofit strategies

4.1. Classroom level

The results about operative temperatures in free running with the dynamic simulation have been compared with the adaptive model-based temperatures’ range. Results underline an important overheating in all three cities from 15\textsuperscript{th} May to 13\textsuperscript{th} September (Figure 3). Table 2 shows the percentage of discomfort hours considering the adaptive thermal comfort model for adults and for children.

| Location      | Adaptive Comfort Model | Adaptive Comfort Model for Children |
|---------------|------------------------|-------------------------------------|
| Southampton   | 15%                    | 34%                                 |
| Brescia       | 56%                    | 84%                                 |
| Thessaloniki  | 87%                    | 98%                                 |

As expected, in the case of the adaptive comfort model for children, the percentage of discomfort hours is increased in of an important amount in all the three locations, emphasizing the importance of a different model for younger users and for an improvement of the indoor conditions.
he zone of the atrium, in free running

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Envelope 1
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Envelope1
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Operative temperature \[\text{°C}\]
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16:00:00
05/25
05/25
05/25
Southampton
Brescia
Thessaloniki
Operative temperature \[\text{°C}\]

Figure 3. Results and comparison with temperatures’ range of the adaptive model.

The comparison of the performances of the three envelopes (Figure 4) shows that:
- Envelope 1 and 2 have almost the same performances.
- Envelope 2 has a worst performance of about 2-3% comparing to Envelope 1.
- Envelope 3 reduces the discomfort hours of about 5-6 %.

A further analysis with the psychometric chart of the three climates allowed the suggestion of the most effective retrofit strategies to ease the comfort indoor: 1. natural ventilation; 2. well shaded windows; 3. high thermal mass; 4. good levels of insulation; 5. night ventilation during summer.

A second cycle of simulations was performed applying a layer of insulation to the envelopes: 10 cm of PSE were added to Envelope 1 and 2, while 5 cm of additional insulation was added to Envelope 3 with the following results:
- Envelope 1 reduces discomfort hours of about 6-8%.
- Envelope 2 reduces discomfort hours of about 6-7%.
- Envelope 3 has similar performances.

This confirms that the insulation could be a good strategy to enhance the performances of old envelopes but the combination with other strategies is needed when comfort and higher performances are the goals.

Figure 4. Comparison of results before and after the retrofit (South façade) with an insulation layer.

4.2. Building level
Considering the educational building adopted as case study, in the zone of the atrium, in free running mode, the operative temperature is much higher than the comfort range approved by the adaptive thermal comfort model. The 76% of total hours in the under examination period are over the limit and therefore the risk of overheating in the free running configuration is high. The almost total glazed surface on the south-east façade is responsible of a harsh greenhouse effect although shading coating and blinds have been partially installed. The educational spaces located at ground floor (MTA, MTB) result to be uncomfortable for 100% of the hours, confirming the need of mechanical ventilation also in the middle season. The windows on the east and west sides are not operable in these classrooms therefore, in the possible passive strategies for this building, the change of the windows and the solar protection of the façade should be unavoidable. The main hall, where 99% of the hours result as uncomfortable without
the use of the cooling system is similar. In the case of the main hall in addition to the change of the windows and shading systems the insulation of the rooftop would be beneficial. The laboratories located in the underground floor have a better situation even though they have higher internal gains due to the IT equipment but they have operable windows. Moreover, the effect of the ground temperature promotes a more stable temperature. However, 44% of the total hours are still uncomfortable according to the adaptive comfort model. In this case, solutions that could increase the ventilation would be appropriate. The building could not benefit of a bioclimatic approach in the design phase and the HVAC system is mandatory to provide the thermal comfort into the indoor space. Unfortunately it should be noted that, also with the mechanical systems, the indoor comfort is not actually guaranteed [11]. Despite of the actual situation, it is possible to improve the overall condition of the building with a series of interventions. The issues that certainly have a greater impact are related to transmission losses, ventilation, solar gains and internal loads. The updating of the technical systems of the building is also an issue, considering that the control and the modulation is a key factor to enhance energy efficiency and calibrating the resources on the actual occupancy level. As first strategy it is better to reduce the energy needs and thus the main interventions are focused on the envelope. As explained in the case of the single classroom, it is also important to evaluate all the possible interventions and to relate them to the winter season too, concerning the overall efficiency of the building. The suggested retrofit strategies achieve a percentage of effectiveness that is summarized in Table 3.

Table 3. Percentage of energy demand reduction through retrofit strategies.

| Retrofit Strategy                                    | Energy Demand Reduction [%] |
|------------------------------------------------------|-----------------------------|
| Addition of internal insulation of about 3 cm;       | 9.9                         |
| Addition of insulation in the zone of the roof of about 10 cm; | 10.2                        |
| Addition of operable windows and all-day ventilation;| 37.3                        |
| Replacement of windows with enhanced thermal transmittance; | 11.5                        |
| Reduction of the north-east window;                  | 11.1                        |
| Addition of shading blade for the vertical portion of south-east façade; | 14.8                        |
| Reduction of the solar heat gain factor of the south-east façade; | 6.1                         |
| Realization of openings at the top and at the bottom of the atrium; | 17.8                        |
| Install automated systems for night ventilation during summer. | 19.8                        |

The results of the simulation on the single classroom and on the whole building show clearly that in the framework of adaptive thermal comfort model and with free running conditions, the most effective strategy against overheating is an adequate ventilation rate. Furthermore, the night ventilation could be very effective and, considering that the school buildings are not occupied during the night, it can be easily controlled and managed with IoTed devices. The shading glazed facades is a further key when free running is the main strategy.

5. BIM to BEM

The integration of Building Energy Models into Building Information Models for the data exchange could be very beneficial but it is not fully deployed and interoperability issues are not completely solved for every application [12]. In the framework of the present research the possibility to develop a workflow of interoperability between the BEM data to enrich the BIM model has been investigated. To communicate data from BEM to BIM there are some procedures using data transfer through dedicated software. In the present investigation the AutodeskRevit plug-in of Dynamo has been used to deploy a connection between energy results and the BIM model. In fact, Dynamo is an open source Visual Programming tool that permits to compose personalized algorithms and to elaborate data through a graphical user interface. In this frame, a simple interface was created with the aim to insert the results of the thermal simulation and to perform an instant comparison with the adaptive comfort model values, mapping the compliance of the temperature with the adaptive model, into the digital model (Figure 5). The “Modulo Didattico” digital model was realized where each thermal zone can be classified as overheated, and red coloured or, in the opposite case, with green colour to visualize the compliance of
the operative temperature with the adaptive model temperature. This can be a useful instrument for the
design team to evaluate some design choices. Moreover, it is very useful for a facility manager who
could have the possibility to faster visualize the results and to also share the information with experts of
other disciplines, working for a common task of energy saving and indoor space comfort. In the most
advanced scenario the verification of the compliance could be connected to actuators to activate
ventilation in the specific spaces with IoT control and actuation devices.

![Figure 5. BIM model of the “Modulo Didattico” educational building and VPL structure used to apply
the colour code of the educational spaces (green/red).](image)

6. Discussion and conclusions

The indoor thermal comfort during the summer period in educational buildings can be a critical issue
and the present research demonstrates that the problem is common in the different European climates.
Additionally, the need of retrofit interventions on existing buildings and an innovation in the design
workflow for new constructions is strong and predictable. Furthermore, the limits on energy
consumption specified by the evolving regulations and the indoor thermal comfort in educational
facilities has a twofold aspect. Those involve two important goals to be achieved, both for environmental
purposes and social outcomes on the improved learning performances that optimized indoor comfort
conditions could enable. Recent studies underlined the difference in thermal perception and comfort
evaluation between adults and sensitive or fragile users. Accordingly, it is compulsory to introduce new
parameters when designing spaces and comfort conditions for children, young students and elderly
persons. On the background there is the need of an integrated design workflow from the very early stage
of the design, in order to reach a higher standard efficiency and thermal comfort, targeting to lower
costs. The preliminary phase of a new or renovation project should be anticipated by a complete location
and climate analysis which should be connected to the setting of the expected indoor thermal comfort
conditions. Nowadays, the designers have two options between the traditional Fanger’s PMV model and
the adaptive comfort model. The achievement of good results with passive strategies is more effective
by using the adaptive comfort model. The reason is that the ADC gives more flexibility in temperature
variations and it is developed especially for free running buildings. Considering that the majority of
national regulations prescribe limits on $U$ values and $Y_{eq}$ of the envelopes it is important to promote a
dynamic approach to their evaluation. The first analysis of this research on envelope components
allowed to develop possible strategies for refurbishment, considering both the thermal transmittance and
thus the heating demand, the thermal mass and the dynamic thermal transmittance, that means the
cooling season performance. The analysis of educational spaces performed in three different locations
allowed a critical comparison between the energy performances and the possible retrofit strategies to be
adopted, in significant climate conditions across Europe. The analysis on a real case study has also given
the opportunity to apply the proposed methodology to a well-known built environment and to investigate
the option to save energy in a mechanically cooled educational building. The analyses unveiled that
passive strategies have to be evaluated with an iterative process to achieve the best option, taking into
consideration that the building has to be comfortable during the whole year. Therefore, there is not a unique strategy however important to underline that in temperate climates the most effective one encompasses the control of the thermal inertia, considering both winter and summer performances. Shading devices for windows are also crucial concerning solar radiation dynamic and adaptive control. Night ventilation can also be suggested as an effective strategy but it could have a low outcome in the dense urban areas where urban heat island effect occurs. Finally, the thermal comfort in summer for educational buildings is a possible achievement in some temperate regions without the use of mechanical systems. Taking into account the thermal perception of children and considering very hot climates subject to heat waves, it is possible to evaluate the installation of high efficiency air conditioning systems to manage the peaks of temperatures (e.g. heat pumps, fans). To achieve an indoor thermal comfort condition is also important to inform the users about the monitoring and the managing of the building. In fact, often the users are not aware of possibilities and strategies of thermal adaptation, missing the goal of a user/climate/building cooperation; in this sense a cognitive building could be strongly beneficial and the case study building is embracing this concept in the framework of the Smart Campus at the university of Brescia [12]. About this concept, the integration between BEM and BIM can be the key factor to enable the control through connected devices and through IoT (Internet of Things) concept that could take advantage of data collected indoor conditions and users behaviour.

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