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Thermal comfort comparison between two classrooms with different ventilation systems

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Abstract

Achieving thermal comfort and indoor air quality in schools is a challenging subject with diverse implications. During the last decade's different ventilation systems have been analyzed from all points of view (efficiency, costs, maintenance, noise), despite that the problem was not solved. In this article it is proposed a hybrid ventilation strategy using natural and mechanical ventilation as an alternative to a more expensive and not feasible heat recovery system. During a 2-day experimental campaign we have analyzed the impact on thermal comfort of such proposed solution. Compared to a non-ventilated classroom, using ventilation has lower the thermal comfort index PMV with average values around -0.28. In fact, we have found that during winter/spring/autumn when outside temperatures are lower (<14^{o}C) it is a wise solution to use only the humidity sensitive air vents to introduce the fresh air. From May to June and September to October when the outdoor temperatures are higher it is better to use a mechanical ventilation not only to introduce fresh but also to evacuate the heat and odors.

Rezumat

Realizarea confortului termic și a calității aerului în școli reprezintă un subiect dificil, cu implicații diverse. În ultimele decenii, diferite sisteme de ventilație au fost analizate din toate punctele de vedere (eficienta, cost, mentenanta, zgomot), totusi problema nu a fost rezolvată. În acest articol se propune o strategie de ventilație de tip hibridă care utilizează ventilația naturală și mecanică ca alternativă la un sistem de recuperare a căldurii mai scump și inaccesibil. În timpul unei campanii experimentale de 2 zile am analizat impactul asupra confortului termic al unei astfel de soluții propuse. În comparație cu o clasă clasica neventilata, utilizarea ventilației a micșorat indicele de confort termic PMV obtinandu-se valori medii de aproximativ -0,28. S-a constatat că pe perioada de iernа/primăvară/toamnă, când temperaturile exterioare sunt mai scăzute (<14^{o}C), este o soluție înțeleaptă de a folosi numai ventilare natural prin intermediul orificiile de aer sensibile la umiditate pentru a introduce aerul proaspăt. Din mai până în iunie și septembrie până în octombrie, când temperaturile exterioare cresc, este mai bine să se folosească o ventilație mecanică, nu numai pentru a introduce o cantitate de aer proaspăt, dar și pentru a evacua căldura și mirosurile degajate in interior.

Keywords: Thermal comfort, Ventilation systems, School environment

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1. Introduction

Thermal comfort is defined by ASHRAE as 'that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation'. Indoor environmental quality (IEQ) as a result of the thermal, visual, acoustic comfort and the indoor air quality is a very important topic both on the energy saving point of view as stressed by the European Community [1] and the performances and productivity. Assessing occupants' satisfaction about the indoor environment has been common practice for evaluating thermal comfort (TC) and indoor air quality (IAQ) perception. Educational buildings, accounting for a large portion of building stock, are responsible for high energy consumptions within a country's non-industrial energy usage. A considerable amount of this energy is used to provide thermal comfort. Due to high occupant density in classrooms and also the negative influence that an unsatisfactory thermal environment may have on students' learning and performance, providing comfort conditions for educational buildings has always been critical.

Excellence in education is nowadays crucial for society's evolution, throughout the intellectual and social development of its citizens. To meet this challenge, research work should be done toward improving learning conditions, including concerns about the classrooms' indoor environmental quality. The association between indoor parameters, humans' health and academic performance is already well known [2]. Jaakkola J.J.K. et al. [3] showed that the room temperature is the most important indoor air parameter for causing symptoms of sick building syndrome (SBS) and the sensation of dryness, concluding that controlling room temperature will improve thermal comfort and decrease SBS symptoms in office workers. Bell P. [4] found that high temperatures may either increase or decrees wakefulness, narrow attention and cause discomfort. In addition, Manzon J. [5] has reported the influence of thermal discomfort on the attention index of teenagers.

According to another study [6], the indoor environment in classrooms can have a large effect on comfort, health and learning performance. The aim was to assess whether the PMV method can be used to improve accuracy of thermal comfort predictions for non-air-conditioned primary school class rooms, with specific attention to the clothing insulation for children and adaptation of clothing during the year. The results of this study showed that the difference between male and female students is small, the largest being 0,1 clo, and that the PMV method underestimates thermal sensation for children, while previous research which found errors in PMV predictions found that it overestimated thermal sensation [7]. This shows that the PMV method cannot be applied to children in a classroom situation and that PMV with surface area corrected metabolism is better, but still does not result in valid predictions of thermal sensations of these children.

A different study [8], which used both objective and subjective methods of analyzing the thermo-hygrometric comfort conditions in several classrooms, both under summer and winter conditions, concluded that students exhibited better adaptation to warm conditions than that predicted by the raw application of Fanger's PMV theory [9], however if an expectancy factor of 0.9 (proposed by Fanger for naturally ventilated building in warm climates) is applied, a good agreement between predicted and subjective votes attributed to the environment has been found both in winter and in summer conditions.

To solidify this, another study made in Portugal [10], provided similar results by comparing the PMV-PPD model to the subjective questionnaires. Even with the referred corrections of the metabolic rate, based on the children's body surface area, Fanger [9] model resulted in higher dispersion and prediction of a lower thermal sensation than detected in the questionnaires.
Another paper [11] reinforces the fact that the PMV index as proposed by Fanger [9] shows some limitations in case of naturally ventilated environment where it usually overestimates the thermal

sensation felt by occupants. This is the reason for the increasing success of the adaptive model proposed by de Dear and Brager, accepted by both ASHRAE and ISO. Starting by this awareness led to the introduction of two correction factors by Fanger [9], to extend PMV model to free-running buildings in warm climates. The first value, *e* (expectancy factor, which was covered by the above referred studies), varies between 0.5 and 1 depending on the presence of HVAC systems. The second factor introduced is a reduced activity level, as it is slowed down unconsciously by people feeling warm as a form of adaptation. The article concluded that the evaluation of thermal comfort in schools by means of the PMV/PPD indices are still unclear or require paying great attention, and can be very effective also in natural ventilated schools if a right expectancy factor is applied.

Another factor of thermal discomfort was noticed in a study done in schools located in upper Egypt [12], and it consists of the limitations regarding the change of clothing value in schools, which leads to an operative temperature of over 30ºC after 12:00 PM. This made the average PMV and PPD across the classrooms be of 1.17 and 38.86%, respectively, which indicates a higher level of thermal discomfort within the primary public school classrooms.

One important study is the meta-analysis (analysis based on the research of the thirst parties) [13], in which the influence of temperature on productivity was investigated. This analysis shows that the average productivity reduces by 2% per degree Celsius once the temperature rises above 25 ºC.
According to a study performed at a Portuguese secondary classroom, located in Beja (south-east of Portugal) [14], it had been shown that the majority of students stated acceptable indoor temperatures up to 25.2 ºC, expressed satisfactory thermal sensation votes and confirmed that thermal neutrality is not the preferred state. On the basis of these results, a trend was found for the thermal preference from slightly warm environments in the mid-season: higher temperature ranges are accepted than those presented in the norms.

Shendell D.G., [15] demonstrated that ventilation has a positive effect on reducing absence of pupils. The CO2 concentrations and student attendance were registered in over 400 American schools. In schools where the CO2 concentration was 1000 ppm higher than in the outdoor air, absence proved to be 10 to 20% higher. It may be assumed that sick leave of teachers also increases as the CO2 concentration raised.

According to Almeida et al. [16] the impact of the built environment factors on learning progress is a major new finding for school's research. The significance of thermal comfort study is related to the relationship between the occupants' satisfaction in the built environment, the functioning of the building, and energy consumption. Energy efficiency in educational buildings is significant for the reduction of total energy intensity. Lack of awareness and education are the most important barriers for progress in energy conservation because of their major influence on the attitude and behavior of the energy consumers. Students spend much of their time in schools, thus it is important to provide a good thermal comfort and indoor air quality levels. Thermal discomfort in educational buildings can create unsatisfactory conditions for both teachers and students. The challenge is to design buildings which will facilitate learning and overcome the state of discomfort with minimum energy consumption. It is crucial that, when designing an educational building, the thermal comfort of students must be a priority.

Building ventilation integrates the advantages of both natural ventilation and mechanic ventilation. Ventilation efficiencies and system costs are found to be associated with different control strategies. Experimental tests were conducted to compare the ventilation systems and impact on thermal comfort in high school classrooms, and the running time of the exhaust fan between the ventilation systems. There are many strategies and methods for ventilation systems that can be used to raise the usage and effects of thermal comfort, e.g. cross-section ventilation, stack-induced ventilation, suitable facing of buildings, and wind velocity, etc. [17-18]. But, there are limitations or shortcomings of natural ventilation in buildings. In the first, natural ventilation effectiveness depends much on outside wind environment, where the outside wind speed above 3.0m/s is generally required for obvious cooling sense inside buildings with natural ventilation [19]. In the second, natural ventilation is unsuitable in rainy days with opening windows or when outside air is dirty or hot for better IAQ and thermal comfort. On the other side, the whole use of mechanical ventilation increases building energy consumption, and sometimes may induce occupant-health problems [20]. The purpose of this article is to analyze the impact of two ventilation strategies on the indoor thermal comfort.

2. Case study

2.1 Classroom description

The experimental campaign was realized in two identical classrooms from the college “Mihai Viteazul”, situated in Bucharest, Romania. In one classroom two types of ventilation systems were installed: the first one is using natural ventilation with the help of six humidity sensitive air inlets mounted on the windows frame and a second system using mechanical ventilation through a window mounted fan with sound acoustic buffer and five air flows steps (100 m^3/h, 200 m^3/h, 350 m^3/h, 450 m^3/h, 600 m^3/h).

The college itself is one of the oldest in Romania and also one of the best classified based on the students’ performance. The walls are non-insulated and made of brick with a width of approximately 1 m, while the windows are double glazing with wood frame. The building interior was renovated during the last years, but lacks of any ventilation system for good indoor air quality. The heating is ensured by a boiler and three steel radiators for each classroom. The two analyzed and used for comparison classrooms are identical in size (area of 54 m2, width 6 m, length 9m, height 4.9 m, air volume of 299.88 m^3) and orientation (West). The heating system during the experimental campaign was off. Both rooms accommodate the same number of students 29 students and 1 professor.

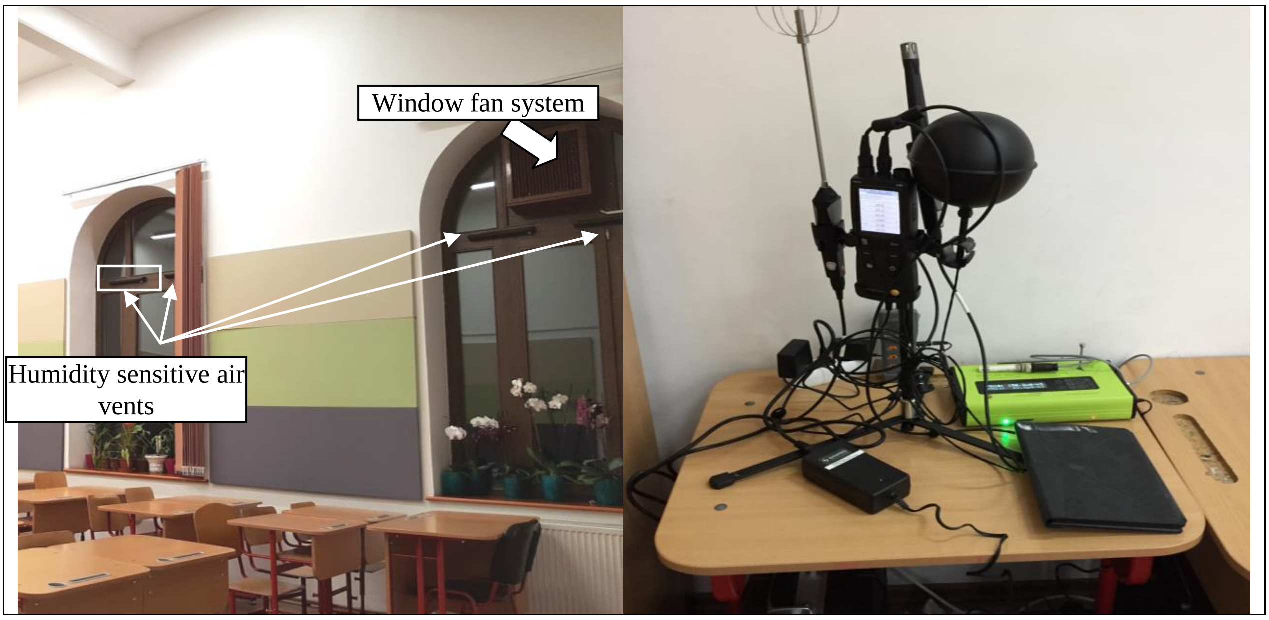

Figure 1. a) Classroom photo with the ventilation systems (humidity sensitive air vents and window fan) and b) Equipment used during experimental campaign

2.2 Experimental protocol

The values of indoor air temperature, average radiation temperature, the speed of air flows, relative humidity of indoor air were measured with two TESTO 480 equipment installed in the two studied classrooms. The equipment is a class 1 precision with low errors on measurements according to the manufacturer:

Table 1**:** Precision of the TESTO 480 thermal comfort equipment

Type	Domain	Resolution
Thermocouple for air temperature	-200…+1370^{o}C	0.1^{o}C
Humidity sensor	0….100%	0.1%
Air velocity hot bulb type	0….+20 m/s	0.01m/s
Pressure	700…1100 hPa	0.1 hPa
Globe temperature – Pt100 temperature sensor	-100….+400 ^{o}C	0.01^{o}C

The time step for one measurement was of 1 min and the data were recorded from 08:00 to 14:00, this period corresponding to the student's presence. The index for thermal comfort was calculated by the TESTO software and the data were analyzed using an Apple Macbook Pro laptop and the EasyClimate,, software.

3. Results

3.1 Thermal comfort index

Thermal comfort analysis was based on measurements of indoor air parameters in classrooms located at the same level of the high school building and having the same exposure – **identical rooms**. For the calculation of the PMV comfort index, it was considered a thermal resistance of occupants clothing of 0.7 CLO and a 1 MET the heat metabolism – this corresponds to occupant's light working. The "Predicted Mean Vote" PMV is indicated in the "Normative for design, execution and operation of ventilation and air-conditioning installations" indicative I5-2010, depending on the category of the building (Table 1).

Table 1**:** Categories of indoor environment (I5-2010, EN 16798-1:2016)

Category	**Characteristics and domain**
I	High level recommended for areas occupied by highly sensitive and fragile individuals with specific requirements, such as sick, disabled, small children, elderly
II	Recommended for new or renovated buildings
III	Moderately acceptable level, recommended in existing buildings
IV	Level outside the above, recommended to be accepted for limited periods of time

The thermal comfort is expressed by the PMV, which for each category of ambience must be included in the values -3 (very cold) to +3 (very hot). The percentage of dissatisfied persons PPD is calculated based on the PMV. Table 2 gives the recommended values of PMV and PPD.

Table2. Values of PMV and PPD for different categories of indoor environment (I5-2010)

Category	**The state of global thermal comfort**	
	PPD [%]	PMV
I	< 6	-0,2<PMV<0,2
II	< 10	-0,5<PMV<0,5
III	< 15	-0,7<PMV<0,7
IV	>15	PMV<-0,7 or PMV>0,7

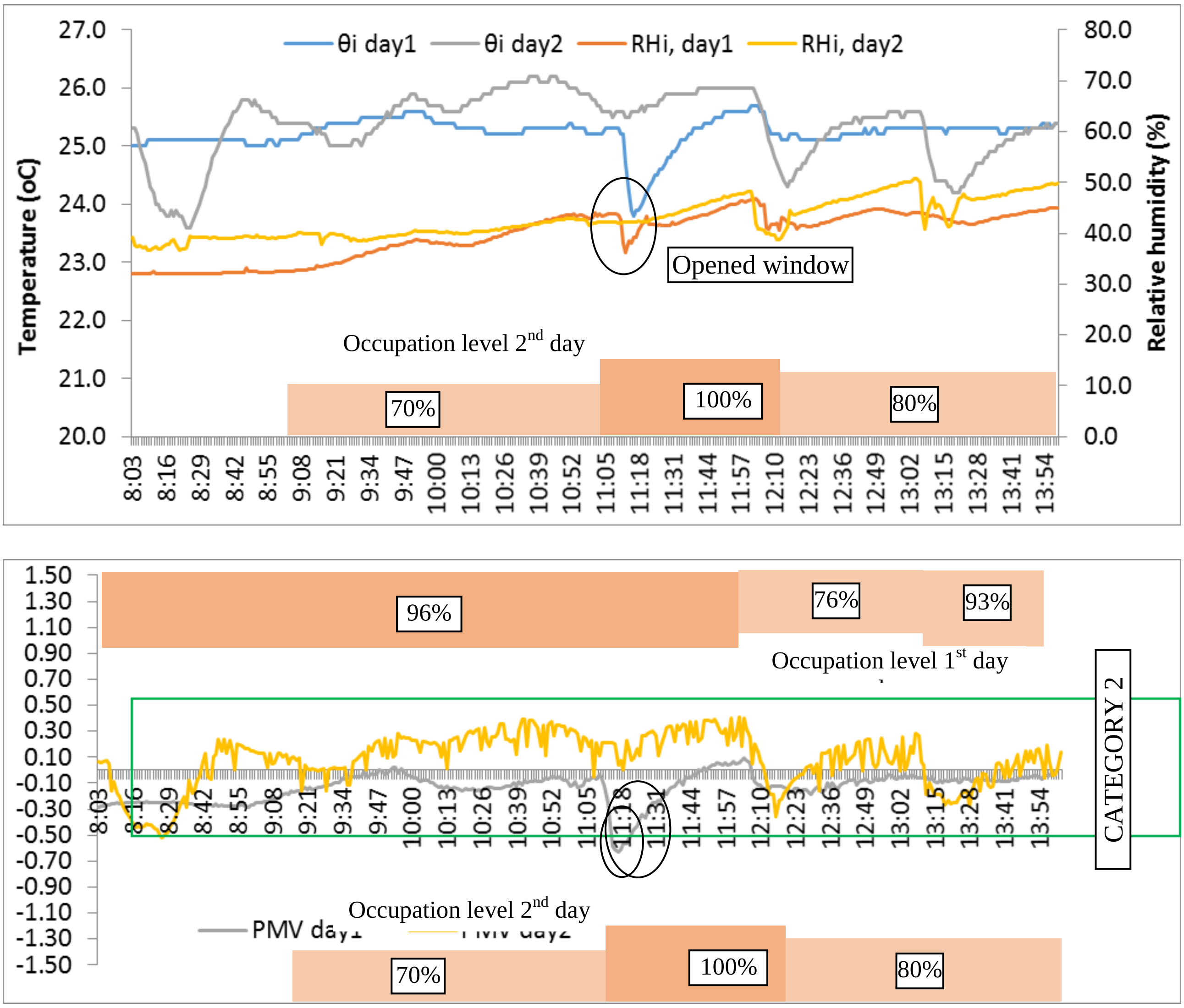

Figure 2. Analysis of thermal comfort for the non-ventilated room

3.2 Non-ventilated room thermal comfort assessment

We have analyzed the evolution of indoor temperature and relative humidity in the non-ventilated room for the 2 experimental days. On 1st day at 11:10, the windows were opened and a decrease in temperature below 24°C was observed. With the maximum number of people (30 pupils and 1 professor) in the classroom, values of over 26°C of indoor temperature are recorded.

The evolution of the indoor temperature and of the average predictable PMV for the non-ventilated hall during these 2 days showed that there is a variation of the PMV in the thermal comfort zone

PMV = -0,5 ÷ +0,5 for the category of ambiance II, for a maximum number of people in the classroom. PMV was determined on the basis of measured values of indoor temperature, relative humidity, airflow velocity and average radiant temperature of surrounding areas of the classroom. The other two parameters of thermal comfort were considered with the following values R_{cl} = 0,7 clo (thermal resistance of clothing) and M = 1 met (heat metabolism for a person performing light physical work).

3.3 Ventilated room thermal comfort assessment

The evolution of indoor temperature and relative humidity in the ventilated room for the two experimental 2 days showed that the due to the fact that this room is ventilated, a drop in indoor temperature of approx. 1°C compared to the non-ventilated room. The difference in temperature for the two days comes from the fact that on the first day, the number of people in the room was maximum in the first part of the morning (29-30 persons), while on the second day the maximum number of people in the room was 24 (time 11:30). As concerns the indoor temperature and of the predicted mean vote PMV for the ventilated classroom, it is found that in both days we have negative PMV values (below the zero value, corresponding to thermal equilibrium) so that the occupants of the room feel a slightly cold sensation, because indoor temperature is lower than that in the classroom unventilated. For the 2nd day the PMV index values are below -1, the occupants are feeling a thermal discomfort.

Figure 3. Analysis of thermal comfort for the ventilated room

This is due mainly from the higher amount of fresh air introduced from outside. The PMV-index is sensitive to the subjective parameters: clothing insulation level and metabolism. We have supposed 0.7 clo, but with higher values (e.g. 1 clo) the PMV values were closer to -0.5.

When comparing the maximum, minimum and average values from the two measurements days we can observe that the thermal comfort is achieved in the non-ventilated room with values close to 0.00 but also during the 1st day in the ventilated room with humidity sensitive air vents. The amount of fresh air was lower in the first day (aprox. 100 m^3/h) compared to 450 m^3/h for the 2nd day. Clearly there is a compromise to be made during these periods (spring/autumn) as the thermal comfort will be affected. Another explanation of the lower values of PMV for the 2nd day is the fact that the average outdoor temperature (08:00 to 14:00) was 10.58°C compared to the 1st day when this value was 11.7°C. Moreover during the 2nd day the occupation of the classroom during morning was at 33% compared to 1st day when we had 100%.

Table3. Comparison between the two analyzed classroom

	Day 1			**Day 2**		
	No ventilation (mechanical or natural)					
	Temp.	**Humidity**	**PMV**	**Temp.**	**Humidity**	**PMV**
Max	26.0	46.9	0.09	26.20	50.70	0.41
Min	24.0	32.0	-0.63	23.60	36.60	-0.52
Average	25.5	39.7	-0.14	25.36	42.91	0.08

	Day 1			**Day 2**		
	Humidity sensitive air vents			**Window fan**		
	Temp.	**Humidity**	**PMV**	**Temp.**	**Humidity**	**PMV**
Max	25.00	43.40	0.02	22.90	56.60	-0.85
Min	23.40	34.70	-0.81	21.30	38.50	-1.36
Average	24.25	39.83	-0.28	22.20	41.22	-1.09

5. Conclusions

The article tackles a very sensitive subject which is indoor comfort in schools. The experimental campaign was realized in two identical classrooms as size, volume, orientation and materials the difference being the fact that in the first one, called the ventilated classroom we had installed two types of ventilation: one using natural ventilation through humidity sensitive air vents and a second system using mechanical ventilation with the help of window fan. The second classroom, called non-ventilated, there was no ventilation – natural or mechanical. As it was impossible to control outdoor conditions we tested the two ventilation systems and their impact on the thermal comfort during two days. After the analysis of the measured data using professional equipment from TESTO 480 we can conclude that during spring/autumn the introduction of fresh air without preheating it can alter the PMV index. In fact, when using the mechanical ventilation with the help of a fan the 450 m3/h modified the indoor ambiance and the occupants felt a chill sensation according to Fanger PMV index. The use of humidity sensitive air vent with lower fresh air flows may be a better solution during winter and spring periods. When the outside air temperature is higher than 15°C the mechanical system is more suitable for ensuring correct air quality. Within this article we have the proof that a hybrid system (natural and mechanical) can be a solution in classrooms with potential to achieve both thermal comfort and air quality.

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