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Influence of decorative materials on cooling load of residential apartments

Shahraein Masoud Taheri Zhao Lihua Meng Qinglin

(School of Architecture, South China University of Technology, Guangzhou 510640, China)

Abstract: The influence of a polyvinyl chloride (PVC)-panel on the cooling load of a residential apartment in Mashad, Iran, is analyzed by the DeST-h software. And the summer natural ventilation of the residential apartment is investigated to determine the wind speed into the apartment through the computational fluid dynamics software. The evaluation results of the indoor wind velocity show that most parts of the apartment are comfortable. The cooling load of the penthouse can be decreased about 10.5% or 6.5% when an air layer exists or does not exist between the ceiling and the PVC-panel, respectively, indicating that the existence of the air layer can decrease the cooling load. However, the effect of the increase in the air layer's thickness on the decrease in the cooling load is obvious. Adding a thin layer of air between the ceiling and the PVC-panel is a good step toward sustainable buildings.

Key words: residential apartments; natural ventilation; energy consumption; decorative materials; Mashad

The residential buildings are the major sector of energy consumption in Iran[1]. Mashad, the capital of Khorasan province, is one of the biggest cities in Iran and is located in an arid region of northeast Iran[2] where the outdoor temperature can reach 40 ℃ in summer[1]. There is a special type of residential buildings with four to seven stories in Mashad, located between one or two stories houses. The ceilings of these buildings constructed with hollow clay blocks have low thermal resistances. Meanwhile, the penthouses of these buildings have vast ceilings, which are the main factors involved in the energy consumption of these apartments.

It has been about five years since people became inclined to use decorative materials such as PVC-panels in residential buildings. People prefer to use air conditioning systems instead of evaporative coolers for cooling in the arid regions of Iran. Natural ventilation has been used in Iran for passive cooling of buildings for centuries[3]. In this study, we try to determine the influence of the ceiling PVC-panel on the cooling load of residential apartments under natural ventilation. The summer energy consumption of the penthouse of a five-story residential building with five different ceiling construction types is investigated.

1 Materials and Method

1.1 Methodology and software

The algorithm schematic of this study is presented in Fig. 1. The apartment is analyzed to determine the amount of the cooling load in summer. According to the algorithm, the thermal properties of the conventional building materials are first investigated. Some of them are measured in the building

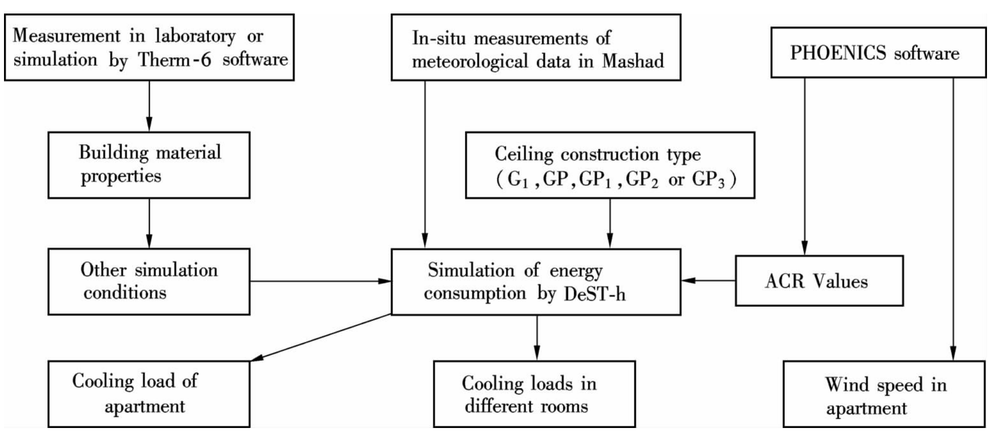

Fig. 1 Algorithm schematic

environment and energy laboratory (BEEL) at South China University of Technology. Others such as the thermal properties of hollow clay blocks is simulated and calculated by the Therm-6 software. The increase in natural ventilation can decrease the cooling load of residential buildings[4–5].

Computational fluid dynamics (CFD) is an affordable, accurate, and informative method among all the prediction methods and it is popularly used in the prediction of building environments[6]. Therefore, the CFD software,

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Biographies: Shahraein Masoud Taheri(1970—), male, graduate; Zhao Lihua (corresponding author), female, doctor, professor, lhzhao@scut.edu.cn.

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PHOENICS, is applied to simulate the wind velocities around and inside the building and determine the amount of the air change ratio (ACR) of the apartment under natural ventilation. Finally, the DeST-h software, an annual dynamic energy simulation software, is used to evaluate the effects of decorative materials on the cooling load of the buildings. Typical meteorological data should be utilized during the dynamic energy calculation procedure. Because there are only meteorological data of Chinese cities in the building material library of the DeST-h software, we measured Mashad meteorological data in June, July and August, 2008 and added them to the building material library.

1.2 Building information

The studied apartment is located on the top floor of a five-storey residential building. There are three bedrooms on the north side. A kitchen, a dining room and a living room are located in the southern part of the apartment. The total height of the building is about 15 m. The area of the apartment is about 228 m^2, in which the air conditioning area is about 178.8 m^2. The window-to-wall ratios (WWRs) of the south, north, west and east façades are 0.38, 0.21, 0.03 and 0.06, respectively. Fig. 2 shows the site plan of this building. The building direction is 40° from the south toward the west. Five different ceiling construction types are evaluated: 1) A conventional ceiling (G_1); 2) A ceiling with an 8 mm thick PVC-panel (GP); 3) A ceiling with a 5 mm thick air layer and an 8 mm thick PVC-panel (GP_1); 4) A ceiling with a 10 mm thick air layer and an 8 mm thick PVC-panel (GP_2); 5) A ceiling with a 100 mm thick air layer and an 8 mm thick PVC-panel (GP_3).

Fig. 2 Site plan of studied building

1.3 Materials

The walls of the studied apartment are hollow clay block ones with a width of 154 mm. A conventional ceiling consists of a 200 mm thick clay block, a 50 mm thick light concrete layer, a 25 mm thick cement mortar, a 5 mm thick bituminous layer and a 5 mm thick gypsum plaster. The floors have similar constructions as the ceiling except that an 8 mm thick parquet floor is used instead of the bituminous layer. And the floors do not include a light-concrete layer. A normal kind of glass with a thickness of 3 mm and a shading coefficient of 0.93 is used for windows. To determine the thermal properties of conventional building materials used in Iran, some of them are measured in the BEEL by the quick thermal conductivity meter (KEM, QTM-500) or the guarded hot plate thermal conductivity meter (TPMBE-300). In addition, The Therm-6 software, a software for analyzing the two-dimensional static heat transfer through building products[7], is used for the simulation of the equivalent thermal resistance (R_{eqa}) of the hollow clay blocks of the walls and the ceilings. The simulated values of R_{eqa} are added to the building material library of the DeST-h software. The thermal conductivities (λ) of the materials are shown in Tab. 1.

Tab. 1 Properties of building materials

Materials	λ/ ($W \cdot m^{-1} \cdot K^{-1}$)	R_{eqa}/ ($m^2 \cdot K \cdot W^{-1}$)	ρ/ ($kg \cdot m^{-3}$)	Determination method
Gypsum plaster	0.35		1 047	Measured in the BEEL
Gypsum mortar	0.54		1 253	
Cement mortar	1.32		1 978	
8 mm thick PVC-panel		0.123	320	
Clay of block [2]	1.3		2 000	
104 mm thick wall block		0.233	618	Simulated by Therm-6 software
150 mm thick ceiling block		0.303	1 034	

1.4 Domain of model

In this work, the CFD software, PHOENICS, is used to simulate the wind velocity. The airflows around and inside the residential building are considered as three-dimensional steady-state incompressible turbulence flows. The turbulence model adopts the standard k-ε model.

First, the outdoor wind environment of the studied building is simulated (see Fig. 3). The size of the building is 15 m × 20 m × 15 m. The size of the computational domain is 70 m × 70 m × 20 m and the numerical grid includes 5.6×10^5 cells. According to the reports of the Mashad meteorological station[8], the average prevailing wind speed during June, July and August in 1951 to 2003 is about 4.7 m/s and from the east toward the west. 0.5 m^2 of the window is assumed to be open, which is approximately equal to 20% and 10% of the window areas in the north and south façades, respectively.

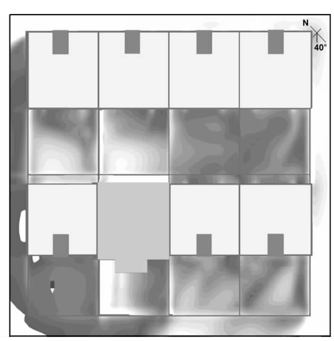

Fig. 3 Domain of simulated building

1.5 Conditions of simulation

In this study, the summer energy consumption of the apartment is simulated. According to the geometric dimension of the studied residential building, the simulation model is established by the DeST-h software as shown in Fig. 4. The ACR of the apartment is about 15.5 times/h. In the simulation, the dining room, the living room, the bedrooms and the kitchen are air-conditioned while the bathroom and the staircase are not. In the dining room and the living room, the air-conditioner works from 7:00 to 22:00 on workdays and from 8:00 to 24:00 on weekends. In the bedrooms, the air-conditioner works from 22:00 to 7:00 on workdays and works 24 h on weekends. Under air conditions, the maximum temperatures in the rooms are 26 to 28℃ and the minimum temperatures are 16 to 18℃. The internal heat gains are considered as the DeST-h default.

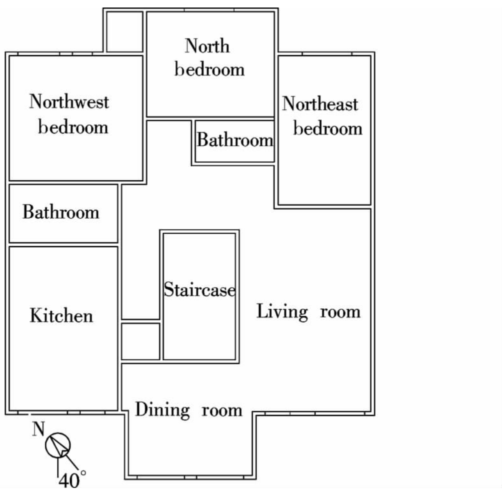

Fig. 4 Simulation model of studied apartment

2 Results and Discussion

2.1 Indoor wind velocity

People cannot feel the air flow when the velocity of the air flow is less than 0.5 m/s. And the air flow whose velocity is greater than 5 m/s is too strong for people to endure[9]. Therefore, in this study, the regions in which the air velocities are above or equal to 0.5 m/s but less than or equal to 5 m/s are thought to be comfortable zones and other regions are uncomfortable ones. The velocity distribution at the height of 1.5 m above the floor of the apartment is depicted in Fig. 5. The wind velocity is from 0.5 to 5 m/s. The blank zones in Fig. 5 stand for the uncomfortable zones. Moreover, the ratio of the uncomfortable area to the whole occupied region area (U_A) is taken as an important index for the evaluation of the results. The calculation results of U_A for all the rooms are shown in Tab. 2. A smaller value of U_A means a more comfortable area for most of the occupants. Tab. 2 shows that when 0.5 m^2 of the windows are open in each room, the value of U_A in each room is less than 50% and the value of U_A of the total area is about 17.2%. In addition, only the values of U_A in the kitchen and the dining room are more than 20%, which can decrease by the expansion of the windows' inlet areas.

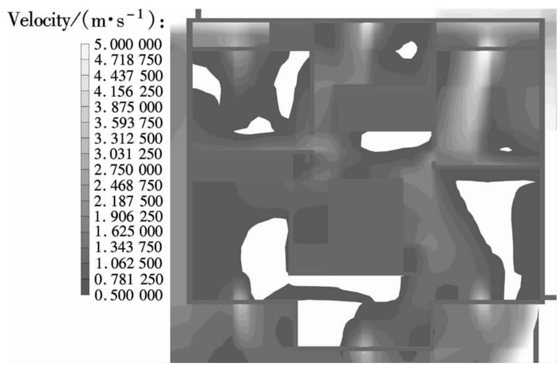

Fig. 5 Velocity distribution at the height of 13.5 m

The ACR is another important parameter under natural ventilation. The evaluation results of the indoor wind velocity show that the ACR calculated by the CFD software is 15.5 times/h. Xue[10] reported that when the ACR is between 10 and 20 times/h, the ventilation condition inside the room is good. So the ventilation condition inside the studied apartment with the ACR of 15.5 times/h is good.

Tab. 2 Evaluation index of U_A in different rooms

Item	Northwest bedroom	North bedroom	Northeast bedroom	Living room	Dining room	Kitchen	Corridor
Area/m^2	26.7	16.5	24.7	40.6	21.4	25.7	20.5
U_A/%	17.6	3.3	0.3	19	40.7	25.7	12.2

2.2 Cooling load in different rooms

The simulation results of the summer energy consumption of the studied apartment with five different ceiling construction types are presented in Tab. 3. The simulation results of the average cooling load in different rooms show that the cooling loads of the living room and the dining room are at a maximum. And the cooling loads in the living room and the dining room can decrease by 6.9% with the ceiling construction type GP instead of G_1. The evaluation results of the cooling load reduction by the PVC-panel show that among the bedrooms, the northeast bedroom has the lowest cooling load and the north bedroom has the highest cooling load. The cooling load reduction by the PVC-panel in the northeast bedroom is approximately 8.1%, which is much higher than that in the other rooms. However, the cooling load reduction by the PVC-panel in the north bedroom is approximately 4%, which is lower than that in the other rooms. The reason for the lower cooling load and the higher cooling load reduction by the PVC-panel in the northeast bedroom is that only the ceiling can absorb solar radiation during hot hours; that is, the ceiling is a main factor of heat flux in the room. The reason for the higher cooling load and the lower cooling load reduction by the PVC-panel in the north bedroom is that the existence of the east window can increase the room temperature in the morning and decrease the effect of the ceiling in the room.

Tab. 3 Average cooling loads with different construction types W/m^2

Room	G_1	GP	GP_1	GP_2	GP_3
Living room and dining room	21.47	19.98	19.07	19.01	18.91
Northwest bedroom	10.94	10.46	10.07	10.06	10.04
North bedroom	11.99	11.51	11.16	11.14	11.11
Northeast bedroom	10.72	9.85	9.45	9.42	9.37

2.3 Cooling load in apartment

The simulation results show that the cooling load decreases about 6.5% by adding the PVC-panel in the ceiling of the apartment. Fig. 6 exhibits the average cooling loads of the studied apartment with different ceiling construction types. The evaluation results show that for the apartment with different ceiling construction types GP_1, GP_2 and GP_3, the application of the PVC-panel with an internal air layer can decrease the amount of the cooling load by 10.5%, 10.8% and 11.2%, respectively. The construction costs and the cooling load reduction of the apartment with the ceiling construction type GP_3 are greater than those of the apartment with other ceiling construction types.

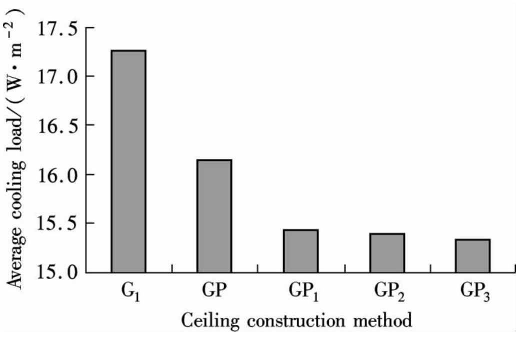

Fig. 6 Average cooling loads of studied apartment

Fig. 7 shows the measured consumed energy and the simulation results of the studied apartment with the ceiling construction type GP_3 from August 1st to August 10th, 2008. The evaluation results indicate that the values of the root mean square error (RMSE), the mean bias error (MBE), the mean absolute error (MAE) and the mean percent absolute error (MPAE) are about 8.5 kW·h, –4.6 kW·h, 7.5 kW·h and 17.1%, respectively. The coefficient of determination R^2 between the measurements and simulations is 0.96. The high value of R^2 shows that the simulations perform well. The negative value of the MBE implies that in the simulations the values of energy consumption are overestimated.

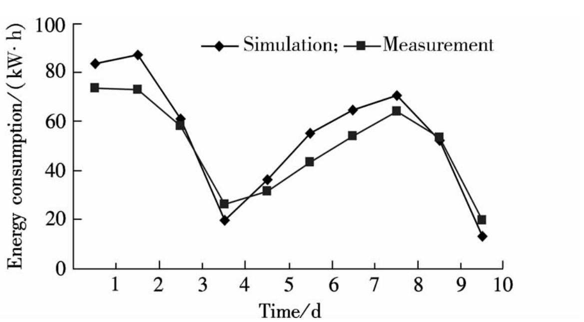

Fig. 7 Measurement results and simulation results of energy consumption

3 Conclusions

From the simulation of the indoor wind velocity and the energy consumption of the residential apartment under natural ventilation, the conclusions can be drawn as follows:

1) In the studied residential apartment under natural ventilation, 82.8% of the area is comfortable for most occupants; in other words, the ventilation condition inside the apartment with the ACR of 15.5 times/h is good.

2) The existence of the PVC-panel reduces the cooling load of the studied apartment by about 6.5%. The cooling load of the apartment with the ceiling construction types GP_1 and GP_2 decreases by about 10.5% and 10.8%, respectively. So the existence of a thin layer of air between the PVC-panel and the gypsum can be a good step toward sustainable buildings when people are inclined to redecorate ceilings with the PVC-panel. Although the energy consumption of the apartment with the ceiling construction type GP_3 is slightly less than those with the ceiling construction types GP_1 and GP_2, it is much higher than those with the other ceiling construction types. Therefore, type GP_3 is not a suitable one.

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天花板装饰材料对居住建筑冷负荷的影响

Shahraein Masoud Taheri　赵立华　孟庆林

(华南理工大学建筑学院,广州 510640)

摘要:采用 DeST-h 软件分析了伊朗马什哈德地区居住建筑 PVC 板对建筑冷负荷的影响,并利用计算流体力学软件模拟分析了夏季建筑室内的自然通风情况,以确定室内风速. 建筑室内风速的模拟结果表明,室内大部分区域是舒适的. 在天花板和 PVC 板之间有无空气层存在的情况下,建筑顶层房间冷负荷分别减少 10.5% 和 6.5%,说明空气层的存在有利于建筑降低冷负荷. 然而,空气层厚度的增加对建筑冷负荷降低的影响并不明显. 这种在天花板和 PVC 板之间增加空气层的策略对发展可持续性建筑十分有益.

关键词:居住建筑;自然通风;能耗;装饰材料;马什哈德

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