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1. Introduction

This report is part of the work performed under the project “Natural cooling and Ventilation through Diffuse Ceiling Supply and Thermally Activated Building Constructions”. In this project, a new system solution combining natural ventilation with diffuse ceiling inlet and thermally activated building systems (TABS) is proposed for cooling and ventilation in office buildings. Due to the application of diffuse ceiling inlet, cold outdoor air can be supplied into the room without any risk of draught. This means that natural ventilation is available even in winter and it is beneficial to reduce the energy consumption for buildings with cooling demand in cold seasons. In this way, the building system can operate at a very low energy use all the year round.

The main purpose of this task is to investigate the energy performance of different HVAC systems used in the office room and the classroom, and find the potential of energy saving for the proposed new system solution. In this report, a typical room is selected according to the previous study, but the occupation is different for the purpose of the office and the classroom. Energy performance of these two types of room under different internal heat loads are evaluated and compared, including cases with and without diffuse ceiling panel, with and without heat recovery, using traditional air-based system and TABS system. At last, the comparison results are presented and some important issues are discussed.

2. Building model

2.1 Building geometry

The characteristics of the building have been chosen similar to the one studied by Winther et al. (2010) in his report about intelligent glazed facades and Dreau et al. (2011) in his work. One typical room in the building with and without diffuse ceiling panel, facing the south, is studied. The geometry of this room is shown in Figure 1, with the external dimension (8.0 m × 3.6m × 4.8 m height). The plenum height from the bottom of the slab to the ceiling panel is 0.5 m, and the net floor area of this room is 26.0 m^2. One window with the dimension of (2.7 m × 2.8 m) is on the exterior wall, and the percentage of glazed area compared to the exterior wall area is around 49.2 %.

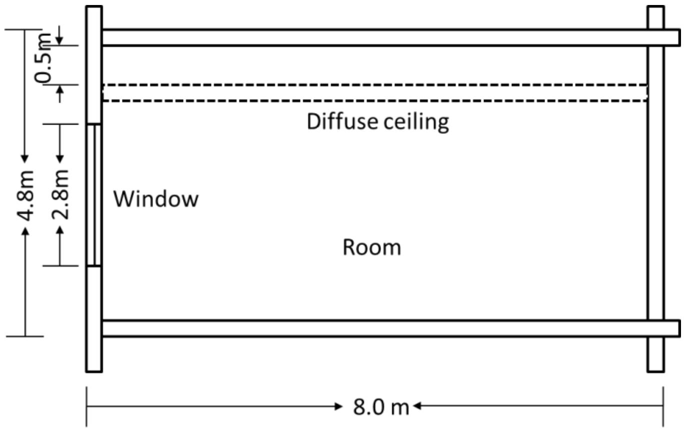
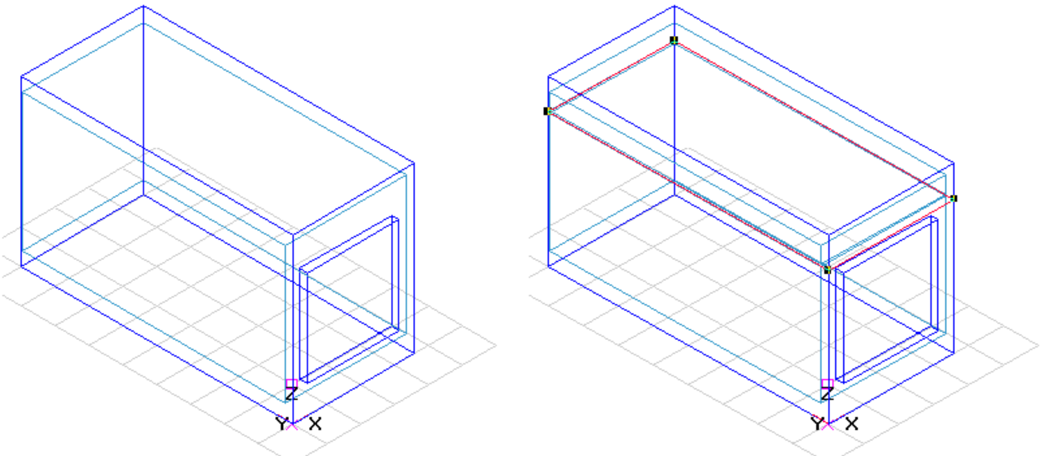


Figure 1 Geometry of the typical room

2.2 BSim model

BSim, which is a widely-used energy simulation software in Denmark, is adopted to perform the energy simulation work in this report. Figure 2 depicts the room models constructed in BSim. In the case without ceiling panel, only one thermal zone is established. While in the case with ceiling panel, the ceiling panel separates the room into two parts- plenum zone and room zone, and these two thermal zones exchange air flow through ventilation. To simplify the model, it is assumed that the adjacent rooms has the same temperature, so there is no heat transfer through internal walls, floor and ceiling.



(a) without ceiling panel (b) with ceiling panel

Figure 2 Room models in BSim

2.3 Building constructions

The detailed materials used in the constructions can be found in Table 1. The total thermal mass of the building is equal to 174.6 Wh/(m^2 K) for the office room and 174.8 Wh/(m^2 K) for the classroom (calculated with reference to EN ISO 13786 (CEN, 2007)), which corresponds to a very heavy construction according to EN ISO 13790 (CEN, 2008).

Table 1 Characteristic of the building components

	Envelope component	Material						
			Thickness d [m]	Density ρ [kg/m^3]	Conductivity λ [W/(m K)]	Capacity C [J/(kg K)]	U-value [W/(m^2 K)]	C_{dyn} [kJ/(m^2 K)]
1	Floor/ceiling	Concrete	0.25	2350	1.72	800	0.71	231.5
		Glass wool	0.05	14	0.042	800		
		Plywood	0.01	561	0.12	1800		18
2	Exterior wall (office)	Concrete	0.18	2350	1.72	800	0.33	240.0
		Glass wool	0.12	14	0.042	800		
		Plaster board	0.02	1240	0.7	1000		28.2
	Exterior wall (classroom)	Concrete	0.18	2350	1.72	800	0.16	240.6
		Glass wool	0.25	14	0.042	800		
		Plaster board	0.02	1240	0.7	1000		27.2
3	Internal wall	Plaster board	0.015	1240	0.7	1000	4.77	127.1
		Sand-lime brick	0.15	1900	0.9	850		
		Plaster board	0.015	1240	0.7	1000		127.1
4	Window	U-value 0.7, G-value 0.25, LT-value 0.3						
5	Ceiling panel	Wood wool	0.035	343	0.072	1300	1.03	11.9
		Mineral wool	0.018	80	0.037	840		4.8

2.4 Building systems

This building is located in Denmark and the weather condition of design reference year of Copenhagen is used. Table 2 lists the main parameters of the building systems. In the simulation, the heat load of equipment is changed to adapt different internal heat load levels. The number of occupant in the room and the minimum ventilation rate depend on the type of building (refer to EN 15251 (CEN, 2007) and SBI-anvisning 230 (SBI, 2013)). A dynamical control of the window is set up to optimize the heat losses in cold seasons and heat gains in hot seasons using shutter and solar-shading, as shown in Table 2. Top_max is the operative temperature limit, above which the shading device is activated, and if the total solar incidence to the room exceeds the Sun Limit. Max sun denotes the limit for solar incidence through the window, above which the shading device is activated (closed). Sun limit denotes the lower limit for the total solar incidence through the window, under which control according to the temperature criteria will not come into action.

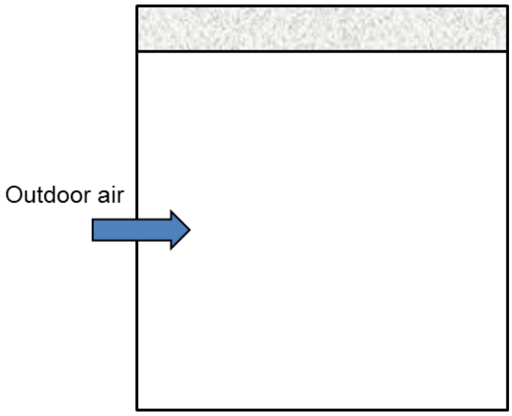
Table 2 Main parameters of the building systems

Building information	Location	Denmark
	Orientation	South
Occupied time	All year, excluding weekend	09-17
Ventilation	Minimum ACH	Office: 121.52 m^3/h=1.1 h^{-1} Classroom: 266.76 m^3/h=2.5 h^{-1}
	Specific Fan Power factor	2.1 kJ/ m^3
	Heat recovery(HR) efficiency	0.75
Infiltration	ACH	All time, 0.15 h^{-1}
People	Number of people	Office: 2 Classroom: 13
	Total heat load	Occupied time: 100 W/person, non-occupied time: 0 W
Equipment	Total heat load	Occupied time: 300 W, non-occupied time: 0 W
Lighting	Task light	Occupied time: 300 W, non-occupied time: 0 W, no daylight control
Shading	Shutter	Active when Top is lower than 20 °C during non-occupied time, R=5 (m^2 K)/W
	Solar-shading	Heating seasons: Top_max=26 °C Max sun=50 W/m^2 Sun limit=0.5 kW Cooling seasons: Top_max=23 °C Max sun=10 W/m^2 Sun limit=0.3 kW

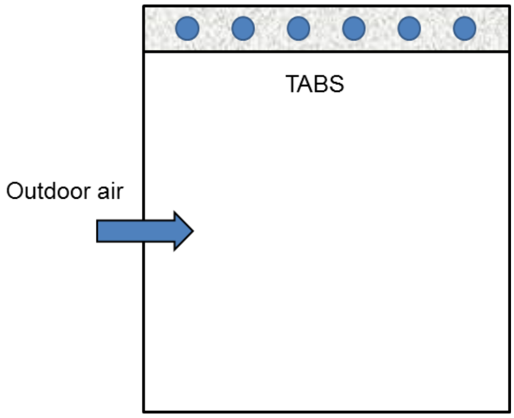
3. Presentation of different HVAC systems

3.1 Selection of different systems

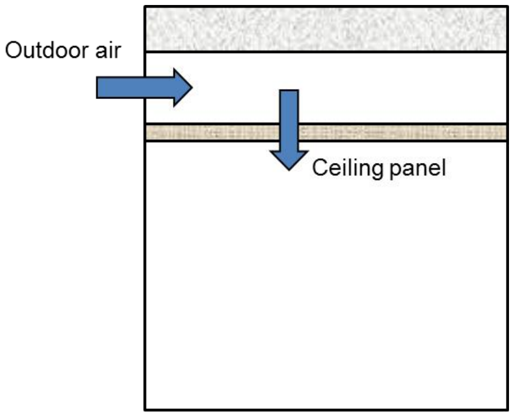
In order to investigate the energy saving potential of the new solution, different HVAC systems for this room are considered. The main concern of the new solution is the utilization of natural ventilation during the whole year and the activation of building thermal mass. So both air-based systems and radiant systems are compared for different room structures. Figure 3 depicts the five cases studied in this report, corresponding to three types of air-based systems and two types of TABS systems.



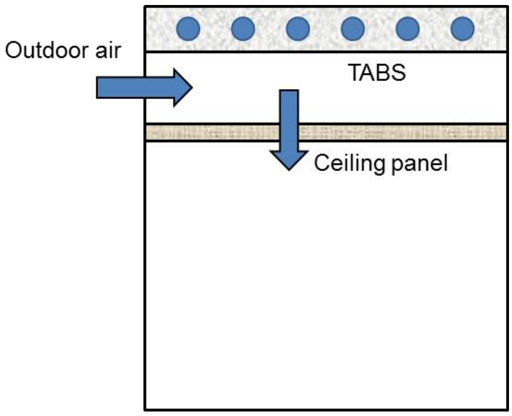
Case 1 traditional air-based cooling and heating system without ceiling panel



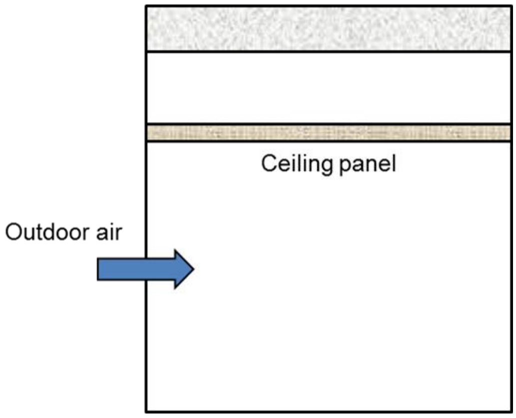
Case 2 TABS without ceiling panel



Case 3 traditional air-based cooling and heating system with ceiling panel
(ventilation air supplied from the plenum)



Case 4 TABS with ceiling panel
(the new solution)



Case 5 traditional air-based cooling and heating system with ceiling panel
(ventilation air supplied from the room side)

Figure 3 Five cases studied

3.2 Illustration of different systems

Case 1-traditional air-based heating and cooling system without ceiling panel: this case is the basic air-based system, room heating and cooling demand is supplied by the handled air and ventilation air is supplied into the room separately. There may be a risk of draught in this case, but the main concern in this report is the energy performance, so the risk of draught is not considered. In BSim the heating and cooling coil are used for the simulation of air-based heating and cooling, and the air temperature is more stable in this way. This means that the preheat energy loss as in the standard air-based system is not calculated for this case in BSim. Therefore, the obtained energy use in this way should be the minimum energy use for an air-based system.

The system parameters of this case are set as the following Table 3.

Table 3 System parameters for Case 1

System	Value
Heating Max power Part to air (convection) Design temperature	 Unlimited 1 Summer occupied time: 23 °C Winter occupied time: 21 °C Un-occupied time: 20 °C
Cooling Max power Part to air (convection) Design temperature	 Unlimited 1 Summer occupied time: 25.5 °C

	Winter occupied time: 24 ℃ Un-occupied time: 26 ℃

Case 2-TABS without ceiling panel: instead of using air cooling and heating, this case is one kind of high temperature cooling and low temperature heating radiant systems. The ventilation air is also supplied into the room directly for the requirement of fresh air as in Case 1. This case can be taken as the basic TABS system.

The basic system parameters of this case are set as the following Table 4. As the internal heat load varies in the simulation, these parameters may be changed according to the thermal comfort in this room space.

Table 4 System parameters for Case 2

System	Control in heating seasons	Control in cooling seasons
TABS Heating set-point: 21 ℃ Cooling set-point: 25.5 ℃	Water inlet temperature is the function of outdoor temperature, active during 9-17 Min outdoor temp=-5; Max water inlet=35; Max outdoor temp=10; Max water inlet=30; January-April and October-December	Water inlet temperature is the function of outdoor temperature, active during 9-17 Min outdoor temp=10; Max water inlet=18; Max outdoor temp=15; Max water inlet=18; May- October

Case 3-traditional air-based cooling and heating system with ceiling panel: cooling and heating is only supplied to the room space and no cooing or heating in the plenum, but the ventilation air is supplied from the outside to the plenum and evenly distributed to the room space through the diffuse ceiling panel.

The system parameters of this case are set as the following Table 5.

Table 5 System parameters for Case 3

System	Value
Heating Max power Part to air (convection) Design temperature	 Unlimited 1 Summer occupied time: 23 ℃ Winter occupied time: 21 ℃ Un-occupied time: 20 ℃
Cooling Max power Part to air (convection) Design temperature	 Unlimited 1 Summer occupied time: 25.5 ℃ Winter occupied time: 24 ℃ Un-occupied time: 26 ℃

Case 4-TABS with ceiling panel: this is the proposed solution in the project. Ventilation air with various ACH is supplied through the plenum into the room space, and the risk of draught can be evitable even in very cold seasons. TABS system can supply the supplementary heating and cooling for the room space. In this case, the key factor affecting the room heat transfer is the ceiling panel, which may have a large influence on the thermal performance of TABS.

The basic system parameters are set as the following Table 6. As the internal heat load varies in the simulation, these parameters may be changed according to the thermal comfort in this room space.

Table 6 System parameters for Case 4

System	Control in heating seasons	Control in cooling seasons

TABS Heating set-point: 21 °C Cooling set-point: 25.5 °C	Water inlet temperature is the function of outdoor temperature, active during 9-17 Min outdoor temp=-5; Max water inlet=35; Max outdoor temp=10; Max water inlet=30; January-April and October-December	Water inlet temperature is the function of outdoor temperature, active during 9-17 Min outdoor temp=10; Max water inlet=18; Max outdoor temp=15; Max water inlet=18; May- October

Case 5-traditional air-based heating and cooling system with ceiling panel: compared with Case 3, in this case the ventilation air is supplied into the room space directly. And the air cooling and heating is only supplied in the room space.

The system parameters of this case are set as the following Table 7.

Table 7 System parameters for Case 5

System	Value
Heating Max power Part to air (convection) Design temperature	 Unlimited 1 Summer occupied time: 23 °C Winter occupied time: 21 °C Un-occupied time: 20 °C
Cooling Max power Part to air (convection) Design temperature	 Unlimited 1 Summer occupied time: 25.5 °C Winter occupied time: 24 °C Un-occupied time: 26 °C

4. Assumptions and evaluation criteria

4.1 Assumptions

In this simulation, some assumptions are necessary.

(1) The ventilation air supplied from the outside is evenly distributed in the plenum, therefore the plenum has the uniform air temperature.

(2) Air flow through the ceiling panel is even and air in the room is well-mixed.

(3) The maximum natural ventilation rate available in this simulation is 5 times and 3 times as much as the minimum ventilation requirement for the office and the classroom, which means the maximum air change rate (ACH) is 5.5 h^{-1} and 7.5 h^{-1} for the new solution, respectively.

4.2 Evaluation criteria

Due to the different characteristics of each system, the air temperatures and heating/cooling energy demand will be different.

In BSim the simulation is based on the operative temperature, which is usually calculated as the mean value of air temperature and mean radiant temperature. Therefore, in this report, the thermal comfort analysis is based on the operative temperature of the room space and is evaluated as reported in the standard EN 15251 (CEN, 2007). Among the three categories of thermal comfort quality in EN 15251, category II is selected because it is in accord with the thermal comfort level in EN ISO 7730 (ISO, 2005) and is widely used when the thermal comfort is concerned (e.g., -0.5<PMV<+0.5). A performance index (PI) associated with the category represents the percentage of values of operative temperatures that fall within the acceptability range of the category. When the PI is at least 90%, the indoor thermal environment is supposed to meet a certain category.

In category II, the operative temperature of 20 °C-24 °C is the thermal comfort condition in heating seasons (October to April), while the operative temperature of 23 °C-26 °C is the thermal comfort condition in cooling seasons (May to October). All the simulation results of the operative temperature during the occupied-time must have a PI of greater than 90% so as to compare each case at the same comfort level.

Office and classroom have the same evaluation criteria in this report.

5. Results for office

The new solution would have high energy saving potential when the building has cooling demand in cold seasons, and the heat load in the room will largely influence this potential. Internal heat sources involve occupancy, lighting and equipment. In this report, the influence of internal heat load on the energy performance of different systems is investigated. Heat recovery system is beneficial to save the energy loss, so ventilation with heat recovery is also considered in case 1, case 2, and case 5.

5.1 Primary energy use

In the simulation, the electricity-chiller and gas-boiler are designated as the primary system equipment. Generally, the temperature of chilled water used for radiant cooling is higher than that used for air-based system, which means that the chiller COP will be higher, and the similar case for the boiler. Considering that it is impossible to get the primary energy use using BSim, some energy factors for the estimation are specified in Table 8. Since the energy use for the domestic hot water and lighting is identical for all cases, the primary energy use listed in this report is the summation of total energy use for heating, cooling and ventilation systems.

Table 8 Energy factors for different HVAC systems

Systems	System factor	Primary energy conversion factor
Air-based heating	0.8	1.0
Air-based cooling	3.0	2.5
Radiant heating	0.8	1.0
Radiant cooling	3.5	2.5
Mechanical ventilation	1.0	2.5

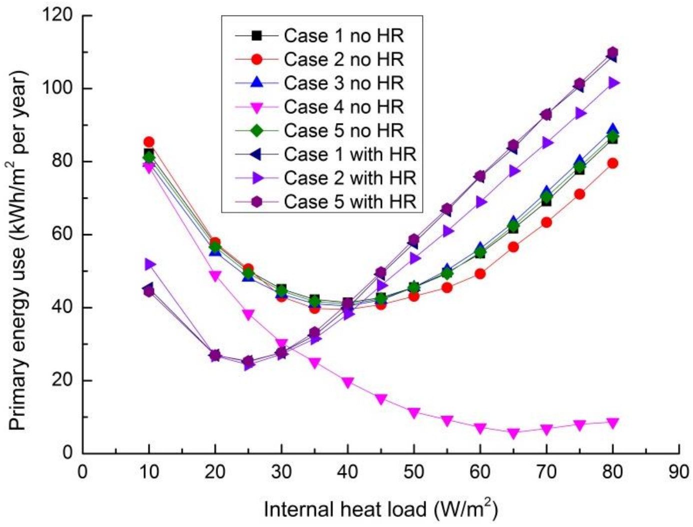


Figure 4 Primary energy use of whole year simulation

Figure 4 shows the primary energy use for the five cases under different internal heat loads. Due to the utilization of natural ventilation during the whole year, the primary energy use of the new solution decreases fast with the internal heat load. At the internal heat load of 65 W/m^2, Case 4 has the minimum primary energy use of 5.8 kWh/m^2 per year. On the contrary, the other 4 cases without heat recovery (HR) have nearly the same pattern, reaching the minimum primary energy use at the internal heat load of about 40 W/m^2 and increasing dramatically when the internal heat load is larger than 40 W/m^2. However, for cases with HR, minimum primary energy use occurs at the heat load of 25 W/m^2 and is lower than that of all other cases. When the heat load is larger than 40 W/m^2, cases with HR have higher primary energy use than that of all other cases. Compared with the other 4 cases, the new solution has less primary energy use when the internal heat load is above 30 W/m^2, which shows that the new solution has very good energy saving potential. Moreover, the larger the internal heat load is, the higher energy saving potential of the new solution is.

For the typical office room, the internal heat load varies at the range of 30-40 W/m^2, corresponding to the energy saving potential of 31.2%-51.3% compared with cases without HR and -10%-50.3% compared with cases with HR.

5.2 Annual heating and cooling need

Figure 5 depicts the pattern of heating (H) and cooling (C) need for the whole year. The heating needs of all cases without HR have the same decreasing trend, and no heating is needed when the internal heat load is above 60 W/m^2. The heating need of Case 4 is always larger than that of the others, which is attributed to the influence of ceiling panel on the heat transfer between the plenum and the room space. For cases with HR, heating need is apparently lower than all other cases.

For the cooling need, the other four cases without HR have the same fast increasing pattern with the increase of internal heat load. Moreover, cases with HR have higher cooling need. While for Case 4, as a result of using natural ventilation all the year round, there is no mechanical cooling need until the internal heat load is above 45 W/m^2. Further, the cooling need of Case 4 increases smoothly, and is always lower than that of other cases.

Since the internal heat load in the typical office room varies at the range of 30-40 W/m^2, this means there is no cooling need and only heating need exists in this kind of office room using the new solution.

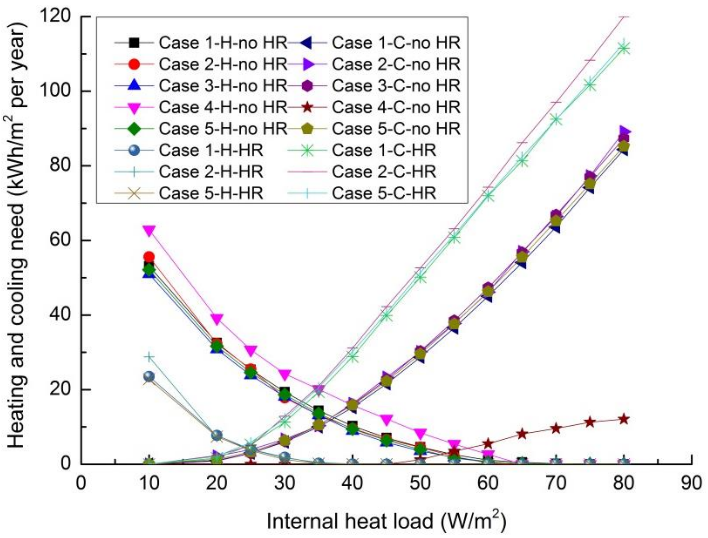


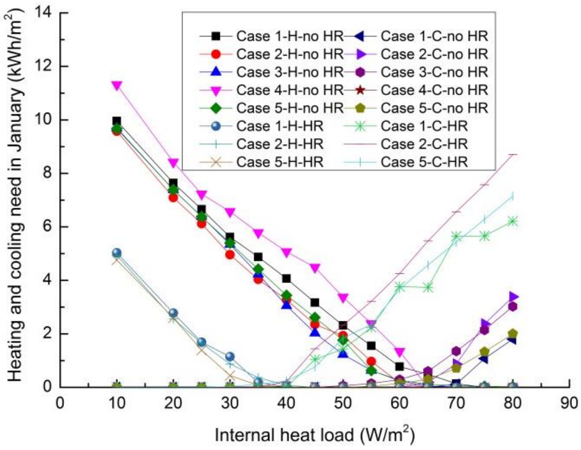
Figure 5 Heating and cooling need of whole year simulation

5.3 Monthly heating and cooling need

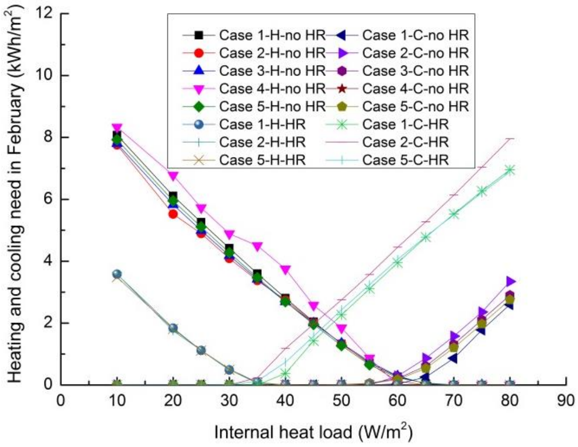
In order to further study the duration of energy saving, monthly heating and cooling needs are illustrated in Figure 6 (a)-(l). From these figures it can be seen that for the new solution there is no cooling need in winter seasons and transitional seasons, cooling need only occurs in summer seasons- June, July and August when the internal heat load is larger than 45 W/m^2. Moreover, the cooling need increases smoothly due to the increase of ventilation rate. While for the other four cases, cooling need exists in winter seasons. Especially for cases with HR, mechanical cooling is needed even at very low internal heat load.

For the heating need, the new solution has a higher value than the others in the winter seasons, but all cases without HR have nearly the same heating need in summer seasons and transitional seasons. In fact, cases with HR have the lowest heating need, especially in winter seasons.

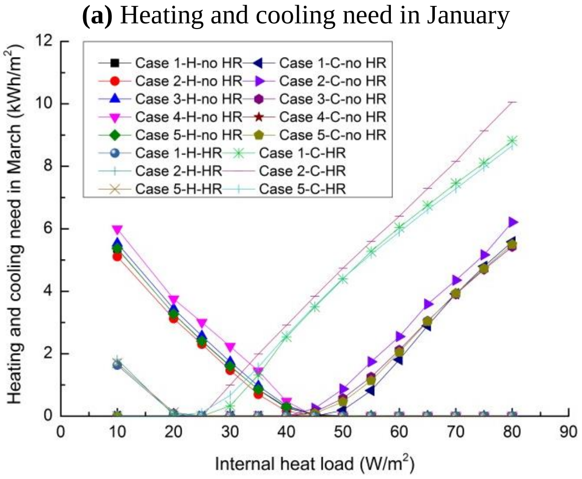
For the typical office room with internal heat load varying at the range of 30-40 W/m^2, the energy saving of cooling in winter seasons occurs in April, October, and November. But if the office room in future has the internal heat load above 50 W/m^2, this energy saving of cooing would occur in all winter seasons.



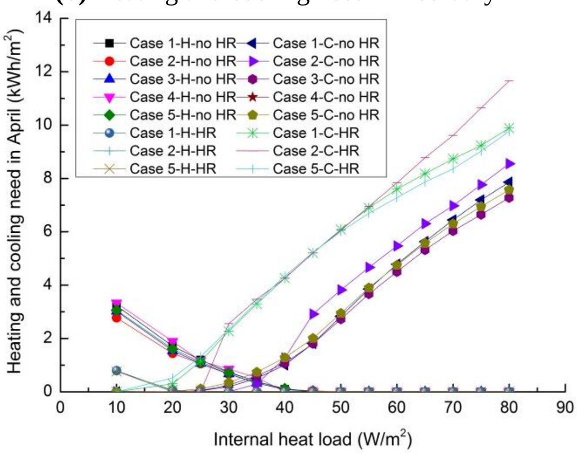
(a) Heating and cooling need in January



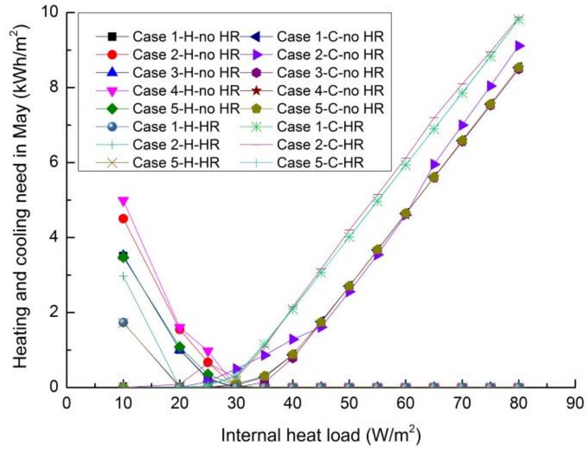
(b) Heating and cooling need in February



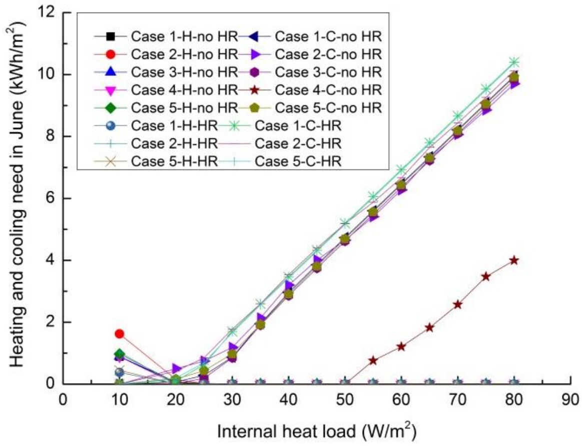
(c) Heating and cooling need in March



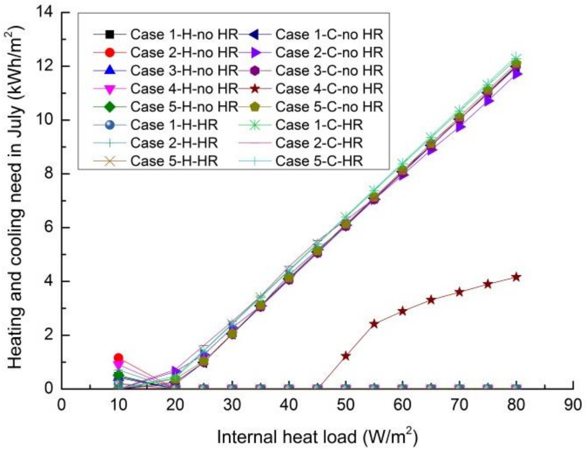
(d) Heating and cooling need in April



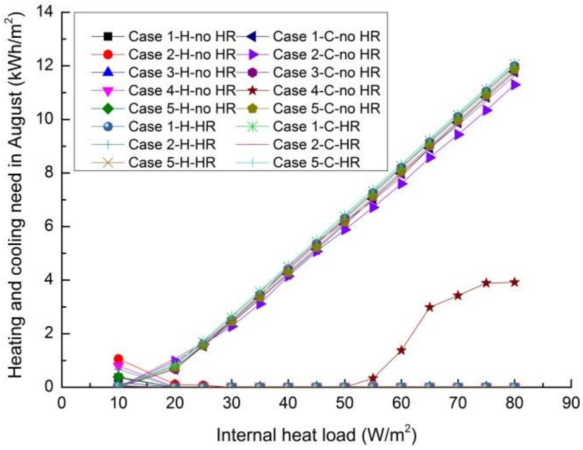
(e) Heating and cooling need in May



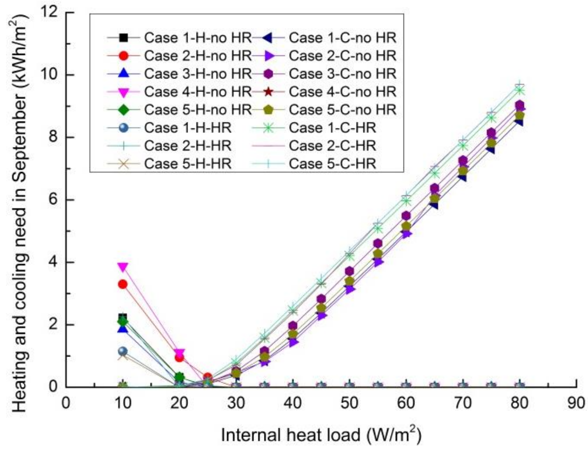
(f) Heating and cooling need in June



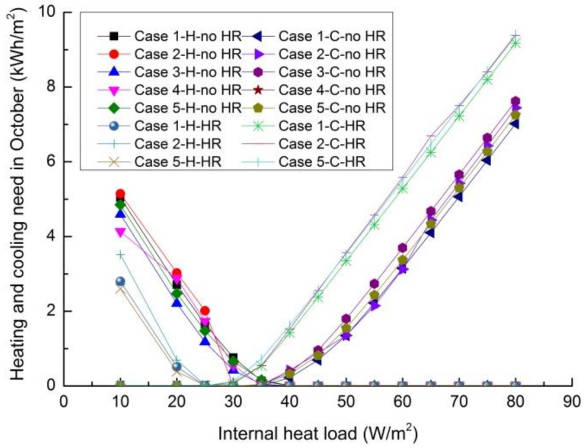
(g) Heating and cooling need in July



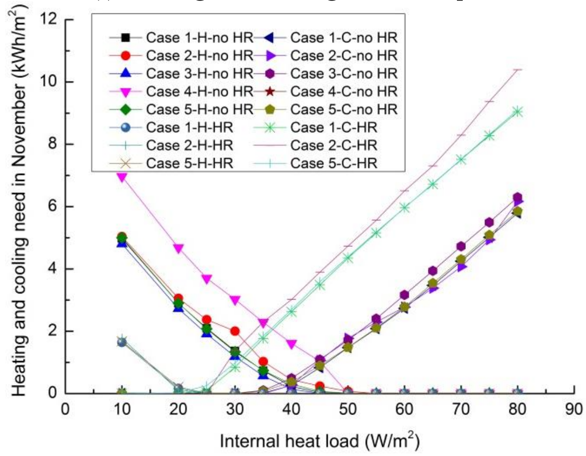
(h) Heating and cooling need in August



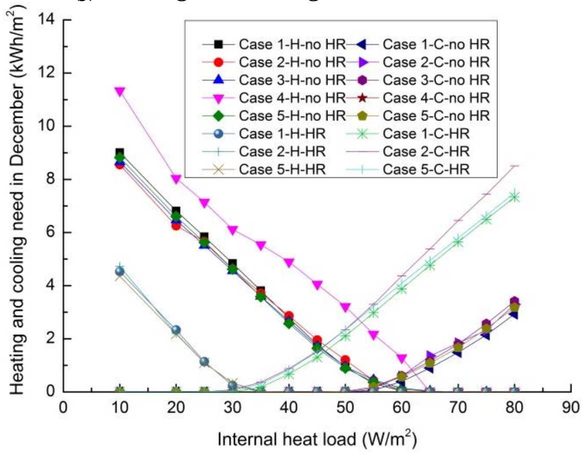
(i) Heating and cooling need in September



(j) Heating and cooling need in October



(k) Heating and cooling need in November

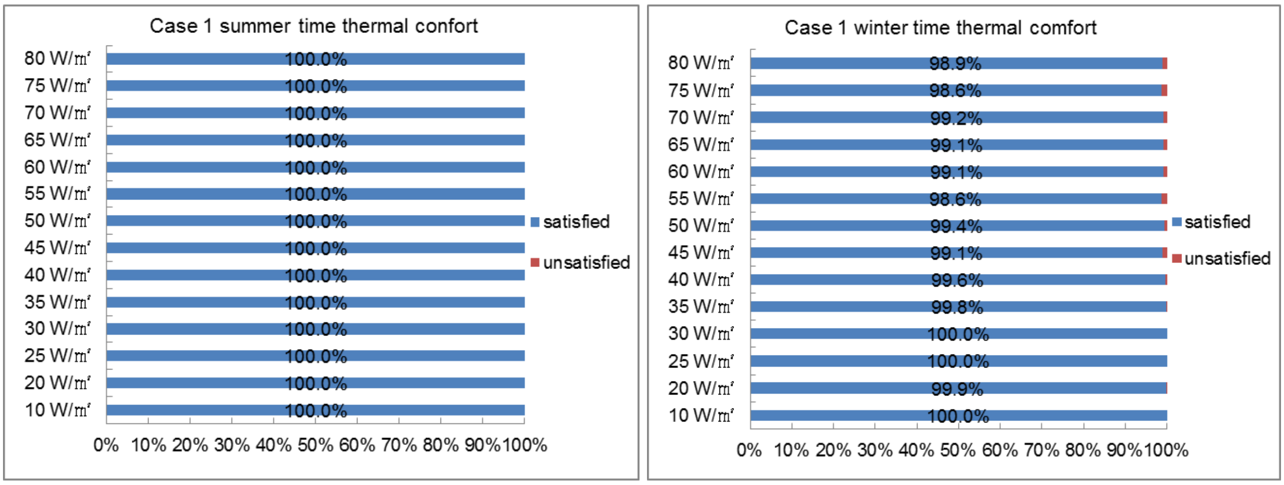


(l) Heating and cooling need in December

Figure 6 Monthly heating and cooling need

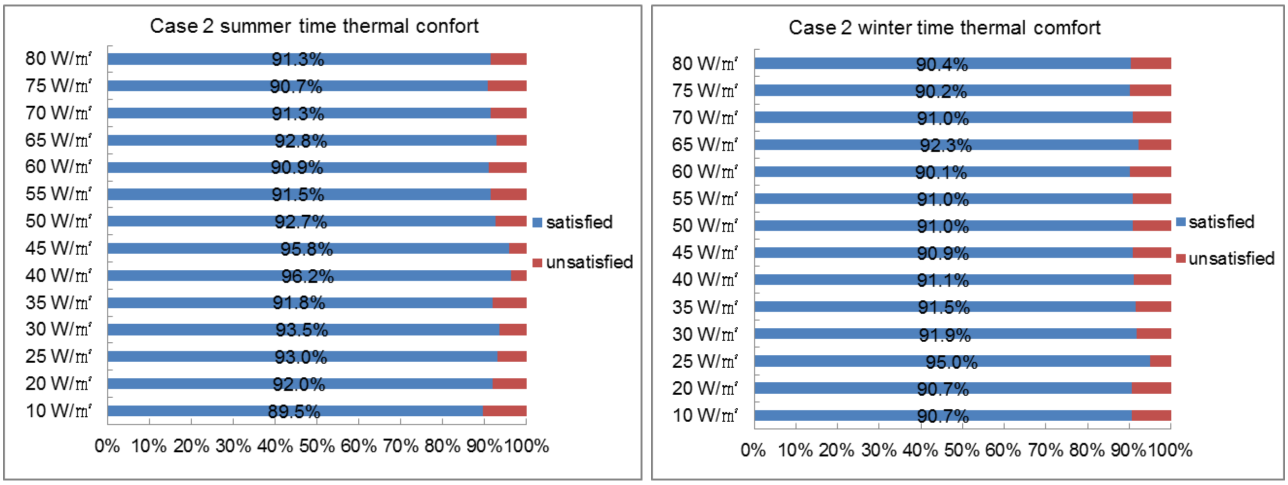
5.4 Thermal comfort evaluation

Figure 7-Figure 14 list the thermal comfort PI for all cases in summer time and winter time. From the thermal comfort analysis, it can be deduced that the thermal comfort level is equal among different systems because the PI of category II is always greater than 90%. The PI of category II for the radiant systems (Case 2 and Case 4) is smaller than that for the other air-based systems, which can be attributed to the complicated control of TABS.



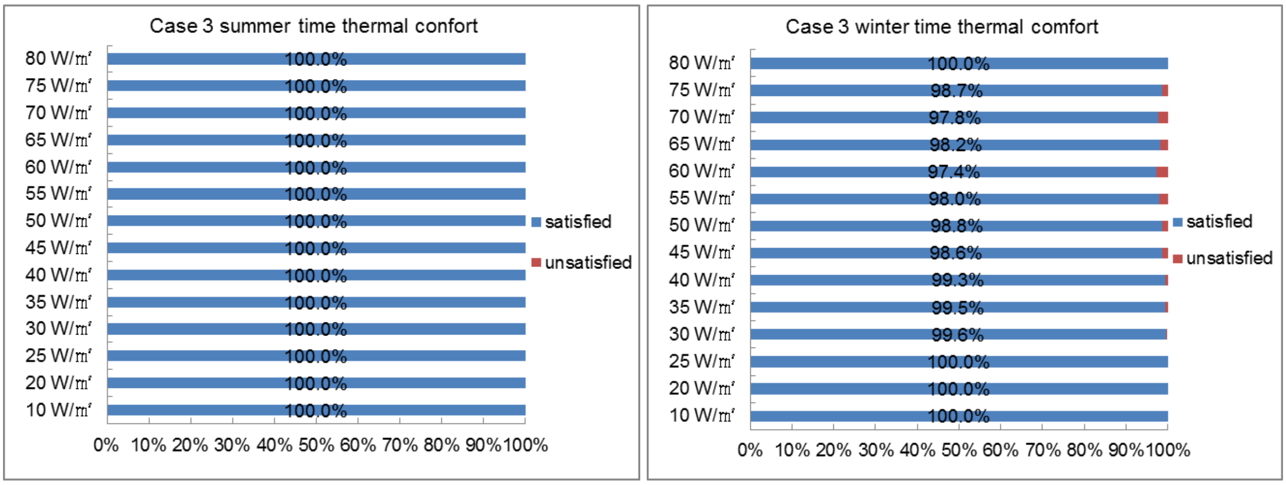
(a) (b)

Figure 7 Thermal comfort PI for Case 1: (a) summer and (b) winter



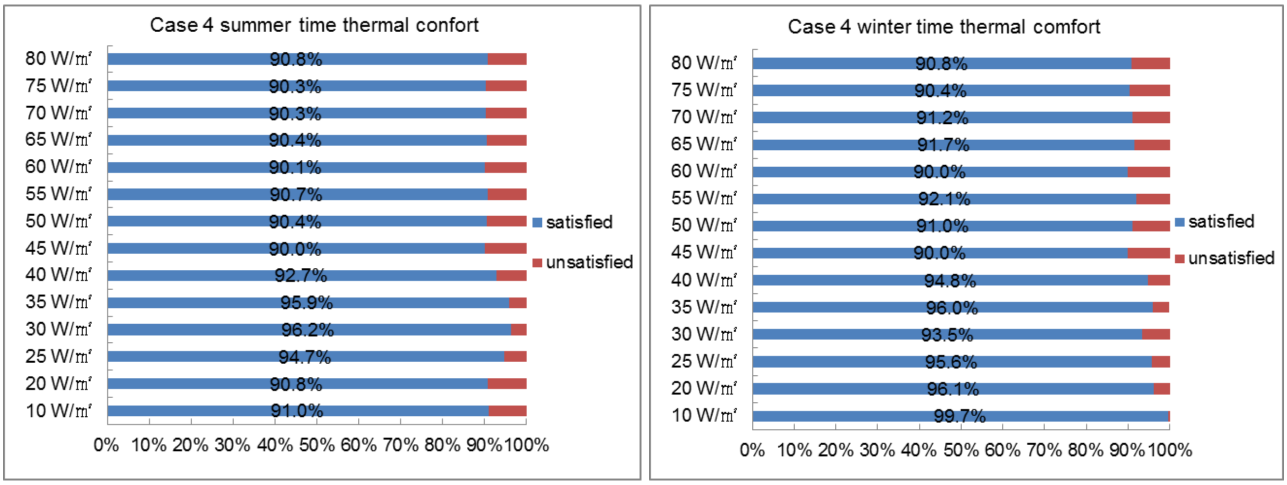
(a) (b)

Figure 8 Thermal comfort PI for Case 2: (a) summer and (b) winter



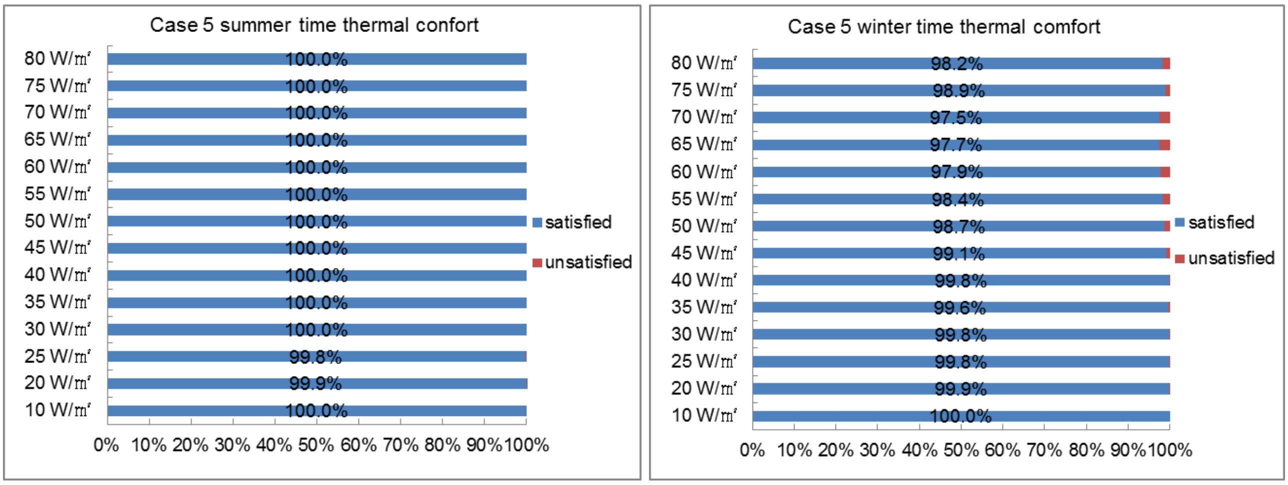
(a) (b)

Figure 9 Thermal comfort PI for Case 3: (a) summer and (b) winter



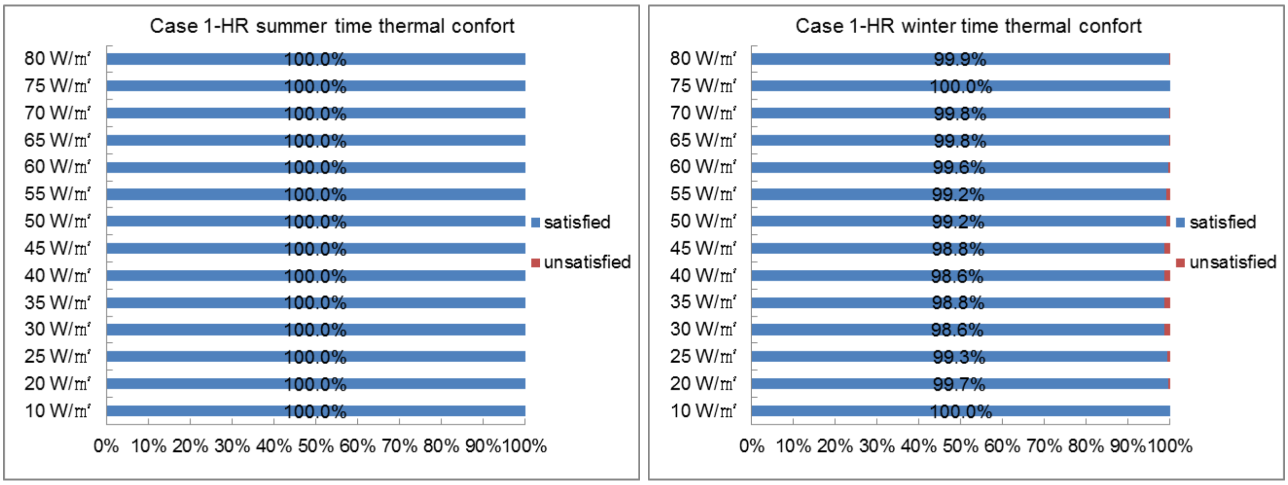
(a) (b)

Figure 10 Thermal comfort PI for Case 4: (a) summer and (b) winter



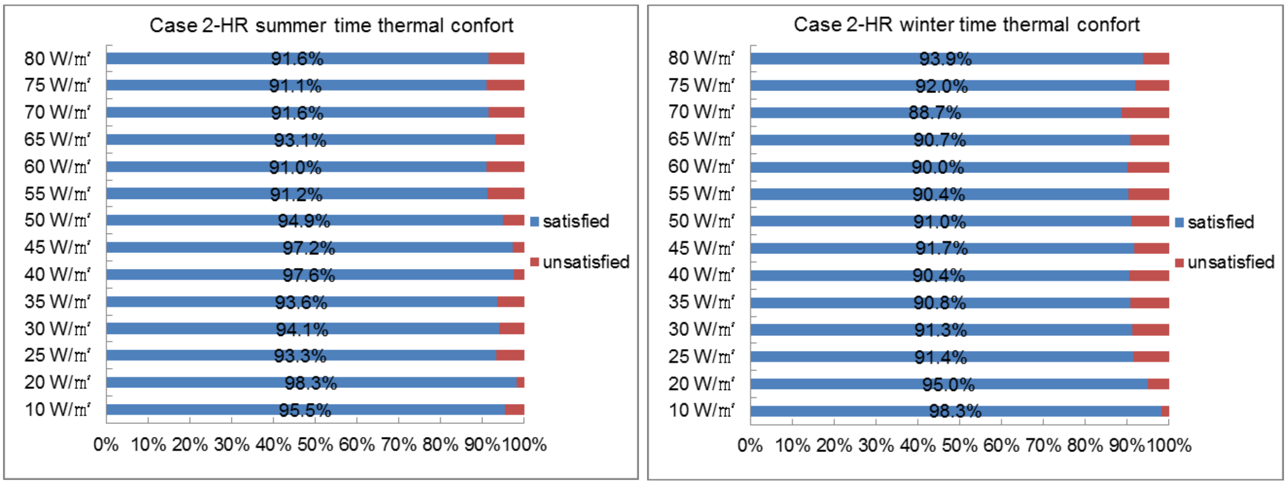
(a) (b)

Figure 11 Thermal comfort PI for Case 5: (a) summer and (b) winter



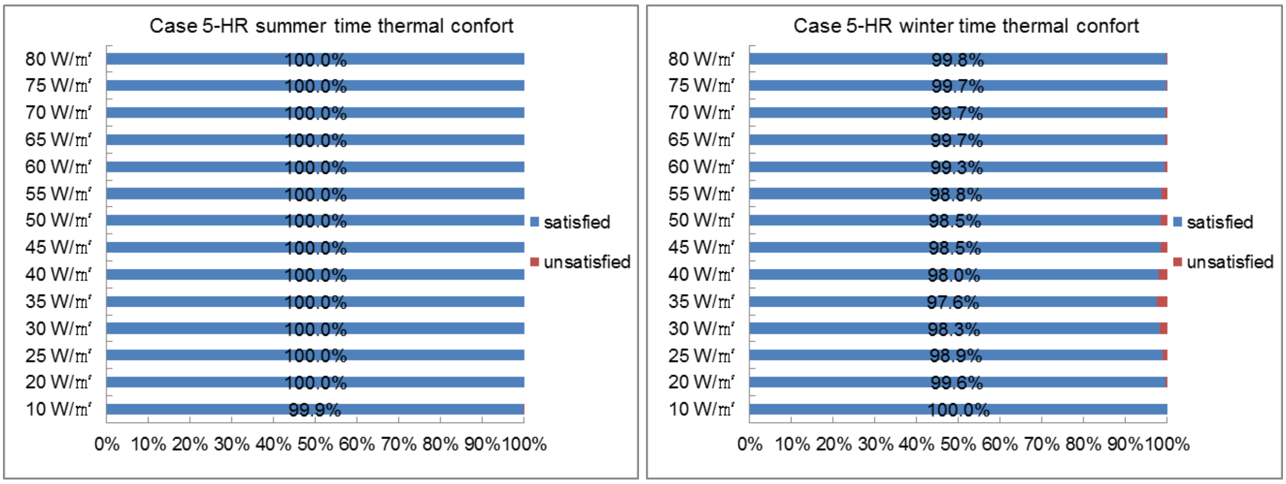
(a) (b)

Figure **12** Thermal comfort PI for Case 1-HR: (a) summer and (b) winter



(a) (b)

Figure **13** Thermal comfort PI for Case 2-HR: (a) summer and (b) winter

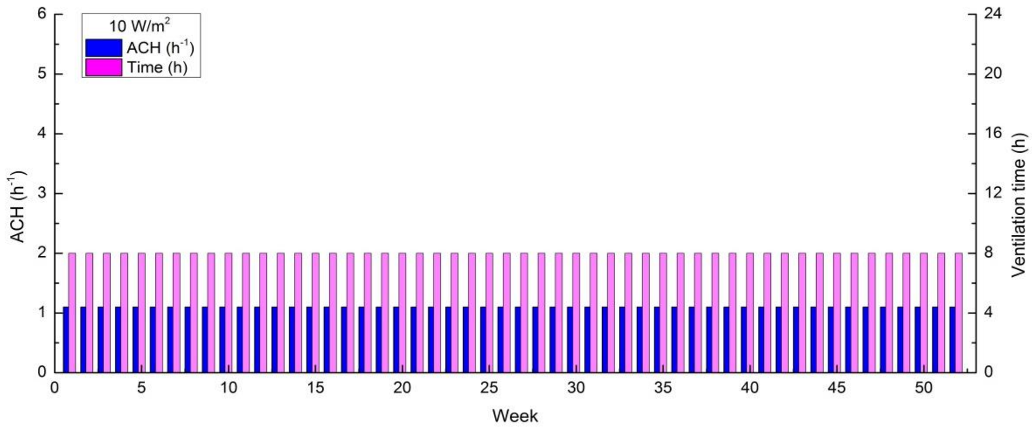


(a) (b)

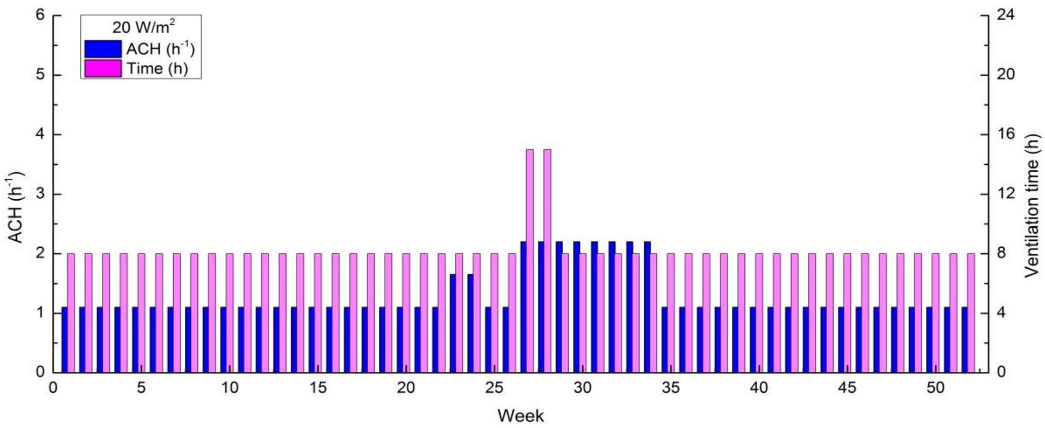
Figure **14** Thermal comfort PI for Case 5-HR: (a) summer and (b) winter

5.5 Ventilation variables in Case 4

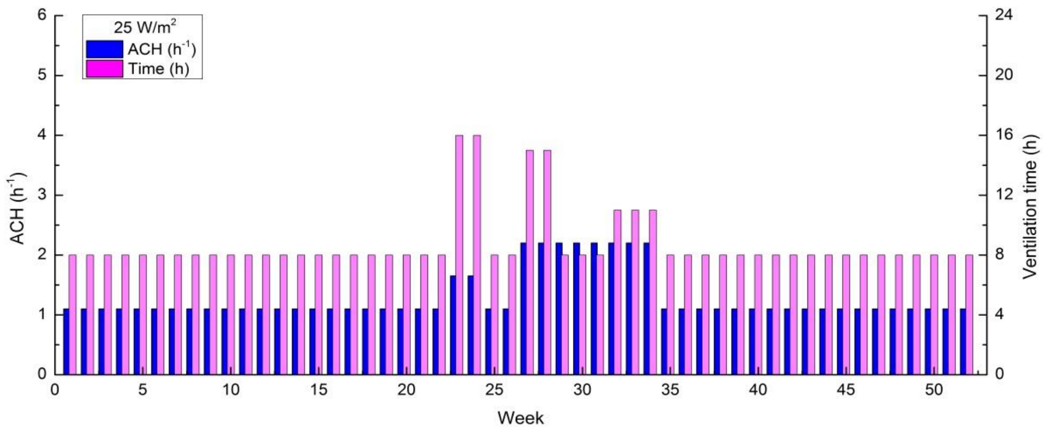
The dynamic control of the ventilation used in Case 4 is based on each week, and Figure 15 (a)-(n) show the average daily ventilation rate and ventilation time in each week under different internal heat loads. With the increase of internal heat load, ventilation rate and ventilation time increase fast in summer seasons and smoothly in the transitional seasons and winter seasons. Generally, summer seasons need higher ventilation rate for the cooling, while in winter seasons only very small ventilation rate is enough for the cooling due to the large cooling potential of cold outside air.



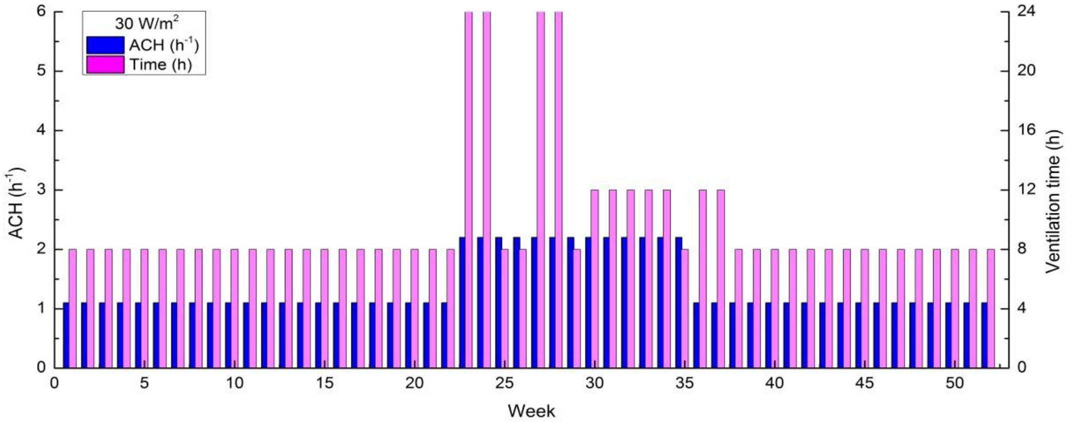
(a) Internal heat load-10 W/m^2



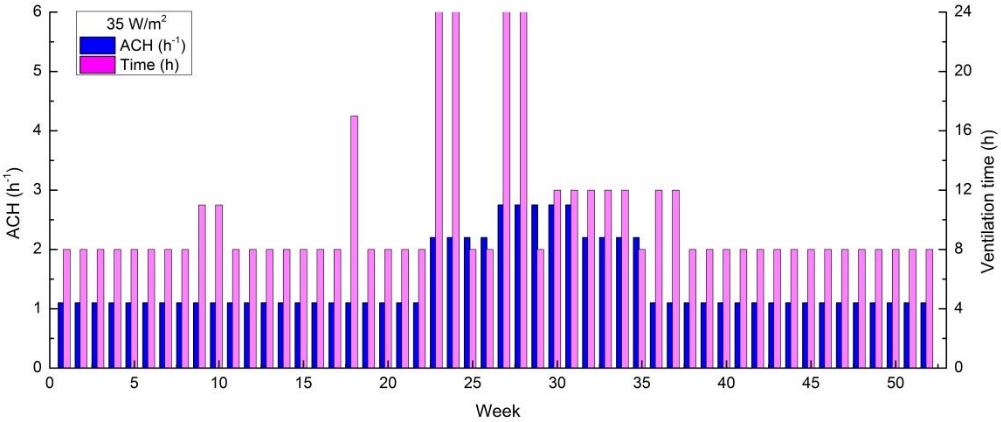
(b) Internal heat load-20 W/m^2



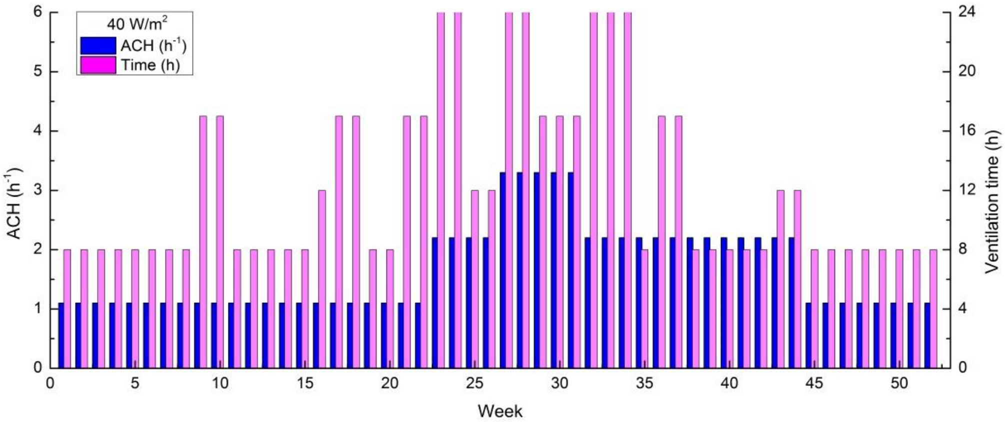
(c) Internal heat load-25 W/m^2



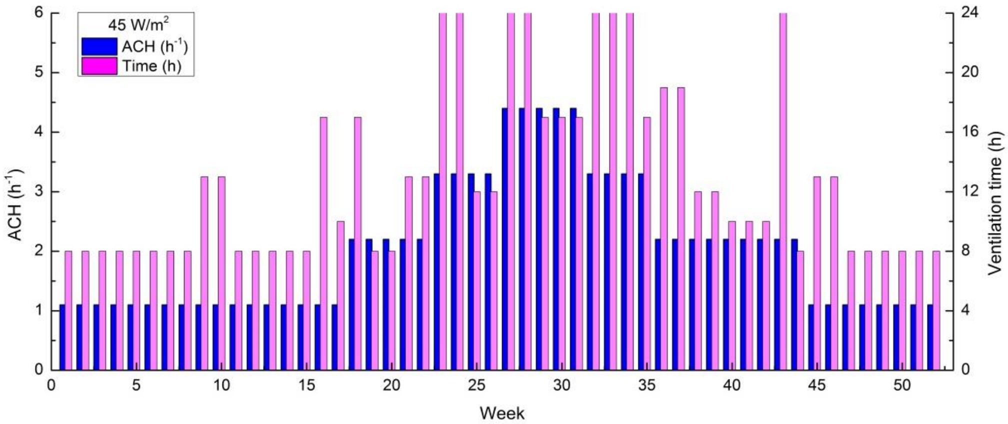
(d) Internal heat load-30 W/m^2



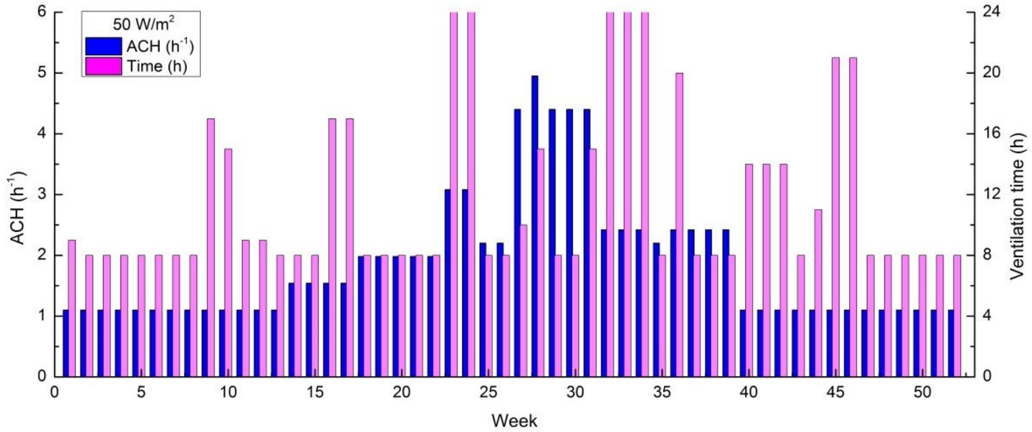
(e) Internal heat load-35 W/m^2



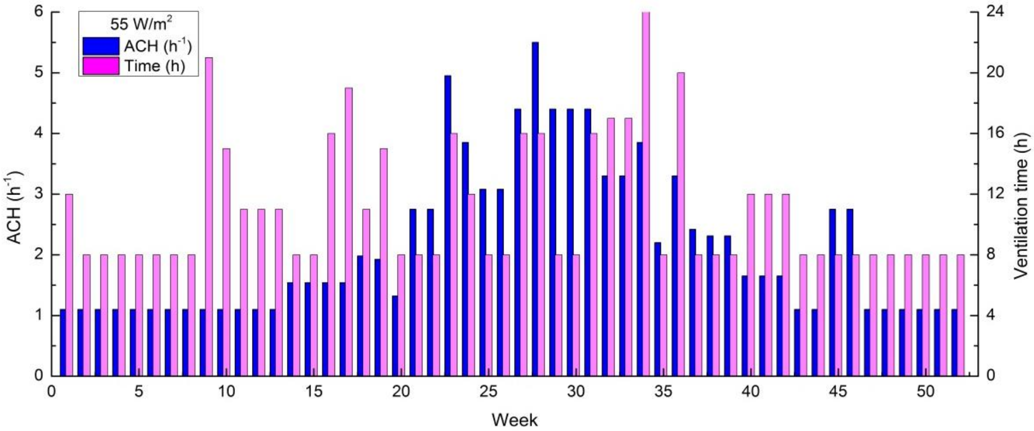
(f) Internal heat load-40 W/m^2



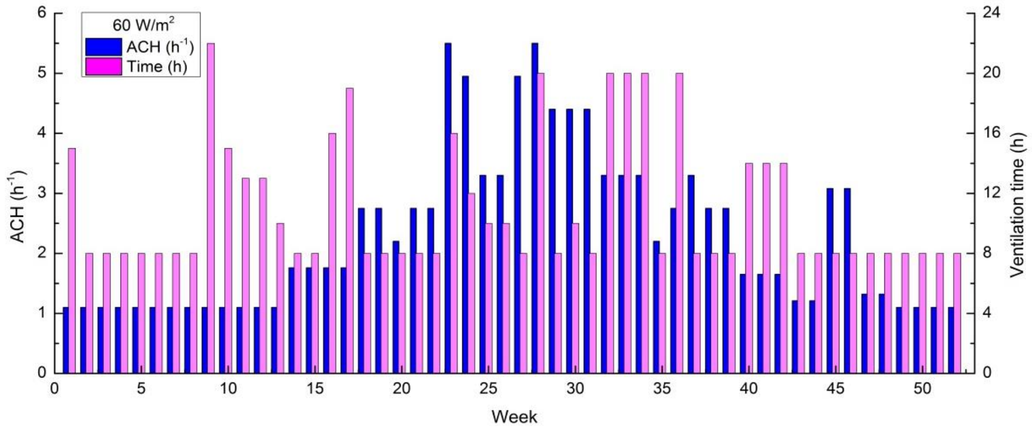
(g) Internal heat load-45 W/m^2



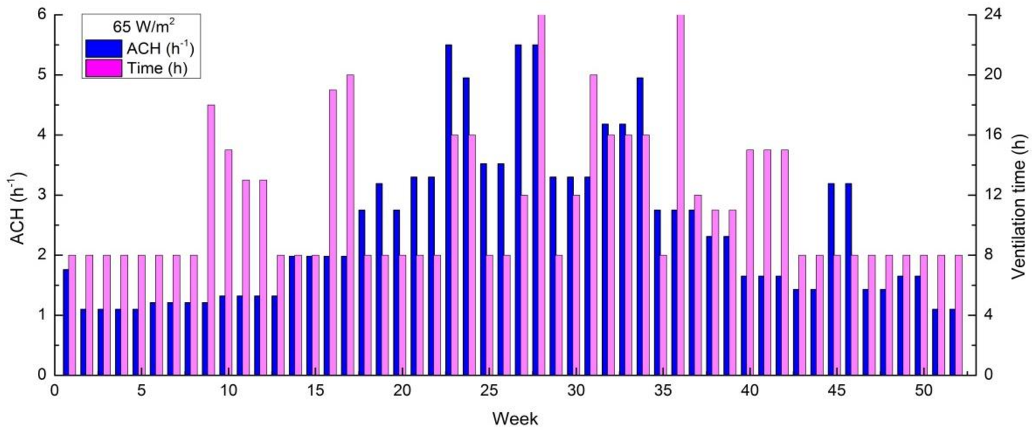
(h) Internal heat load-50 W/m^2



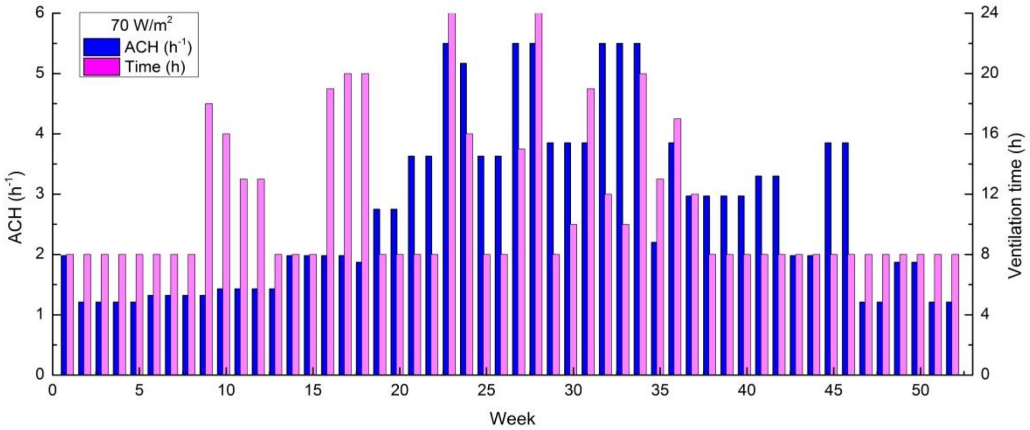
(i) Internal heat load-55 W/m^2



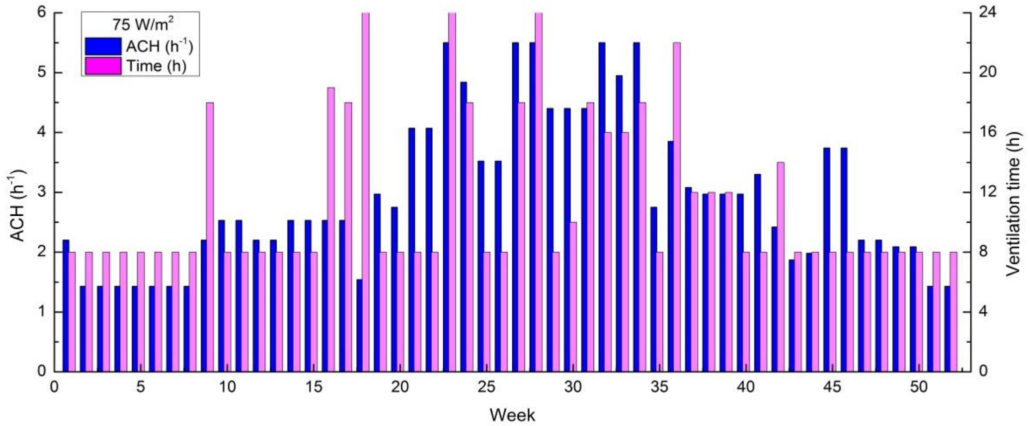
(j) Internal heat load-60 W/m^2



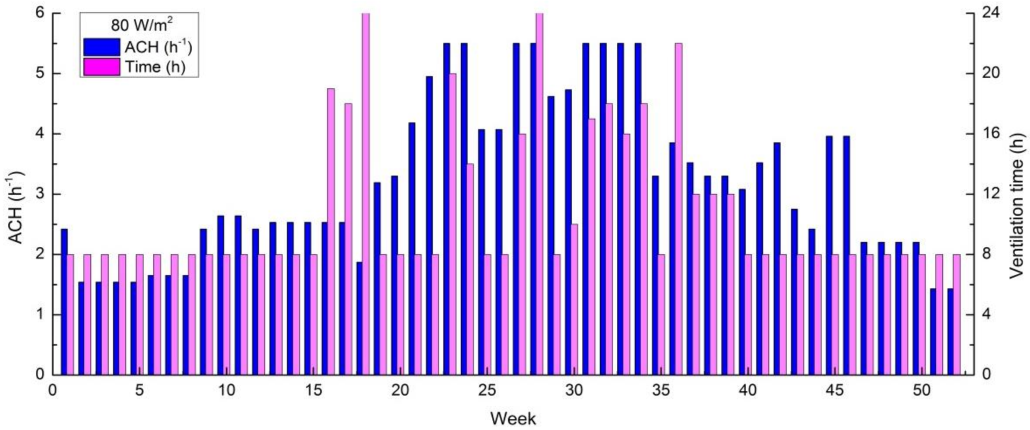
(k) Internal heat load-65 W/m^2



(l) Internal heat load-70 W/m^2



(m) Internal heat load-75 W/m^2



(n) Internal heat load-80 W/m^2

Figure 15 Ventilation time and air change rate (ACH) in Case 4

6. Results for classroom

In the typical classroom, the internal heat load varies at the range of 60-70 W/m^2. In order to reduce the calculation work and cover this heat load range, internal heat load level from 50 W/m^2 to 80 W/m^2 are evaluated.

6.1 Primary energy use

The system factors and primary energy conversion factors are defined the same as that in Section 5.

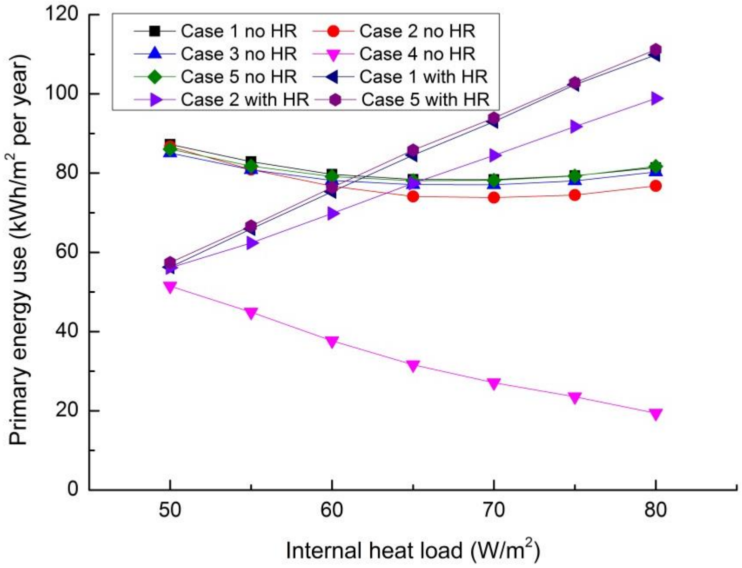


Figure 16 Primary energy use of whole year simulation

Figure 16 shows the primary energy use for the five cases studied. Due to the utilization of natural ventilation all the year round, the primary energy use of the new solution nearly linearly decreases with the internal heat load. On the contrary, the other 4 cases without HR have almost the same pattern, reaching the minimum primary energy use at the internal heat load of appropriately 65 W/m^2. However, for cases with HR, the primary energy use linearly increases with the internal heat load. Compared with the other 4 cases, the new solution has less primary energy use under all internal heat loads, which shows that the new solution has very good energy saving potential for classroom. Moreover, the larger the internal heat load is, the higher energy saving potential of the new solution is.

For the typical classroom, the internal heat load varies at the range of 60-70 W/m^2, corresponding to the energy saving potential of 52.0%-64.7% compared to cases without HR and 49.0%-70.0% compared to cases with HR.

6.2 Annual heating and cooling need

Figure 17 depicts the pattern of annual heating and cooling need for the five cases studied. The heating needs of all cases without HR have the same decreasing trend. The heating need of Case 4 is always larger than that of the others, which is attributed to the influence of ceiling panel on the heat transfer between the plenum and the room space. While 3 cases with HR almost do not have heating need under all internal heat loads.

For the cooling need, the other four cases without HR have the same fast increasing pattern with the increase of internal heat load, and cases with HR have higher cooling need. While for Case 4, as a result of various natural ventilation rate used for different internal heat load levels, the cooling need keeps at a low level.

Since the internal heat load in the typical classroom varies at the range of 60-70 W/m^2, this means there is high cooling energy saving potential but a little bit higher heating need using the new solution.

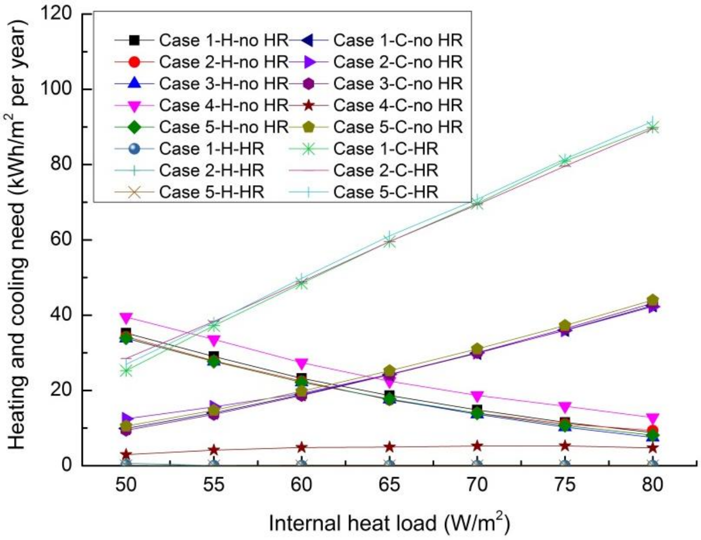


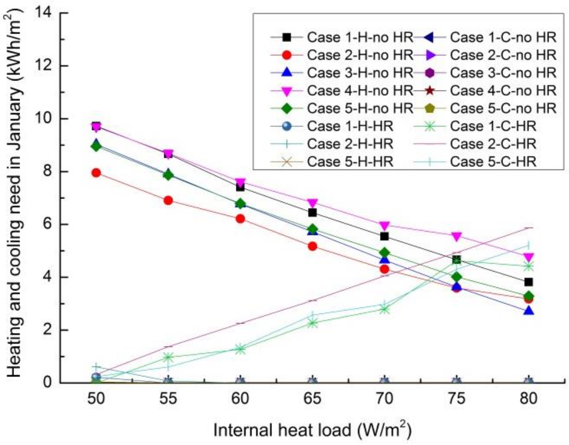
Figure 17 Heating and cooling need of whole year simulation

6.3 Monthly heating and cooling need

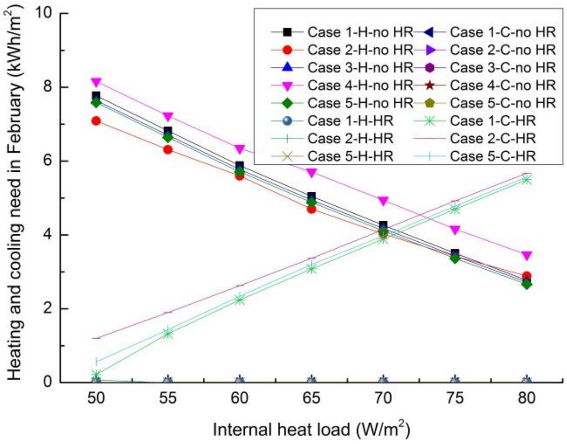
In order to further study the duration of energy saving for the classroom, monthly heating and cooling needs are illustrated in Figure 18. From these figures it can be seen that for the new solution there is no cooling need in winter seasons and transitional seasons, cooling need only occurs in summer seasons- June, July and August. While for the other four cases without HR, cooling need exists in winter seasons- March, April, October and November, and cooling need exists in the whole year for cases with HR.

For the heating need, the new solution has a higher value than the others in the winter seasons, the season is the influence of ceiling panel. But no heating need exists in summer seasons because of high internal heat loads and only very small heating need occurs in May for all cases at low internal heat load level.

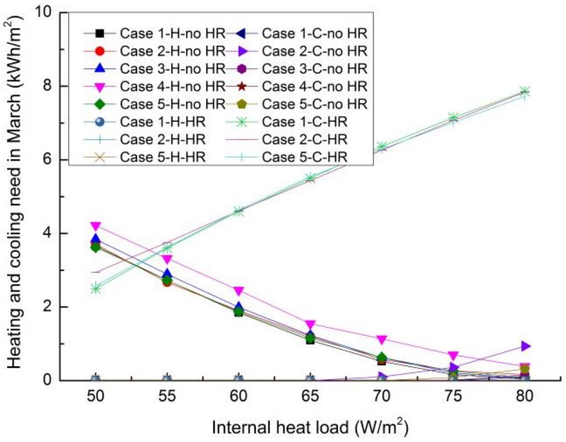
For the typical classroom with internal heat load varying at the range of 60-70 W/m^2, the energy saving of cooling in winter seasons occurs in April, October, and November. Of course, the energy saving of cooling in summer seasons and transitional seasons is obvious.



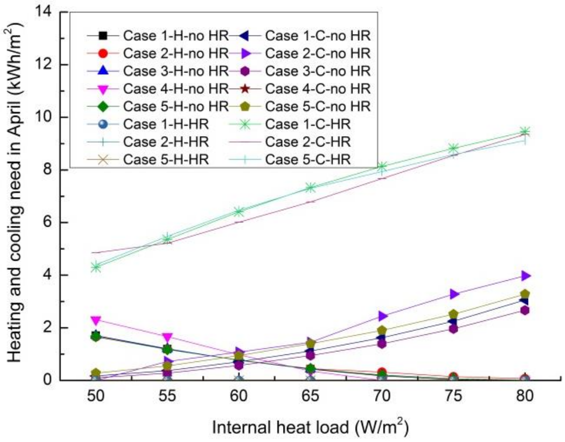
(a) Heating and cooling need in January



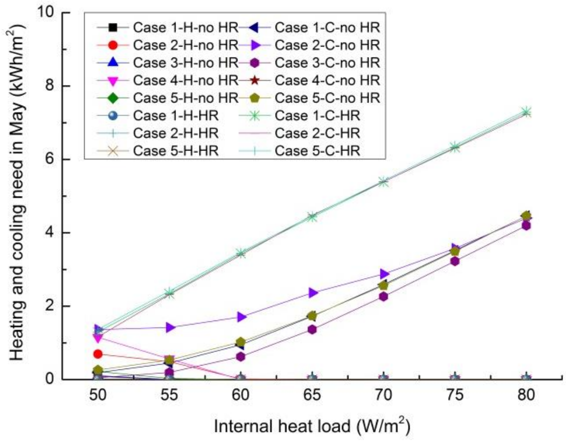
(b) Heating and cooling need in February



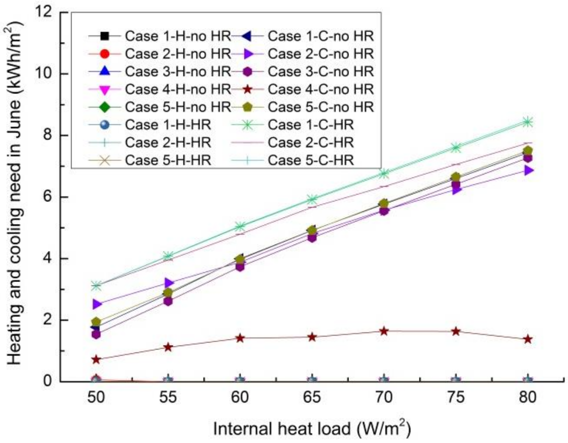
(c) Heating and cooling need in March



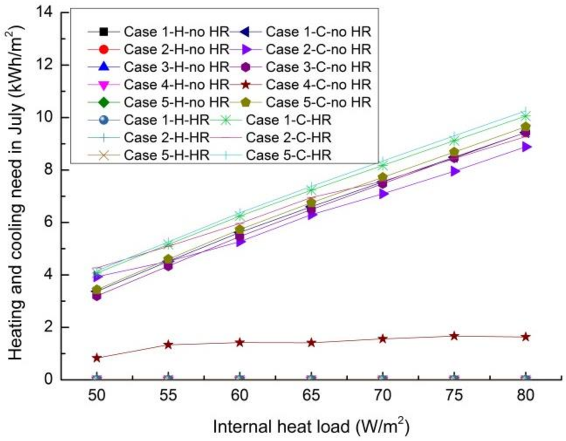
(d) Heating and cooling need in April



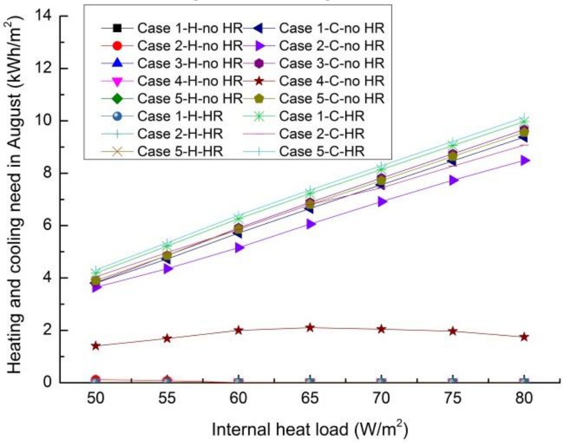
(e) Heating and cooling need in May



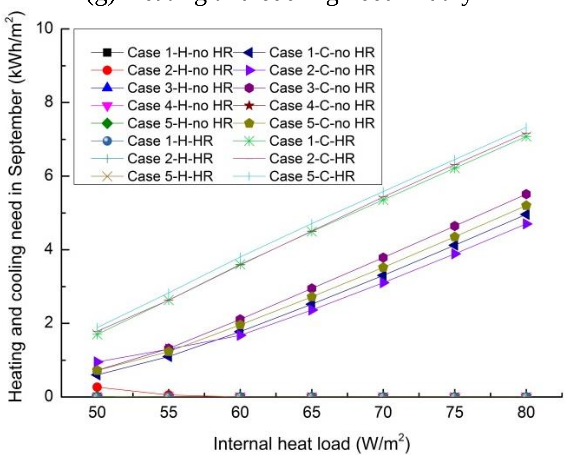
(f) Heating and cooling need in June



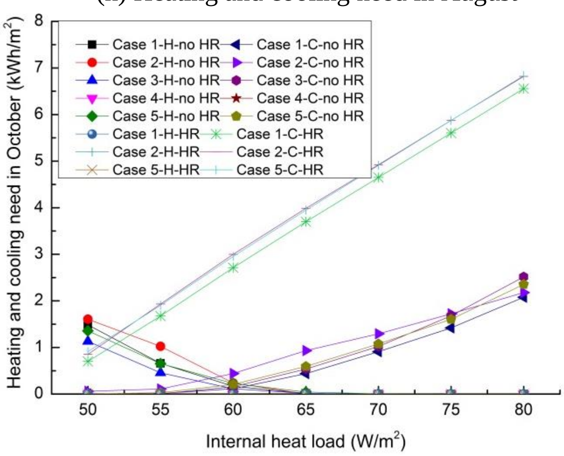
(g) Heating and cooling need in July



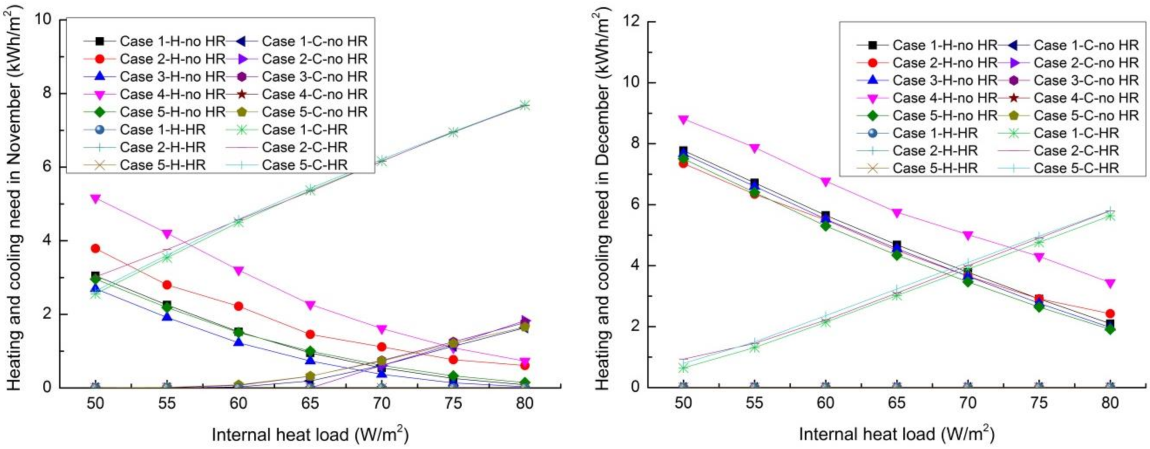
(h) Heating and cooling need in August



(i) Heating and cooling need in September



(j) Heating and cooling need in October

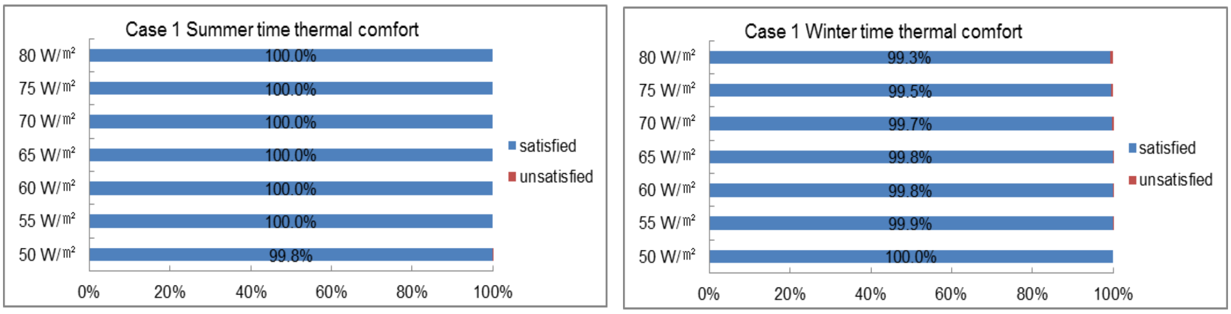


(k) Heating and cooling need in November (l) Heating and cooling need in December

Figure 18 Monthly heating and cooling need

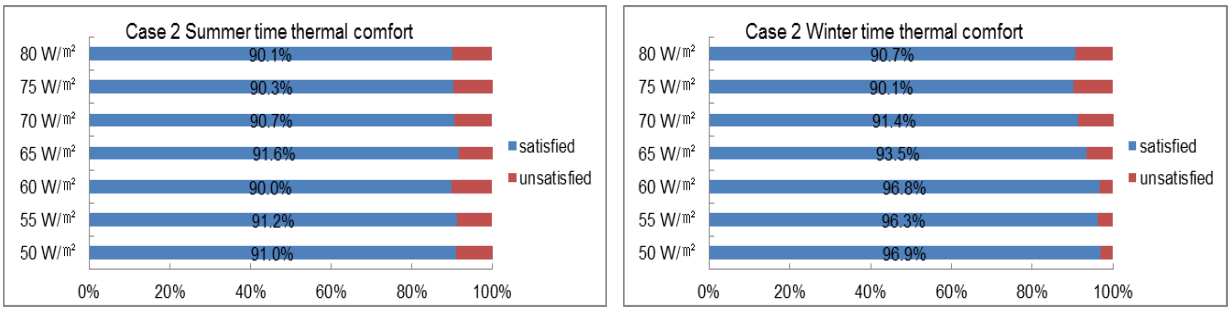
6.4 Thermal comfort evaluation

Figure 19-Figure 26 list the thermal comfort PI for all cases in summer time and winter time. From the thermal comfort analysis, it can be deduced that the thermal comfort level is identical among different systems because the PI of category II is always greater than 90%. The PI of category II for the radiant systems (Case 2 and Case 4) is smaller than that for the other air-based systems, which can be attributed to the complicated control of TABS.



(a) (b)

Figure 19 Thermal comfort PI for Case 1: (a) summer and (b) winter

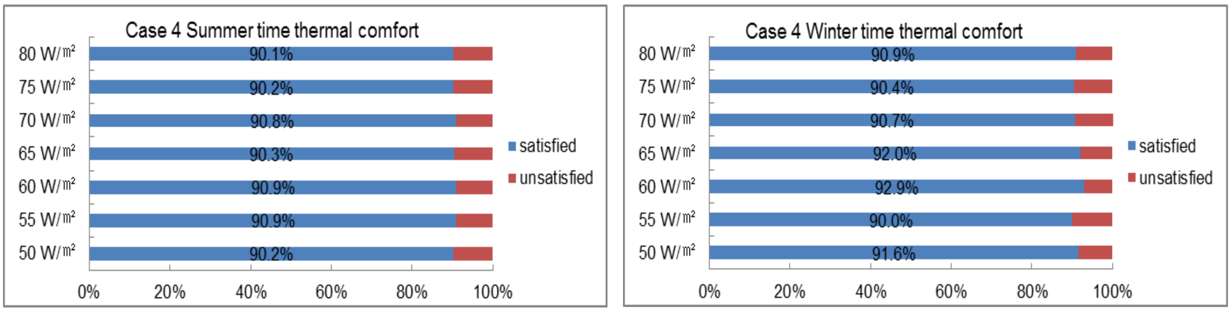


(a) (b)

Figure 20 Thermal comfort PI for Case 2: (a) summer and (b) winter

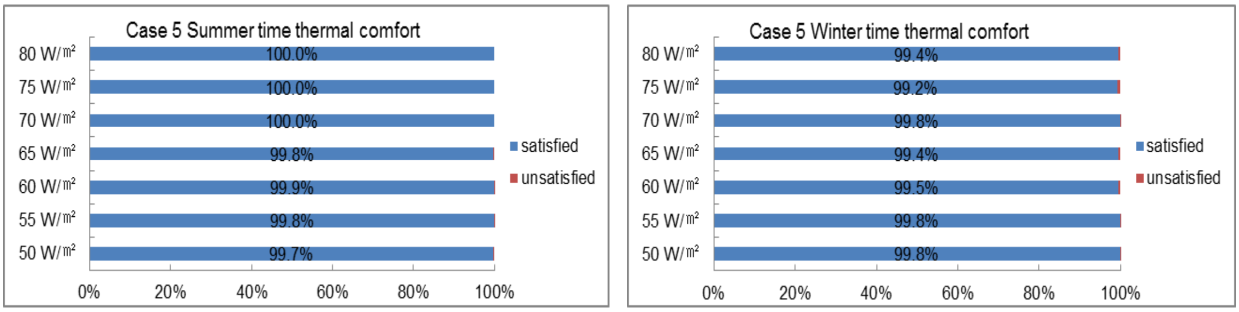
(a) (b)

Figure 21 Thermal comfort PI for Case 3: (a) summer and (b) winter



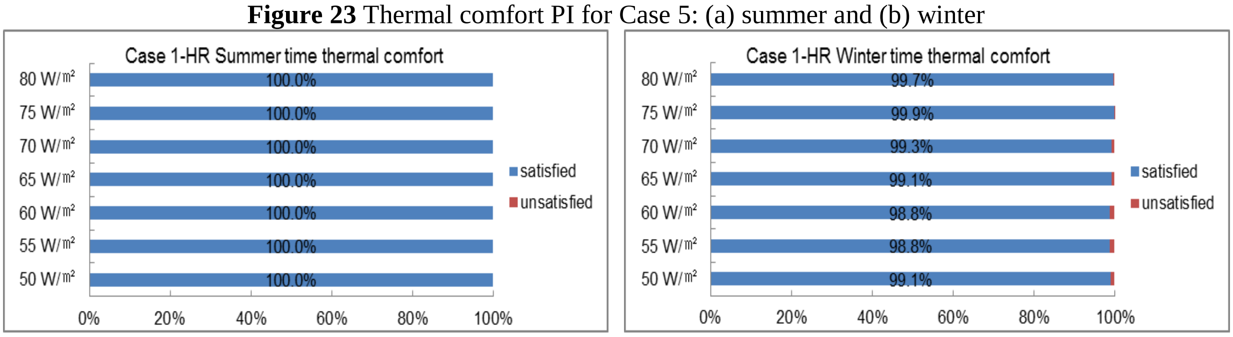
(a) (b)

Figure 22 Thermal comfort PI for Case 4: (a) summer and (b) winter



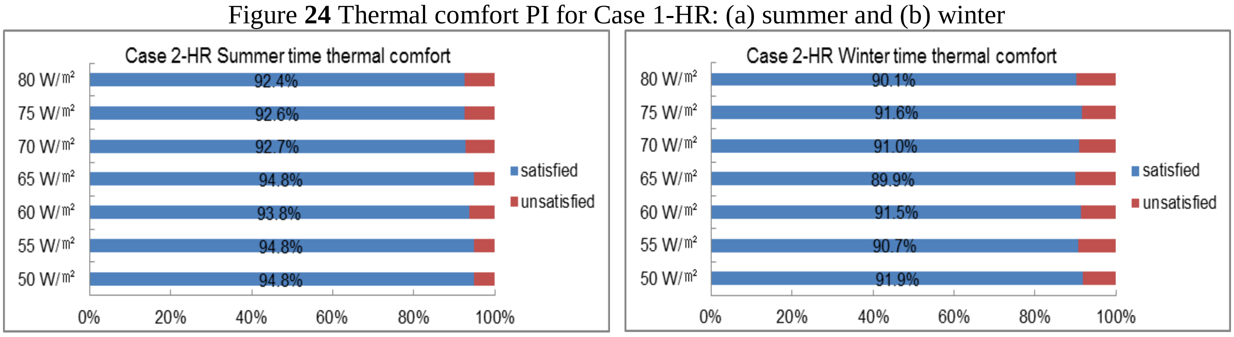
(a) (b)

Figure 23 Thermal comfort PI for Case 5: (a) summer and (b) winter



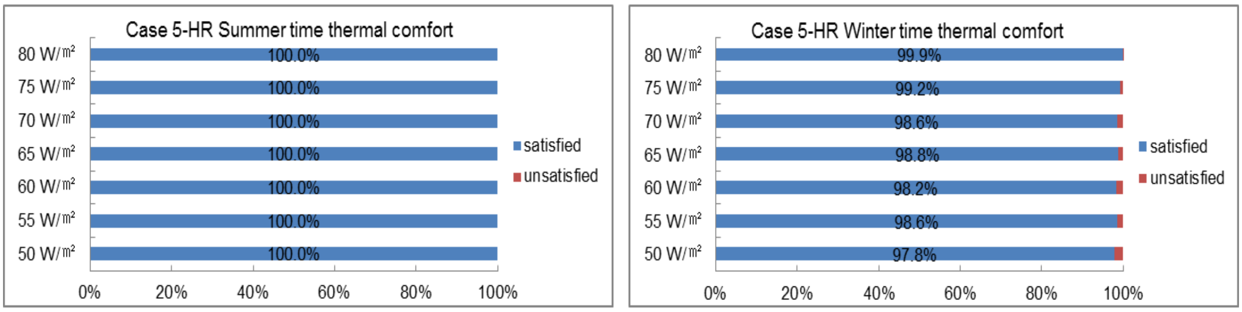
(a) (b)

Figure **24** Thermal comfort PI for Case 1-HR: (a) summer and (b) winter



(a) (b)

Figure **25** Thermal comfort PI for Case 2-HR: (a) summer and (b) winter

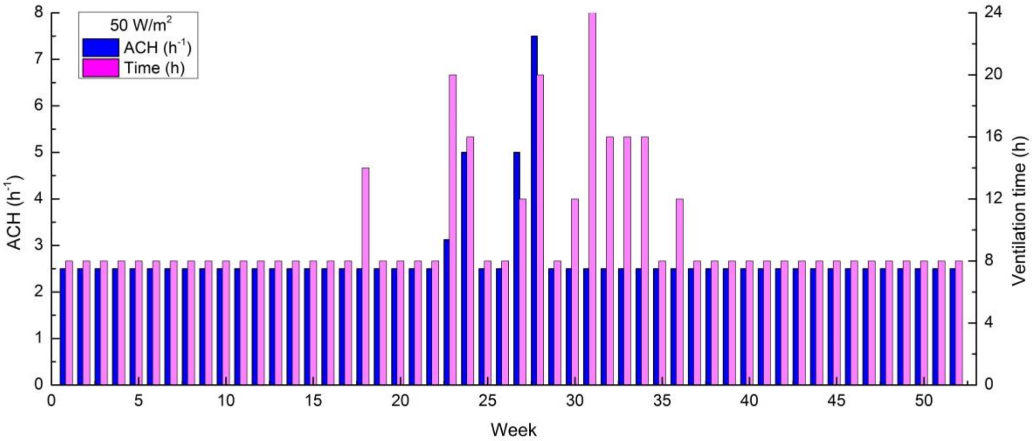


(a) (b)

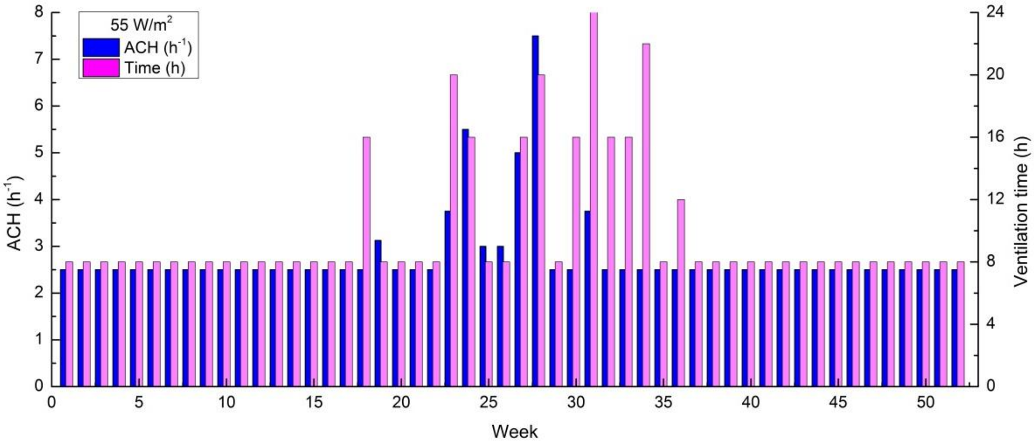
Figure **26** Thermal comfort PI for Case 5-HR: (a) summer and (b) winter

6.5 Ventilation variables in Case 4

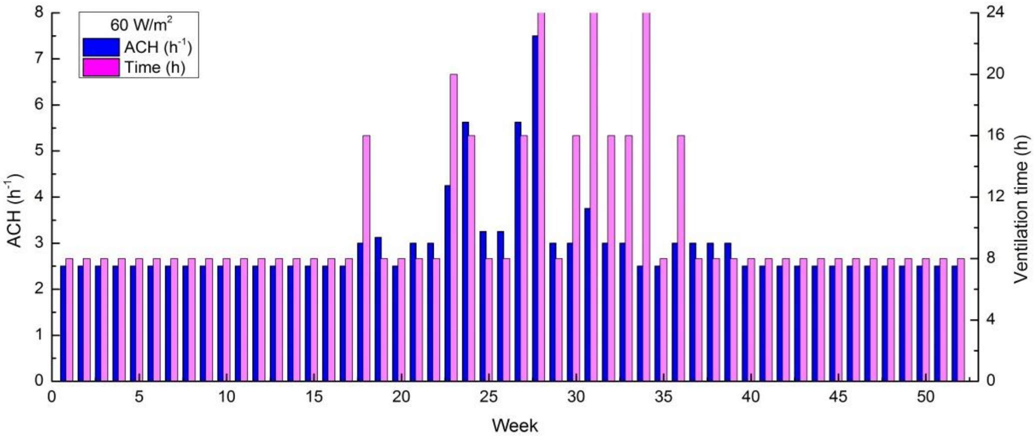
The dynamic control of the ventilation used in Case 4 is based on each week, and Figure 27 (a)-(g) show the average daily ventilation rate and ventilation time in each week under different internal heat loads. With the increase of internal heat load, ventilation rate and ventilation time increase fast in summer seasons and smoothly in the transitional seasons and winter seasons. Generally, summer seasons need higher ventilation rate for the cooling, while in winter seasons only very small ventilation rate is enough for the cooling due to the large cooling potential of cold outside air.



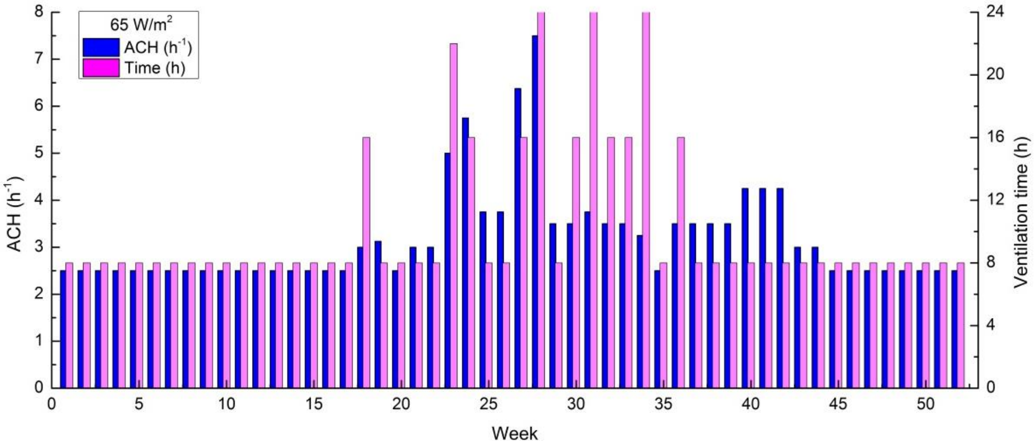
(a) Internal heat load-50 W/m^2



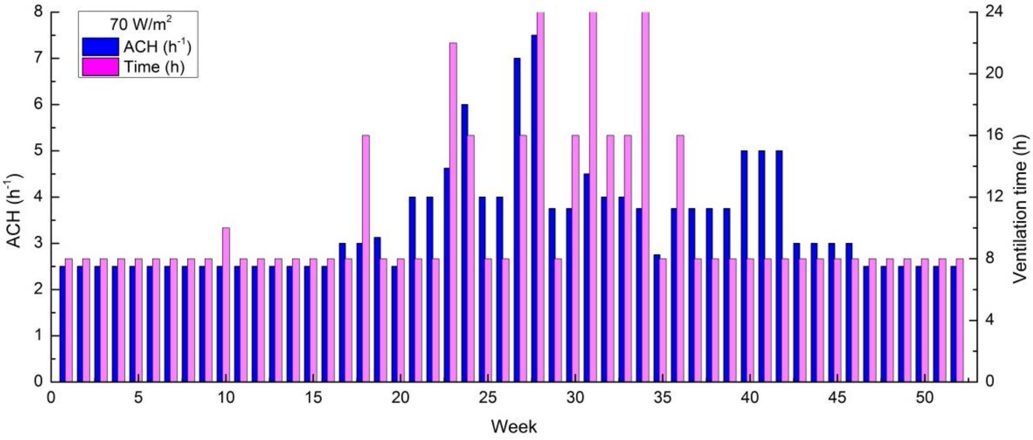
(b) Internal heat load-55 W/m^2



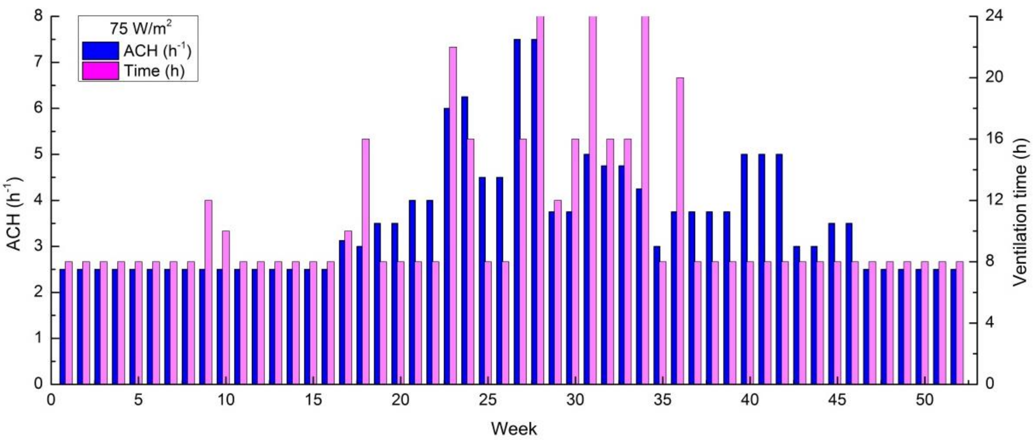
(c) Internal heat load-60 W/m^2



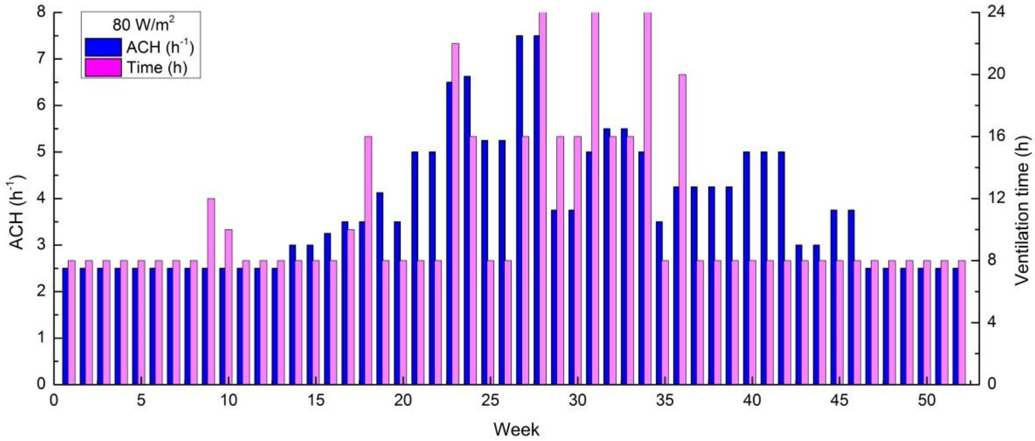
(d) Internal heat load-65 W/m^2



(e) Internal heat load-70 W/m^2



(f) Internal heat load-75 W/m^2



(g) Internal heat load-80 W/m^2

Figure 27 Ventilation time and air change rate (ACH) in Case 4

7. Discussions and Conclusions

As buildings in future may become well-insulated and highly-airtight, there will be an increasing cooling need not only in summer but also in winter. In order to reduce the building energy use, the interest of using natural ventilation all the year round has arisen as a result of the huge cooling potential of cold outdoor air. Based on this idea, the project "Natural cooling and Ventilation through Diffuse Ceiling Supply and Thermally Activated Building Constructions" proposes a new system solution for cooling and ventilation in office buildings. In this new solution, cold outside air can be used to cool the building even in winter without any risk of draught because of the help of diffuse ceiling panel, which significantly saves the energy use for mechanical cooling. Meanwhile, the application of TABS largely improves the thermal comfort in the building.

In this report, the energy performances of a typical office room and a typical classroom using this new system solution and the other four types of HVAC systems are evaluated and compared. The following conclusions can be obtained:

(1) The primary energy use comparison shows that the new solution has less primary energy use than that of other cases under certain internal heat loads, and the energy saving potential of the new solution increases with the increase of internal heat load. For a typical office room or a typical classroom, this energy saving potential can reach up to 50%.
(2) The analysis of monthly heating and cooling need shows that there is a cooling need for the new solution used in the office and the classroom only in the summer seasons including June, July and August. While in the other four cases there is a cooling need even in cold winter seasons, so mechanical cooling have to be used. For the heating need, all cases have nearly the same heating need in summer seasons and transitional seasons. However, the new solution has a higher heating need in the winter seasons, which can be attributed to the large influence of diffuse ceiling panel on the heat transfer of TABS and room space.
(3) The study of ventilation parameters in the new solution shows that the required ventilation rate and ventilation time increase with the internal heat load, and only small amount of natural ventilation rate is enough for the cooling in winter seasons. However, in the extreme hot summer, the cooling potential of natural ventilation is limited and TABS should be activated to supply the supplementary cooling.

Overall, the new system solution has large energy saving potential compared with other systems once it is properly designed and used. However, some problems still need to be further studied. The first is the maximum available natural ventilation rate, which is largely depending on factors as the outside wind pressure, the inlet configuration, pressure drop of diffuse ceiling panel, and so on. It is critical to evaluate this maximum in the design stage. Secondly, in the simulation, it is obvious that the diffuse ceiling panel reduces the heat transferred between the concrete ceiling and room space due to the weakened radiative heat transfer. But the ventilation in the plenum in fact increases the convective heat transfer. Thus, this effect should be investigated in the future experiments. In addition, the dynamic control of TABS and natural ventilation is also very important. Both TABS and natural ventilation can eliminate the internal heat loads, and an optimal combination of these two systems will lead to the least energy use.

References

CEN. 2007. Standard EN 15251. Indoor environment input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Brussels.

CEN. 2007. Standard EN ISO 13786. Thermal performance of building components- Dynamic thermal characteristics- Calculation method. Brussels.

CEN. 2008. Standard EN ISO 13790. Energy performance of buildings – Calculation of energy use for space heating and cooling. Brussels.

ISO. 2005. Standard EN ISO 7730. Ergonomics of the thermal environment-Analytical determination and interpretation of the thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Switzerland.

J. Le Dreau, P. Heiselberg. 2011. Potential use of radiant walls to transfer energy between two building zones, In: Proceedings of ISHVAC 2011, Shang Hai, China.

F. Winther, P. Heiselberg and R. Jensen. 2010. Intelligent glazed facades for fulfillment of future energy regulations, In: 3rd Nordic Passive House Conference, Aalborg, Denmark.

SBI.2013. SBi-anvisning 230. Anvisning om Bygningsreglement 2010. Denmark.

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