SUMMER COMFORT ANALYSIS

As in chapter 7, the aim of chapter 8 is to provide some examples of analysis that can be performed by the whole building model as defined in chapters 2 to 6.

The building model can be used to evaluate the performance of different ventilation systems regarding *summer comfort*. Fanger's *Predicted Percentage of Dissatisfied* people can be used as comfort indicator (chapter 1, §1.1.2). Optimal comfort is reached when PPD equals 5%.

Summer comfort can be analysed for houses (§ 8.1) or offices (§ 8.2). It can be related to *average summer* conditions or to *hot wave* conditions. Average summer data can be those related to Saint Hubert, Belgium: the period of time when the maximum outdoor temperature is reached ranges from the 27th June to the 15th July. Hot wave can the one recorded in Uccle, Belgium in summer 1976. The period of time when the maximum outdoor temperature is reached ranges from the 24th June to the 18th July

Different strategies regarding summer comfort improvement can be tested by the model: the use of controlled blinds, the use of free cooling by opening windows, the use of free cooling by creating an indoor stack effect with opened windows and doors or the use of fan powered "free" cooling (the latter strategy is not "free" as fans consume electricity). Fans electricity consumptions can be evaluated by the model as well as cooling energy demands and consumptions when an air conditioning system is in use.

8.1. House summer comfort analysis

The natural ventilation model described on fig 6.3 (completed by fig. 6.2) can be applied to Esneux house (fig. 8.1, see also annex 2, §1). The model is able to perform summer comfort analysis for average summer conditions as well as for summer hot wave conditions. The model also allows testing different improvement strategies including free cooling and controlled blinds.

The natural ventilation model can be combined to a simplified dynamic two zones model (chapter 5, fig. 5.33) in order to perform simulations on a quarter of hour basis. Air flow through infiltration leaks can equal 12 $m^3/h.m^2$ of the external wall area for a 50 *Pa* pressure difference. Controlled Supply Orifices and Controlled Exhaust Orifices can be sized to reach 3.6 $m^3/h.m^2$ of floor area for a pressure difference of 2 *Pa*. Transfer Orifice between zone 1 and the staircase can correspond to two doors in parallel, both provided with a 1 cm aperture beneath.

Occupancy profiles are displayed in annex 8 fig. A 8.1.

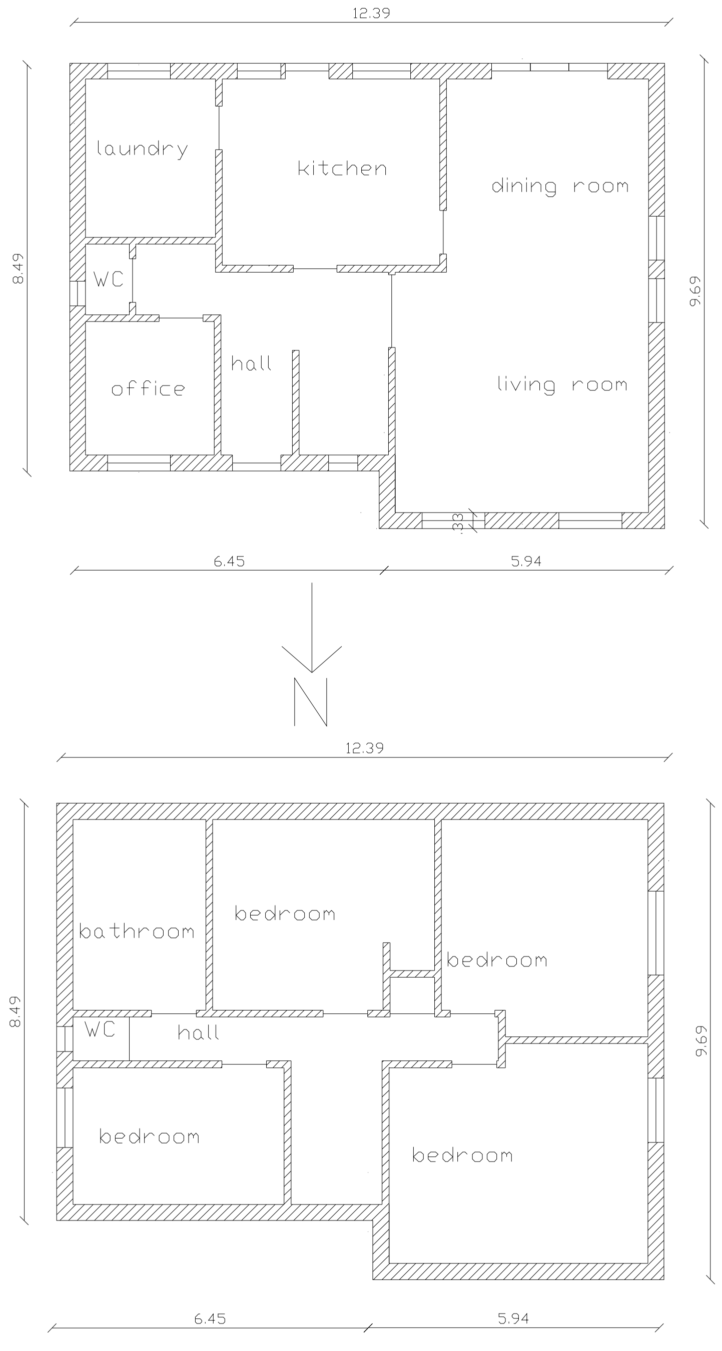


Fig. 8.1: Esneux house plans

8.1.1. Comfort improvement strategies

Two strategies can be tested by the model to improve summer comfort: controlled *external blinds* and free cooling by *opening the windows*.

External blinds can be controlled by a solar intensity probe on each facade and by a minimum zone indoor temperature. External blinds can close as soon as the total solar intensity reaching the window exceeds 180 *W/m²*, provided that the indoor temperature exceeds 22 °C:

$$I_t > 180\ W/m^2\ and\ \ t_{in} > 22°C \qquad (8.1)$$

Free cooling can be performed by opening the windows at 20 % of their area. A window stack effect model can complete the house ventilation model for that purpose (fig. 6.2). Free cooling conditions can be defined as:

$$t_{in} > 25°C\ and\ 19°C \leq t_{out} \leq t_{in} \qquad (8.2)$$

The conditions (8.2) are also used to by-pass the heat recovery device when it exists in double flow ventilation systems (D system) provided with both supply and exhaust fans.

8.1.2 Average summer conditions

Simulation can be performed for an average summer. The clothing insulation level can be adapted to the weather by adopting a 0.5 *clo* clothing insulation level (an average clothing insulation level equals 1 *clo*). The *Predicted Percentage of Dissatisfied* (PPD) can be computed during the required comfort hours: during day time for the ground floor, and during night time for the first floor (annex 8, fig. A 8.1). When no strategy is applied to improve comfort, the indoor temperature can reach 30°C in both zones 1 and 2 (ground floor and first level) (fig 8.2). The PPD can reach 34 % in both zones.

A first strategy to improve comfort can be to perform natural free-cooling by opening the windows (at 20 % of their area) when conditions (8.2) occur. The PPD can then be reduced to 11 % in both zones (annex 8, fig. A 8.3). Another strategy can be to close external blinds when conditions (8.1) are reached. The PPD can then reach 9 % in the two zones (annex 8, fig. A 8.5).

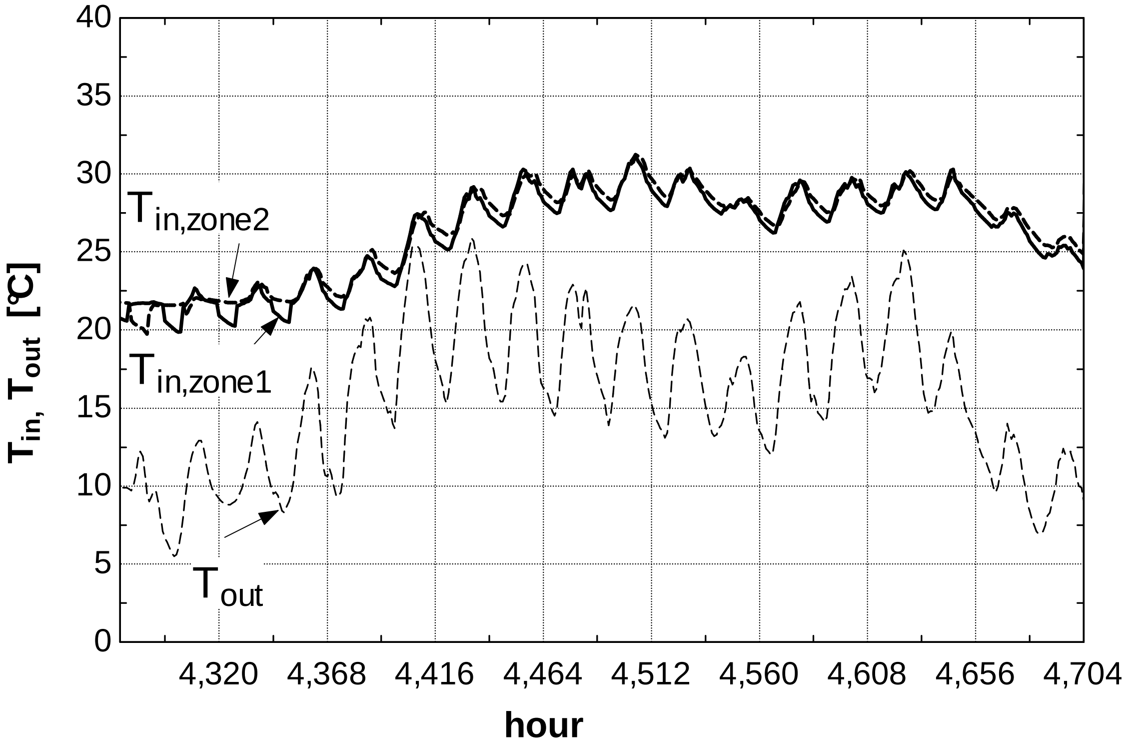
The combination of the two strategies i.e. free-cooling and controlled external blinds can still improve the comfort by decreasing the PPD until 7 % in both zones, which is rather good, reminding that a PPD doesn't fall under a minimum level of 5 %. The indoor temperature remains close to 25°C for the hottest days (fig. 8.2).

8.1.3 Summer hot wave conditions

Esneux house can be submitted to the 1976 hot wave. The clothing level is adapted at 0.5 *clo*. When no strategy is applied to improve comfort, the PPD can reach 94 % in both zones, i.e. ground floor and first level (fig. 8.3). Natural free-cooling reduces the PPD to 42 % in both zones (annex 8, fig A 8.7). The use of controlled external blinds, without free-cooling, reduces the PPD to 68 % in zone 1 and to 72 % in zone 2. It is thus less efficient than free cooling strategy (annex 8, fig A 8.8).

The combination of natural free-cooling and controlled external blinds reduces the PPD to 22% in zone 1 and 26 % in zone 2 (fig. 8.3).

Apart from those no energy consuming strategies, room air conditioners can be used to reach comfort. The model can compute the *cooling demand* required to fulfill the comfort without using blinds, or in association with them: the cooling demand is reduced by 38 % when using controlled blinds, decreasing from an average of 8 W/m^3 to 5 W/m^3 of conditioned space, over the hot wave time period (annex 8, fig. A 8.10). The average PPD then equals 5 %, which is the optimal comfort value.



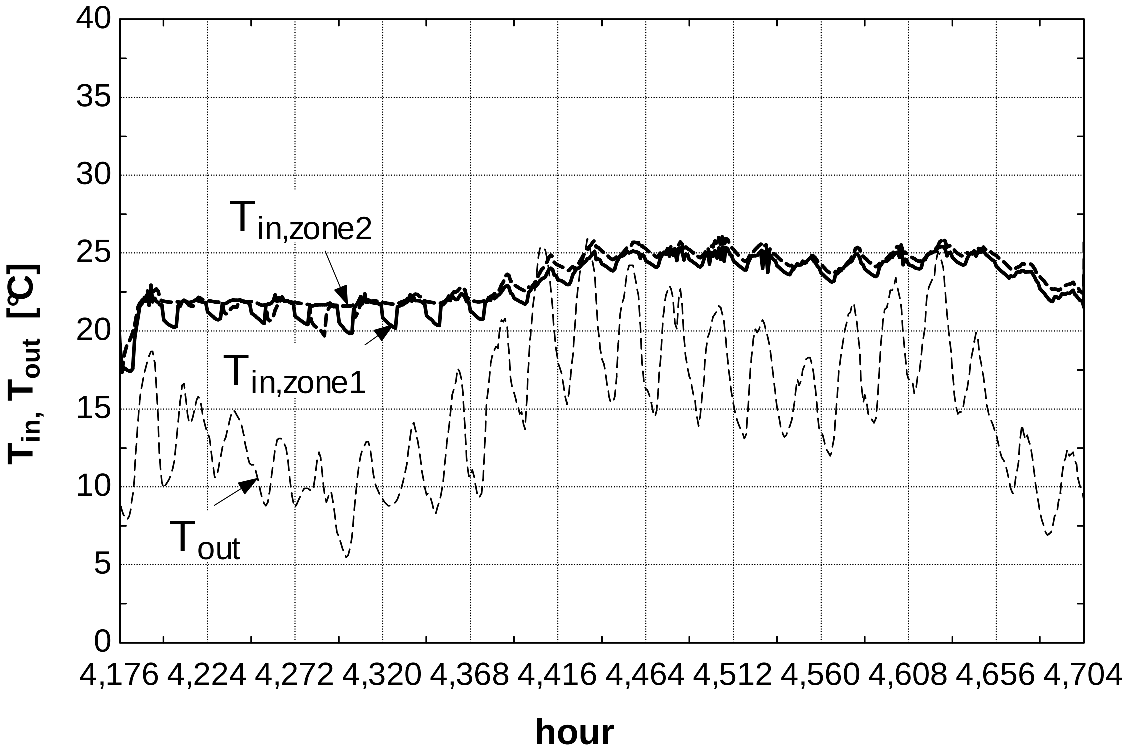
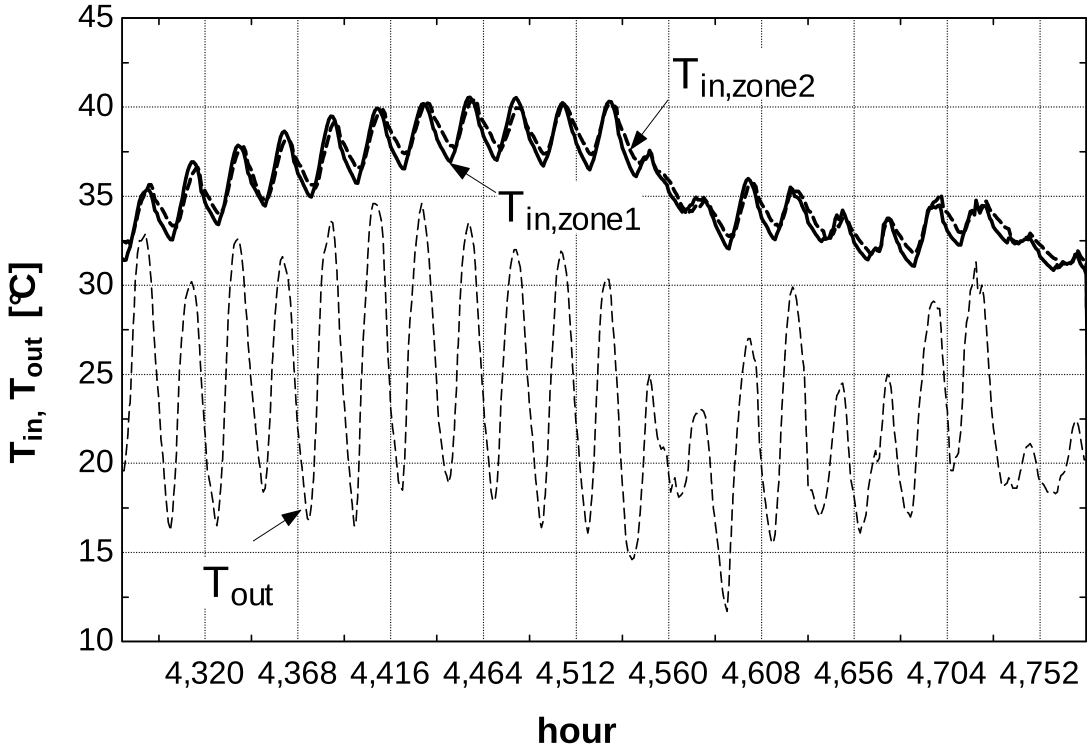


Fig. 8.2: Indoor temperatures computed in both Esneux house zones, with corresponding outdoor temperatures, for a ***mean summer****, without comfort improvement strategies (up) and with controlled external blinds and free cooling by opening windows (down).*



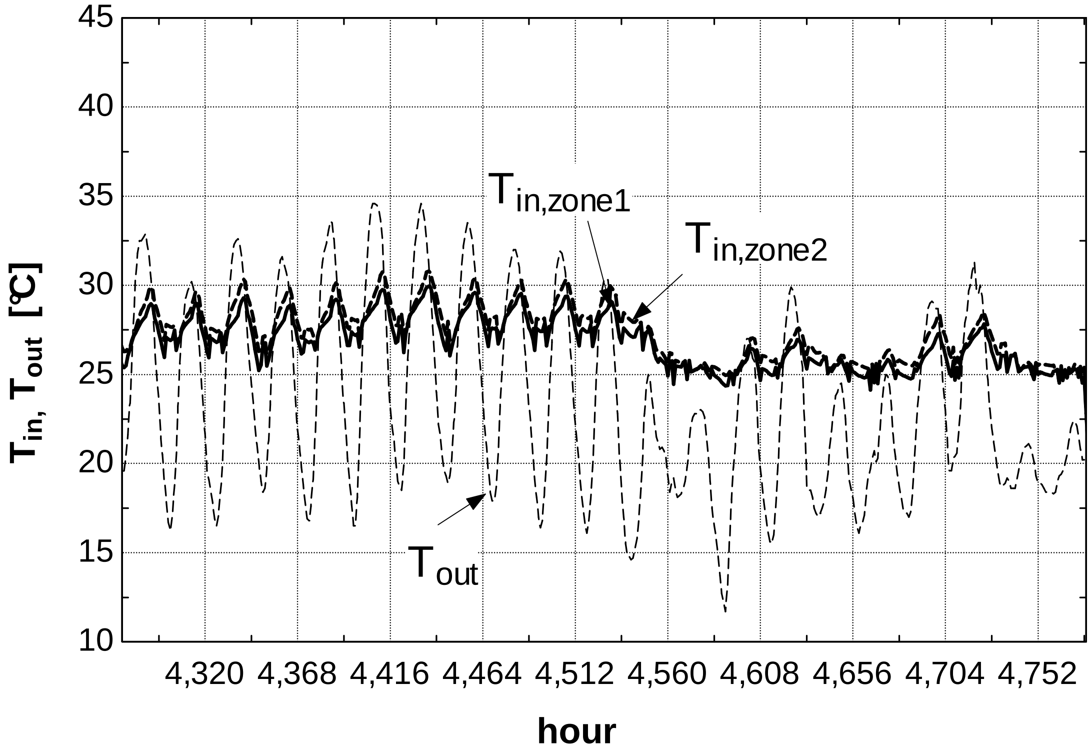


Fig. 8.3 Indoor temperatures computed in both Esneux house zones, with corresponding outdoor temperatures, for ***1976 summer hot wave****, without comfort improvement strategies (up) and with external blinds and free-cooling by opening windows (down).*

8.2. Office building summer comfort analysis

The office room described in chapter 4 §4.1.3 can be repeated as described in chapter 7 § 7.2.2 to generate a four floors office building. The natural ventilation model defined in chapter 6, fig. 6.5 (completed by fig. 6.2) can be combined to a simplified dynamic five zones model (chapter 5, fig. 5.34) which can be adapted to simulate different natural free cooling strategies.

8.2.1 Natural free cooling strategies

The model can be adapted to simulate the following free cooling strategies (fig 8.4):

- Opening the windows until 10% of their area. This strategy is called *room free-cooling*. The window stack effect is modeled by replacing the K constant of the Controlled Supply Orifices by the K constant of opened window, when free cooling is performed (chapter 6, fig. 6.2).

- Opening the windows and the doors separating offices from the corridor, until 10% of their area. This strategy is called *cross free-cooling*. Door opening is modeled by replacing the K constant of Transfer Orifices by the K constant of opened internal doors, when free cooling is performed (chapter 6, fig. 6.5).

- Opening the windows and the doors and adding the *stack effect* of an opened staircase surmounted by louvers. Opened staircase stack effect is modeled by replacing the K constant of Controlled Exhaust Orifice, by the K constant of opened louvers located above the staircase, when free cooling is performed (chapter 6, fig. 6.5). An area of 6.4 m^2 opened louvers can be considered.

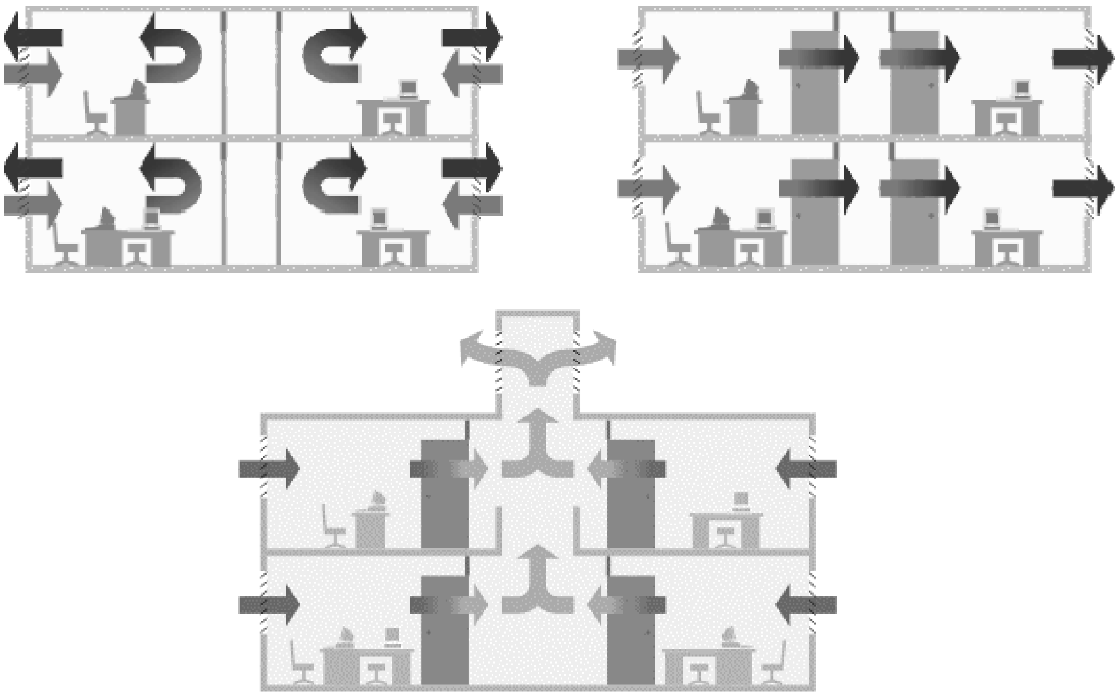


Fig. 8.4 Natural free-cooling through room free-cooling (left), cross free-cooling (right) or stack effect (below))[39].

The office building free cooling conditions can be defined as:

$$\text{Free-cooling starts when } t_{in} > 24°C \text{ and } 15°C \leq t_{out} \leq t_{in}$$
$$\text{Free-cooling stops when } t_{in} < 18°C \text{ or } t_{out} < 15°C \text{ or } t_{out} > t_{in} \qquad (8.3)$$

External blinds can be controlled as described in § 8.1.1.

Three combinations of strategies can be considered: blinds combined with room free-cooling, with cross free-cooling and with stack effect free-cooling (fig 8.4).

8.2.2 Natural free cooling in average summer conditions

The clothing level is supposed to be adapted to the weather i.e. 0.5 *clo*. The *Predicted Percentage of Dissatisfied* (PPD) can be computed during the occupancy hours, i.e. from 8 AM to 6 PM, for the ground floor and fourth floor offices, the fourth floor offices being located under the roof.

When no strategy is applied to improve thermal comfort, the PPD can reach its maximum in East offices: 33 % at ground floor and 41 % at fourth floor (fig 8.5) (see also annex 8, fig. A 8.10). The reason is that South and West facade air supply orifices are mainly wind pressurized, while East facade air supply orifices are depressurized, so that East offices mainly receive warm air from South and West offices, through the corridor.

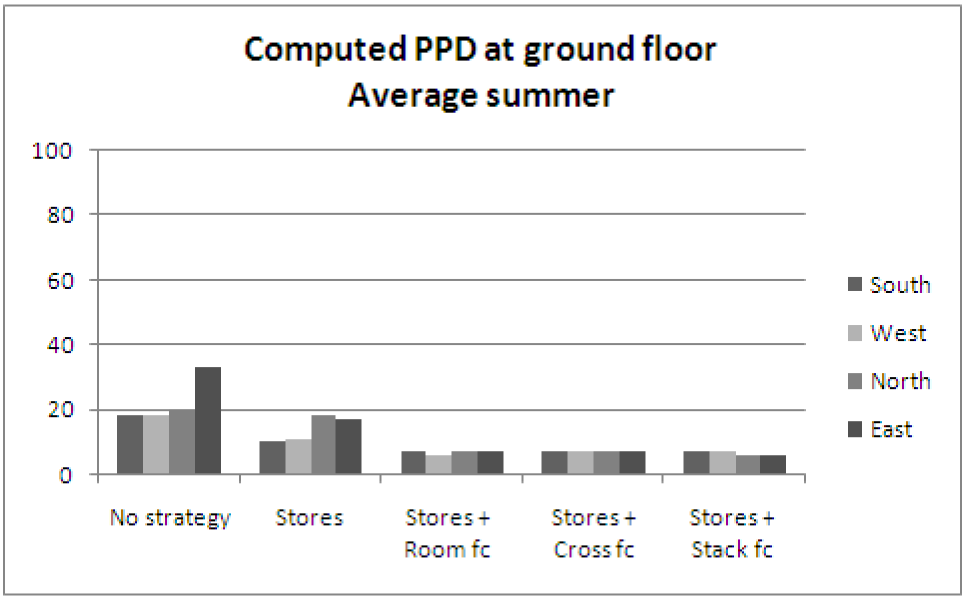
A first strategy to improve thermal comfort can be to use *controlled blinds*. The PPD can be reduced to 17% at ground floor and 21 % at fourth floor in East offices, which means a decrease of about 50%. South orientation can also record 50% decrease at fourth floor, while West can receive about 40% reduction. North orientation can get less benefit from controlled blinds as its decrease is only 25 % at fourth floor and 10% at ground floor (fig 8.5).

A second strategy can be to use natural free-cooling in combination with controlled blinds. Compared to *room free-cooling*, cross free-cooling and stack free-cooling don't improve the comfort significantly (fig 8.5). All those strategies reach a PPD of about 7 % in all offices.

So the model can help to define the best strategy to improve thermal comfort, for average summer conditions in offices: combine *controlled blinds* with *room free-cooling*.

The model shows that controlled blinds improve thermal comfort for all orientations, while free cooling mainly decreases PPD for North and East orientations.

As it can account for both wind effect and stack effect, the ventilation model can highlight the influence of those effects on North and East oriented offices. When no free cooling is performed, those orientations are mainly wind depressurized and receive warm air from South and West zones, but as soon as windows are opened, their fresh air flow rate significantly increases thanks to the stack effect.



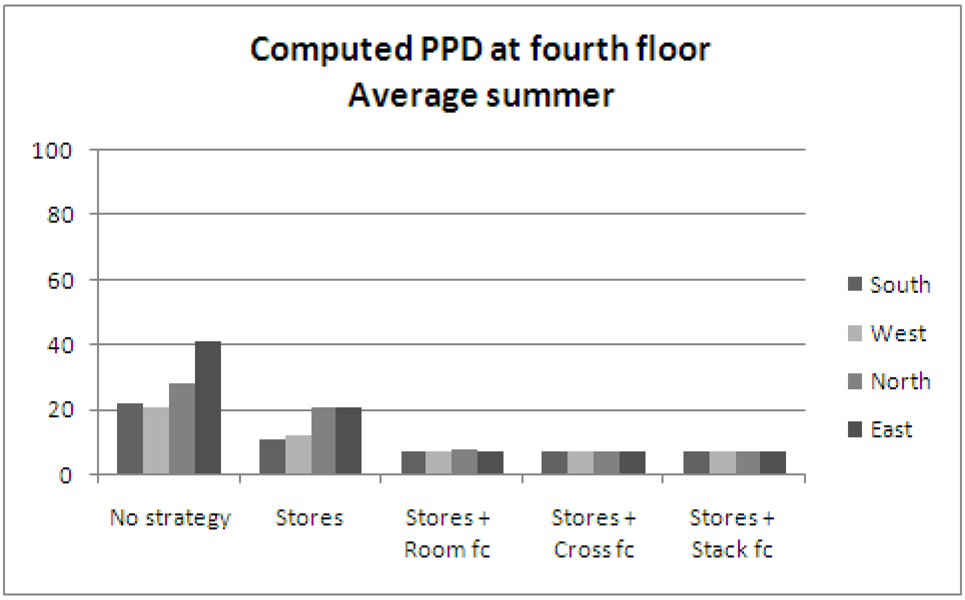
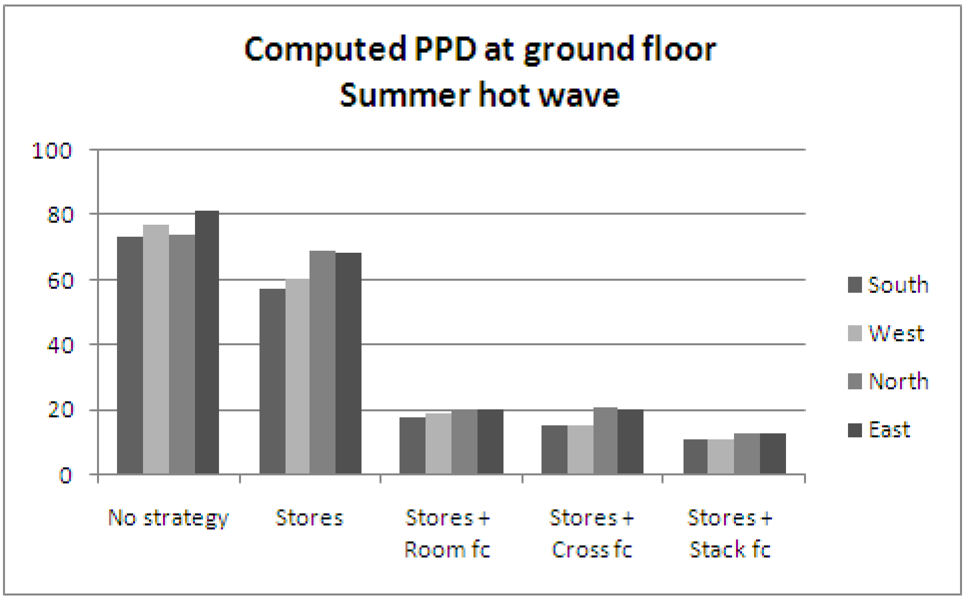


Fig 8.5 Predicted Percentage of Dissatisfied related to different office orientations and to different natural free cooling strategies, for an average summer, at ground floor (up) and at fourth floor (down) of a four levels office building.

8.2.3 Natural free cooling in summer hot wave conditions

The clothing level is supposed to be adapted to the weather i.e. 0.5 *clo*.

The model can evaluate how bad the thermal comfort is when no strategy is applied to improve comfort: in East offices, the PPD can reach 80% at ground floor and 90% at fourth floor (fig. 8.6). *Controlled blinds* respectively reduce those values to 70% and 80%.



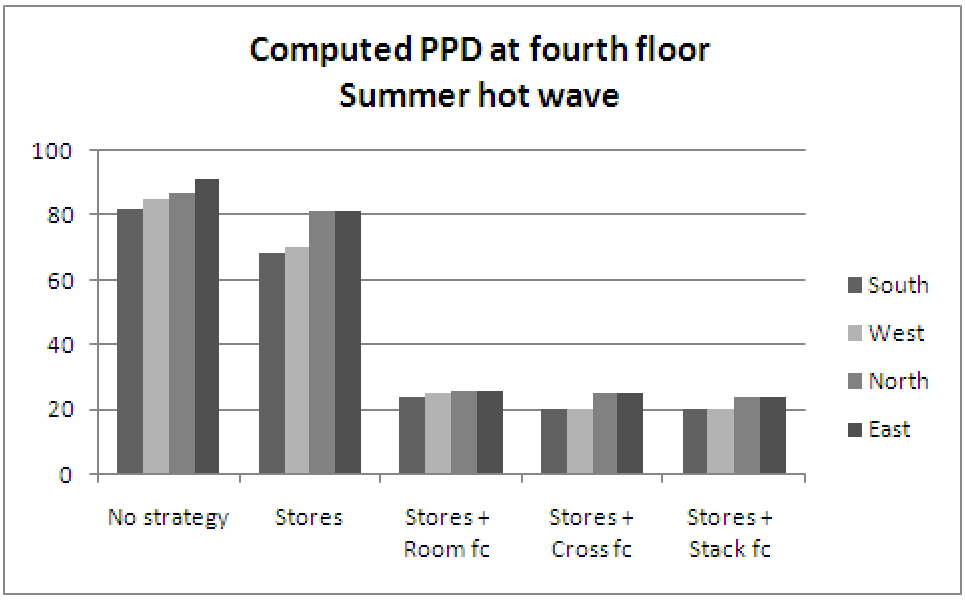


Fig 8.6 Predicted Percentage of Dissatisfied related to different office orientations and to different natural free cooling strategies, for a summer hot wave, at ground floor (up) and at fourth floor (down) of a four levels office building.

The ventilation model can highlight the significant thermal comfort improvement brought by *room free cooling* yielding about 70% decrease in East orientation PPD (fig. 8.6). *Cross free-cooling* still improve comfort a little in wind exposed South and West orientations, while *stack free cooling* is only effective at ground floor.

The model can also provide indoor temperature profiles, illustrating the significant thermal comfort improvement brought by free cooling strategy at ground floor: the indoor temperature curves are getting closer to the mean of the outdoor temperature curve witch is the limit ideally reachable by free-cooling strategy (fig. 8.7).

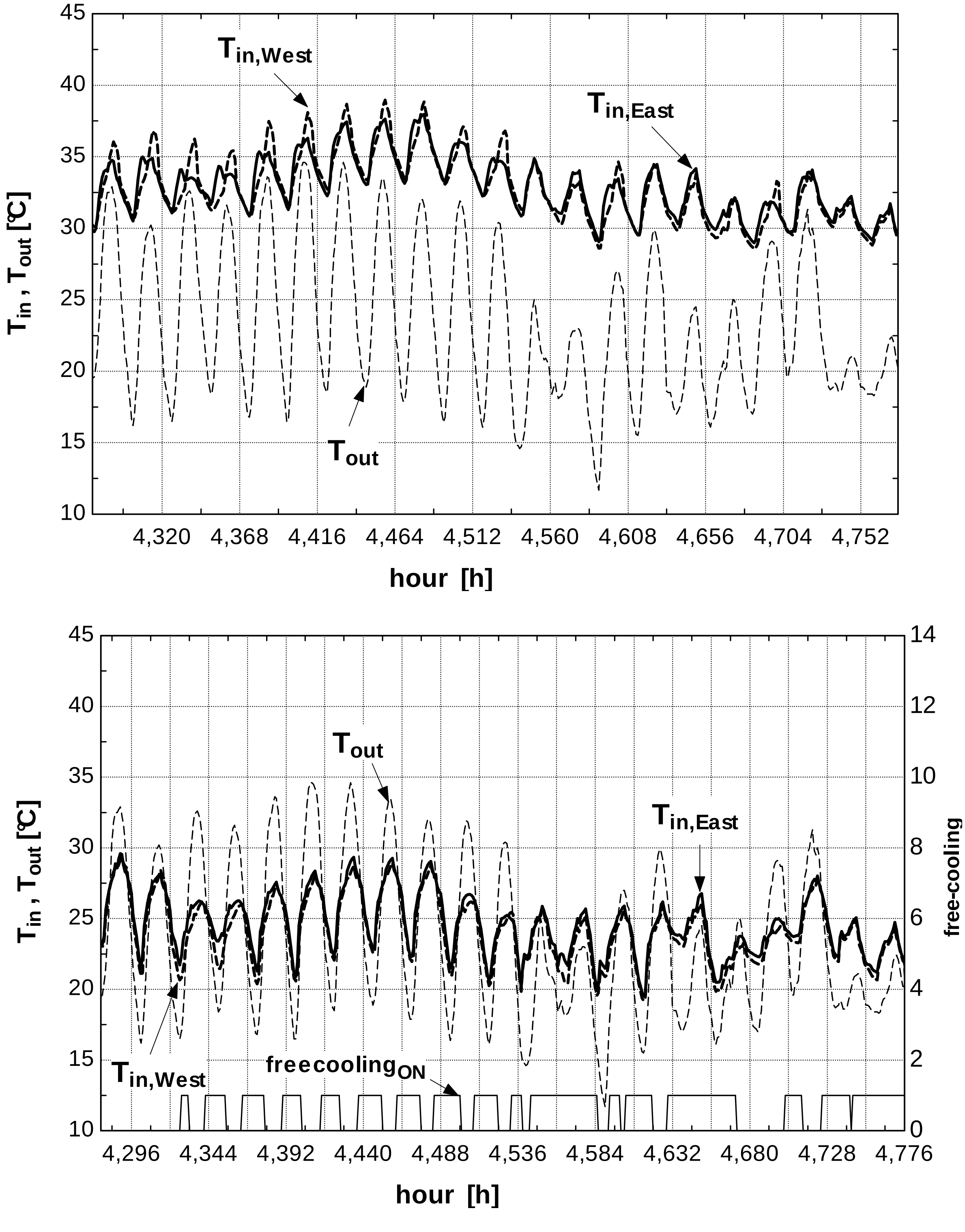


Fig. 8.7 Indoor temperatures computed in the East and West ground floor offices, and corresponding outdoor temperatures, for a summer hot wave, without comfort improvement strategy (up) and with stack free-cooling and controlled blinds (down).

Here again, the model can help to define the advised strategy to improve comfort: combine controlled blinds with any free-cooling strategy, with a preference for stack effect when it is compatible with fire regulations. The PPD can be reduced to a 12% average at ground floor, and 22% at fourth floor.

8.2.4 Fan powered "free" cooling strategies

The model can simulate the following mechanical "free" cooling strategies (fig 8.8):

- Opening windows and doors at 10% of their areas and running a roof exhaust fan (type C system). The exhaust fan is sized for a $0.6\ h^{-1}$ ventilation rate at each floor. The strategy can be performed when the building isn't occupied. During occupancy hours, natural ventilation devices (Controlled Supply Orifices and Transfer Orifices) can be used.

- By running the AHU supply and return fans during the unoccupied hours, with the same rotation speed (type D system).

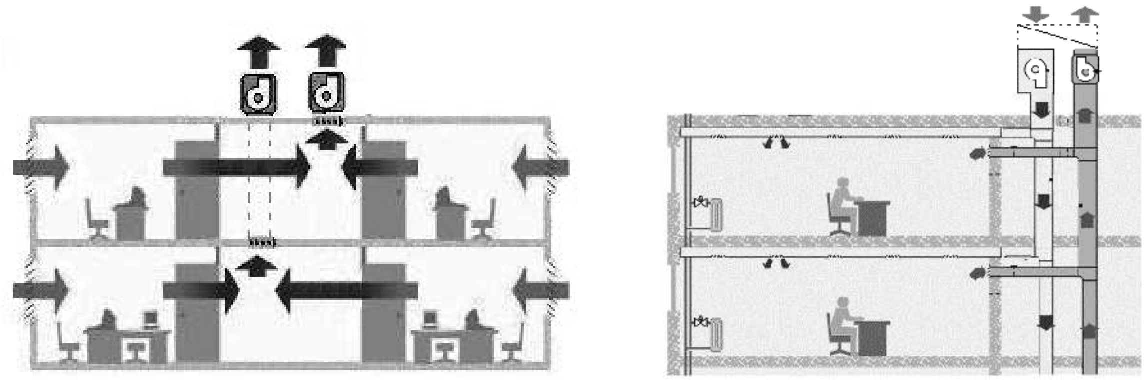


Fig 8.8 Combined natural and mechanical free cooling strategies in office buildings: system C (left) or D (right).

When type C free-cooling is used, the corridor can be directly connected to a specific ventilation shaft at each building floor, through a grid aperture (fig. 6.6). An exhaust fan can be located on the roof to perform free-cooling during unoccupied hours. Each floor is provided with its own free-cooling exhaust fan and ventilation shaft.

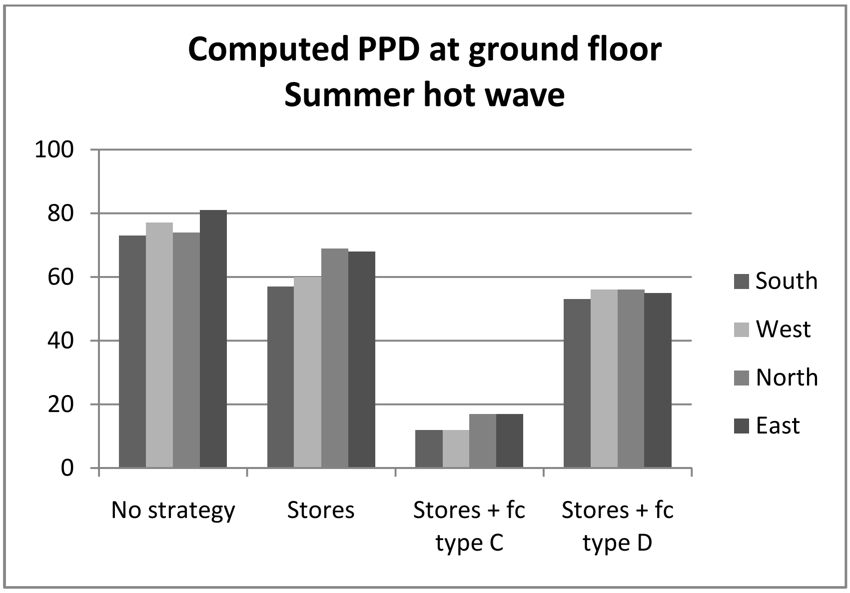
When type D free-cooling is used, the model can be that described on fig. 6.7.

8.2.5 Fan powered "free" cooling in summer hot wave conditions

The ventilation model can be combined to a simplified dynamic five zones model (chapter 5, fig. 5.34) in order to perform simulations on a summer hot wave.

Free cooling conditions can be defined by (8.3). To avoid overheating risks, heat recovery by pass conditions, related to type D free-cooling system, can be defined as:

$$t_{out} > 10°C \text{ or } t_{in} > 24°C \qquad (8.4)$$



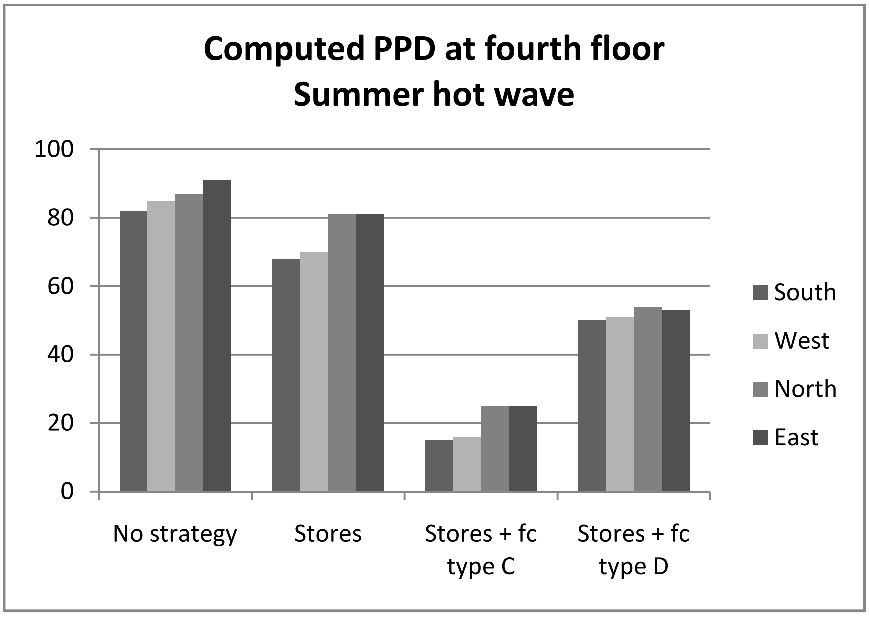


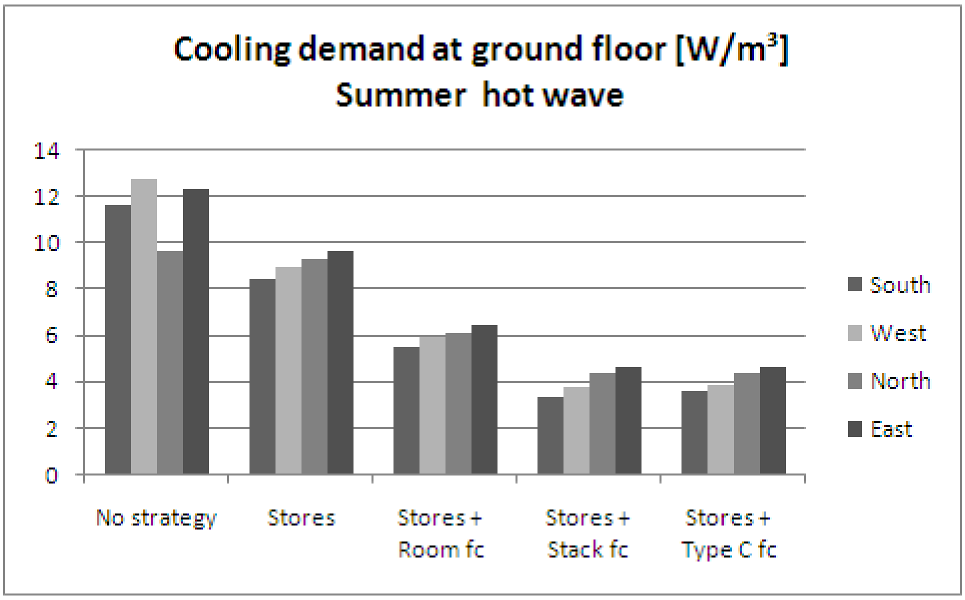
Fig 8.9 Predicted Percentage of Dissatisfied related to different office orientations and to different natural free cooling strategies, for a summer hot wave, at ground floor (up) and at fourth floor (down) of a four levels office building.

The model shows that the most significant comfort improvement is brought by *type C* free-cooling system, yielding 70% decrease in East orientation PPD at fourth floor offices, and 75% at ground floor offices (fig. 8.9). The model can provide indoor temperature profiles: they are similar to those observed for natural stack free cooling strategy (fig. 8.7 and annex 8, fig. A 8.13).

Type C results are close to those provided by natural stack free-cooling, but this performance requires a fan electricity power averaging *12 W* per office during the free-cooling hours.

Type D free-cooling system is less effective than type C because the associated free-cooling air flows are smaller. The average ventilation rate provided by type D is *1.5* h^{-1}, while type C exhaust fan is sized to reach *0.6* h^{-1} ventilation rate. Another reason is that type C exhaust fan heat power is only transmitted to the exhaust air and doesn't affect the air supply temperature, while type D supply fan heat power is transmitted to the supplied air, increasing its temperature. The model shows that increasing type D supply fan rotation speed, in order to get higher ventilation rates, leads to higher fan powers and higher air supply temperatures.

8.2.6 Combined "free" and "mechanical" cooling in hot wave conditions



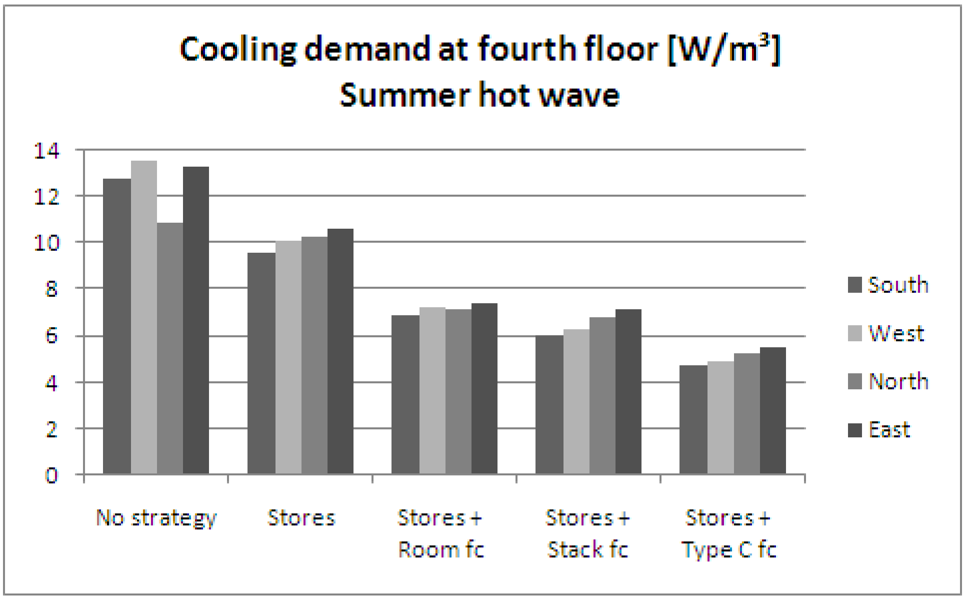


Fig 8.10 Cooling demands per m³ of conditioned space, related to different office orientations and to different natural free cooling strategies, during occupancy hours for a summer hot wave, at ground floor (up) and at fourth floor (down) of a four levels office building.

Mechanical cooling can be used to reach comfort for hot wave conditions, with or without controlled blinds or free-cooling strategies. The average PPD then equals 8 %, which is close to the 5% optimal thermal comfort value.

Fig. 8.10 compares the specific cooling demands required to fulfill the comfort without using blinds, or in association with them: the *cooling energy demand* is reduced by 21 % when using controlled blinds, decreasing from an average of 12 *W/m³* to 9.5 *W/m³* of conditioned space, during occupancy hours, over the hot wave time period. Free cooling strategies can reduce this cooling demand to an average of 4 *W/m³*. Those values may be higher, as occupancy gains due to lighting and appliances are equal to *10W/m²* of floor area, which is a rather low estimation.

For type C free-cooling strategy, the reduction of the cooling demand requires a fan electricity power averaging *12 W* per office during the free-cooling hours. Anyway, when it is added to controlled blind strategy, type C free-cooling strategy provides about 20% decrease of the total electricity consumption *related to the hot wave*.

8.3. Conclusion

The ventilation model defined in chapter 6 can provide interesting results regarding buildings summer thermal comfort, using Fanger's *Predicted Percentage of Dissatisfied* people as a comfort indicator.

The model allows testing different thermal comfort improvement strategies including free cooling and controlled blinds. Mechanical cooling demand can also be assessed. The model can help to define an advised strategy to improve comfort, either for average summer conditions, or for hot wave conditions.

The effect of window opening on summer comfort in houses can be evaluated. For example, the model shows that mechanical cooling isn't necessary to reach comfort in houses, for average summer conditions: the use of controlled blinds combined with window opening is sufficient. In offices, natural strategies such as room free-cooling, cross free-cooling and stack free-cooling can be tested. Fan powered "free" cooling strategies can be evaluated as well, regarding comfort and energy cost. The efficiency of a type C free cooling strategy, combining windows and doors opening with a roof exhaust fan, can be highlighted in offices.

As it can account for both wind effect and stack effect, the influences of both effects on wind pressurized and depressurized orientations can be evaluated.

When mechanical cooling is used, the model can estimate the energy savings provided by controlled blinds and free cooling strategies. As an example, in houses equipped with mechanical cooling, controlled blinds can save up to 38% of the cooling demand in hot wave conditions.