UDC 624.01/69.628.8

USING THE BUILDING MASS TO OBTAIN THERMAL COMFORT IN THE SUMMER PERIOD: A GREEN SOLUTION

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Introduction

Indoor environmental quality (IEQ) is an important issue for many stakeholders: be it the owner, the user either the employee. Many studies pointed out that the annual cost for getting a good quality indoors, can be located between 9 and 25 EUR per square meter. While the functional cost (including salary) can be as high as 680 to 5100 EUR per square meter. The ratio between those two costs being two orders of magnitude different.

IEQ deals with: thermal comfort, air quality, noise acoustics, illumination and exposure time. The personal factors that help to realize comfort are: activity, clothing, adaption and expectation. If good IEQ cannot realized with personal factors a good air conditioning system has to be put in place. During the preliminary design the design engineer should propose different solutions to the owner and architect. Different projects call for different solutions. In this contribution an example will be discussed, showing how a design engineer could suggest acceptable solutions for thermal comfort and air quality, without generating ventilation noise neither use active cooling energy.

Case study: an open office

The example deals with an open office with large glazed surfaces facing east and west located 50 km south of Brussels in Belgium (Fig. 1). In the open office 70 people could work with their computers and since large glazed surfaces are surrounding the room, overheating could be a problem while on the other hand a lot of produced bio effluents could be the origin of poor indoor air quality.

The minimum requirements of Annex B of Comité Européen de Normalisation (CEN) Standard EN 15251:2007 (Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics); and the requirements of CEN Standard EN 13779:2007 (Ventilation for nonresidential buildings, Performance requirements for ventilation and room conditioning systems) show that the indoor air quality should be better than 1.2 decipol. This value allows to make a first estimation of the needed ventilation air.

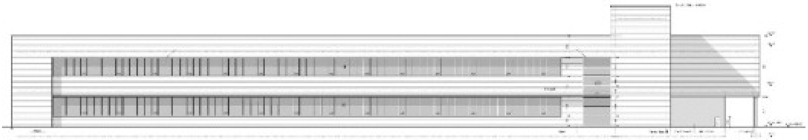

Fig. 1. East Facade of the building containing a large open office at the first floor

While the heating load is significantly reduced by installing thermal insulation, cooling is a more challenging problem. This need is enhanced by changing climatic conditions. In mild winters the heating load decreases, but more frequent and longer hot spells result in a rise in cooling energy demand. Although it is difficult to foresee the evolution of the climate a continuous increase in cooling degree days is believed to be very likely.

The owner prefers to avoid mechanical cooling equipment. Among the different possibilities we chose:

– to use the building mass as thermal storage;
– to apply night ventilation and cool the building mass (if needed);
– to shade the windows.

The night ventilation deals with convective heat transfer in the built environment and is dealth with in a lot of articles: e.g. [1] and [2]. In the open office at hand no raised floor neither dropped ceiling will be used: this implies that both surfaces could contribute to the building mass. This choice is made since the fenestration in the walls is above 80 percent and therefore the walls can hardly store “cold energy”. The night ventilation air flow is delivered through a rectangular opening (15 cm x room width) close to the ceiling (15 cm from the ceiling) over the complete width of the wall separating the room from the outside environment. The extraction of the air is done on the opposite wall 15 cm above the floor level and again over the complete width of the open office. In Fig. 2 a 2D-numerical simulation (using Cool fluid) of the night cooling is shown in a room with a cross section 3 m by 2.40 m. During the night the incoming air has a lower temperature than the room: for the case depicted the temperature difference is at the start of the cooling process 5°C, what is a typical temperature difference. The flow pattern of the incoming air develops thanks to two competing forces: the buoyancy (or Archimedes) force and the Coanda force. Indeed, due to the lower temperature the incoming air has a higher volumetric mass density: therefore it will fall due to gravity. On the other hand, the static pressure of the air at the entrance diffuser is the same as the static pressure in the room. But the total pressure is very different since the incoming air disposes of kinetic energy… The incoming air is slowed down therefore the static pressure increases. At the same time the air squeezed between the jet and the ceiling is entrained and therefore the static pressure decreases: this means that the jet is sucked to the ceiling. These two phenomena are in competing: a big temperature difference will be in favor of the Archimedes forces, while a higher entrance speed will favor the Coanda effect. Besides an increased flow velocity near the cooled surface also a high temperature difference will enhance the cooling capacity. Since the floor is covered with furniture, and the layout of the objects spread over the floor could change from day to day, we would like to favor the ceiling cooling. At first sight we must determine the available difference between the room temperature and the ambient temperature, and if this difference is significant, air should be delivered. A big temperature difference (favoring the buoyancy force) should correspond to a high inlet velocity in order to assure sufficiently attached flow to the ceiling due to the Coanda effect. The question to be answered is of course: “Given a certain temperature difference, what is the best speed to deliver the air to the room?”

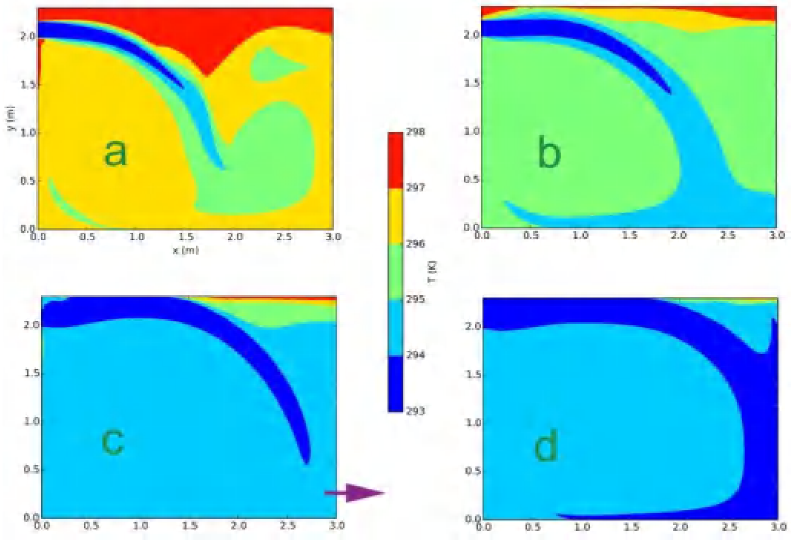

Fig. 2. Incoming cold flow in a room: during the cooling process different flow patterns develop:
a – flow pattern the start of the cooling ventilation process;
b, c, d – are in a chronological order later stadia of the cooling process (for this simulation no ceiling cooling is applied, only the air is cooled)

Fig. 2 shows the result of a calculation with a CFD tool (here Cool fluid is used). It is shown that the flow does not remain stationary over the night when cooling the room. Apparently there are three different flow regimes:

1. Natural convection (the incoming flow falls immediately: buoyant flow) – Fig. 2 a. In this case the room is still very warm compared to the incoming air such that the buoyancy forces prevail.

2. Mixed convection (the incoming flow attaches to the ceiling but separates at some point: separating flow) Fig. 2 b and 2 c. The room cools down and the temperature difference between the incoming air and the zone decreases. The

Coanda effect assures an attachment to the ceiling, but since the velocity decreases the separation occurs at some point. The cooling process makes that the temperature difference further decreases and the separation point moves further on the ceiling.

3. Forced convection (the incoming flow attaches to the ceiling and remains attached: forced flow)Fig. 2 d. As can be seen on the figure, the separation could not go until the opposite corner since the flow has to separate and some small re-circulation vortex installs in the corner. Anyway a large part of the ceiling is wetted by the incoming ventilation air. (During day time this will be the most likely flow situation.)

Since the local convection heat transfer coefficient depends largely upon the speed of the flow, one should in the design phase be able to define the flow regime (of the flow over the ceiling) at some time during the night. The best way to represent the different situations is to use the Richardson dimensionless number (Leenknegt 2013): this number represents the importance of natural convection compared to the forced convection, it is defined as:

$$Ri = \frac{g\beta(T_{ceiling} - T_{ventair})H}{V^2},$$

where g – is the gravitational acceleration;

β– is the volumetric thermal expansion coefficient;

$T_{ceiling}$ – is the ceiling or hot wall temperature;

$T_{vent\ air}$ – is the reference temperature (chosen to be the incoming air temperature);

H – is the characteristic length in this case the height of the room;

V– is the characteristic velocity what is here the incoming air speed.

The calculation shows that the transition from the buoyant flow regime to the forced flow regime occurs at a R_i number around 1 (as indicated by the vertical line in Fig. 3). Initially during the buoyant flow regime the R_i number is well above 1 and could be as high as 9, while on the other hand during the forced flow regime this value is around 0.5.

The heat convection coefficient is calculated by:

$$h_c = 0.037\ Re^{0.8} Pr^{0.333} \frac{\lambda}{L},$$

where $\frac{\lambda}{L}$– is the heat conduction coefficient of air divided by the characteristic length.

The Richardson number correlation (Fig. 3 – [3]), allows to choose the convenient heat transfer convection coefficient to be inputted in a building energy simulation (BES) program. For the present effort the TRNSYS program was chosen.

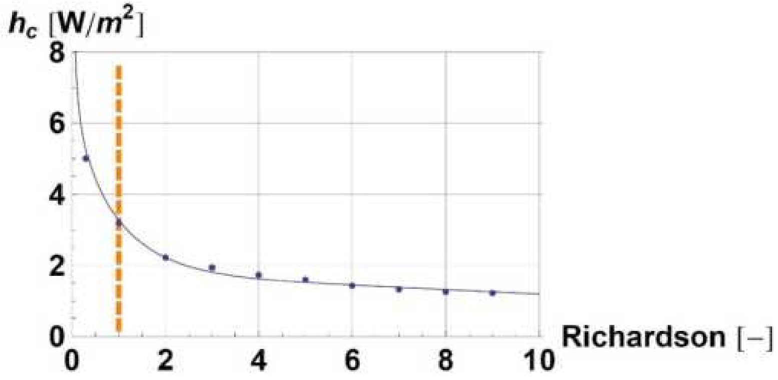

Fig. 3. Calculated Richardson number correlation

In Fig. 4 is represented the evolution of the temperature in the open office with four different strategies. First the room is studied in a free floating situation when no internal gains are present (this could be seen as the weekend situation where the room remains empty). In the second case the room is occupied, but no night ventilation neither shading devices are used. The first and the second situation are the extreme (minimum and maximum) reference situations. In the third case night ventilation is applied, while in the last case both night ventilation and shading are applied. It is easy to see that night ventilation helps to reduce the temperature peaks by 1 or 1.5°C, while the shading devices allow a reduction of about 1.5 to 2°C. Anyway the use of these passive (or hybrid techniques if a fan should be used to push the night cooling air in the room with a speed equal to 0.5 m/s) do permit to obtain a temperature for the room in use lower than the temperature of the unused room.

Conclusion

A building energy simulation program allows an engineer to check whether a passive cooling technique could be applied to a building with a particular occupation and activity level. The cooling of the building mass is in the BES program a delicate operation. With CFD the heat convection coefficient as a function of the Richardson number has been calculated and an appropriate correlation model has been designed. This model is introduced in the BES (TRNSYS) program.

The simulation shows that in the given circumstances the applied passive techniques allow to assure correct indoor environment quality without consuming to much energy. The only energy that is needed is the fan driving the cooling air, but compared to an air handling unit cooling the air during office hours, this energy consumption is only a few percent.

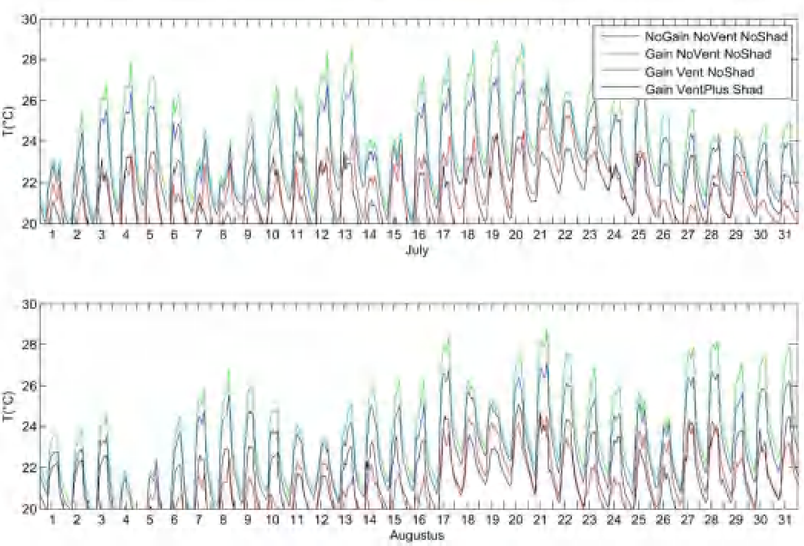

Fig. 4. Temperature evolution in the Open Office. Different strategies: Internal gains present or not (70 persons, laptops, light).Night ventilation applied or not (the ventilation rate equals 5 volume exchanges per hour with outdoor air if the outdoor air is at least 3 degrees cooler than the indoor air); external shading devices present or not (a horizontal plate at the top side of the window with a depth 0.5 m).

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