PASSIVE COOLING IN A LOW-ENERGY OFFICE BUILDING

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ABSTRACT

Natural night ventilation and an earth-to-air heat exchanger are applied in the low-energy office building 'SD Worx' in Kortrijk (Belgium). Temperatures measured during summer 2002 are used to discuss the operation and cooling effect of these passive cooling techniques and the achieved thermal comfort.
Simulations with a coupled thermal and ventilation simulation model TRNSYS-COMIS are carried out to estimate the impact of passive cooling. For this purpose, the simulated indoor temperatures are first compared to the measurements.

KEYWORDS

Low-energy office building, passive cooling, natural night ventilation, earth-to-air heat exchanger, coupled thermal and ventilation simulation model, TRNSYS-COMIS.

LOW-ENERGY OFFICE BUILDING

The office building 'SD Worx' is situated in Kortrijk, Belgium and consists of two office floors on top of the ground floor with building services. At the southern side, the floors are connected with an open vertical circulation zone. Reduction of cooling load and energy losses, use of passive cooling and heating and control automatisation lead to a low-energy office building (Cenergie, 2002).
This paper focusses on the actions taken to achieve a good thermal summer comfort. Firstly, the cooling load is reduced by orientating the offices north and the circulation zone south. Controlable external sun blinds are applied in the circulation zone. Heat emission of lighting and office equipment is also minimized. In addition, an exposed concrete ceiling delivers a high thermal capacity, which reduces and postpones the cooling load. Secondly, passive cooling is applied (see Figure 1). By day, an earth-to-air heat exchanger cools down the supply air flow. By night, outside air enters the office floors through grilles at the northern side, cools down the exposed ceiling and leaves the building at the top of the circulation zone. Temperature peaks the next day are reduced and postponed consequently. Thirdly, controlling passive cooling determines the performances of these techniques. The ventilation rate by day increases proportionally with the mean indoor temperature from 5400 m³/h at 23°C to 8000 m³/h at 26°C. The operation of natural night ventilation depends on maximum inside and outside air temperature during the previous day ($T_{i,max}$ > 23°C and $T_{e,max}$ > 20°C), inside air temperature (T_i > 20°C), difference between inside and outside air temperature ($T_i > T_e$ + 2°C), relative humidity inside ($R.V._i$ > 70%), rainfall (no rainfall) and wind velocity (v < 10m/s) at that moment.

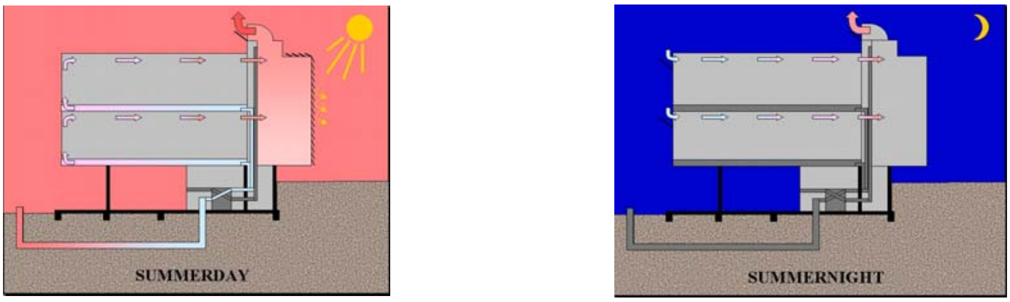

Figure 1: Operation of passive cooling: earth-to-air heat exchanger and ventilation by day (left) and natural night ventilation (right) (Cenergie, 2002)

The first part of this paper discusses the measured operation of the building. The second part focusses on the simulated performances and estimates the impact of the passive cooling techniques on the thermal summer comfort.

MEASUREMENTS: DISCUSSION

Outdoor and indoor climate, air flows in the mechanical ventilation system and control parameters are monitored continuously (every 15 min.) by the building operation system. This paper discusses the measurements from May to September 2002.

Natural night ventilation

Figure 2 shows the operation of natural night ventilation. The outside air cools down the surface temperatures of the exposed building structure at night and reduces and postpones consequently the air temperature peaks by day.

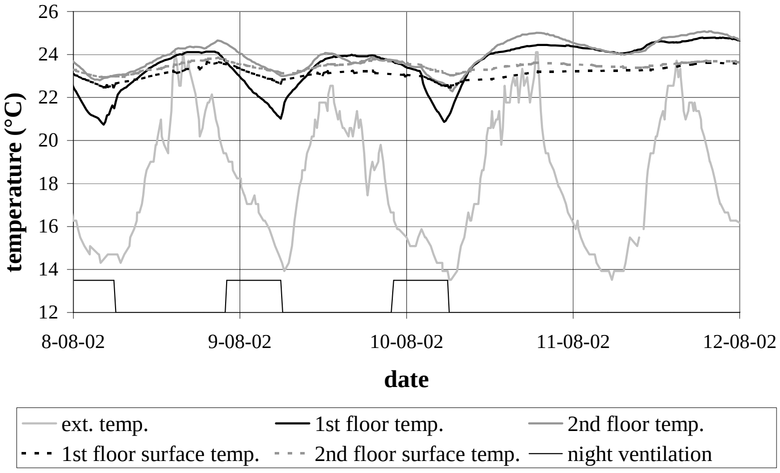

Figure 2: operation of natural night ventilation

Natural night ventilation operates 55 days from the end of June until the end of September 2002. The cooling effect is higher on the first floor due to higher thermal stack effect. The surface temperature on the first and the second floor respectively decreases at most 4°C and 2.5°C during the night, depending on inside-outside temperature difference. The outside air temperature peak is postponed with an average of 5h. Due to this, the indoor air temperature peaks occurs after the working hours. No condensation problems are noticed. A conflict between heating and cooling exists in the morning during 8 working days in September. The supply grills open and close several times a night. Both phenomena are avoided by optimising the control parameters: inside surface temperature replaces inside air temperature, the treshold value is increased (T_{si} > 22°C). (De Paepe, 2003)

Earth-to-air heat exchangers

Earth-to-air heat exchangers are tubes, located in the ground, through which ventilation air is drawn. At a sufficient depth, the ground temperature is suffient low to cool down the ventilation air in contact with the tube in the ground. The depth, tube diameter and length and number of tubes determine the cooling effect (De Paepe and Janssens, 2003). In this project two concrete tubes with a diameter of 80cm and a length of 40m each are buried 3 to 5 m deep and connected to the ventilation system by PE-tubes (De Paepe, 2003).

Figure 3 shows the operation and the cooling effect of the earth-to-air heat exchanger. Ventilation air is cooled down on a summer day. The achieved temperature varies with the external temperature and depends on the ventilation flow. The temperature in the earth-to-air heat exchanger adopts the ground temperature when the ventilation doesn't work. The maximum temperature never exceeds 22°C, i.e. an important cooling effect on hot summer days. A limited cooling effect exist between 12 and 22°C outside (De Paepe, 2003).

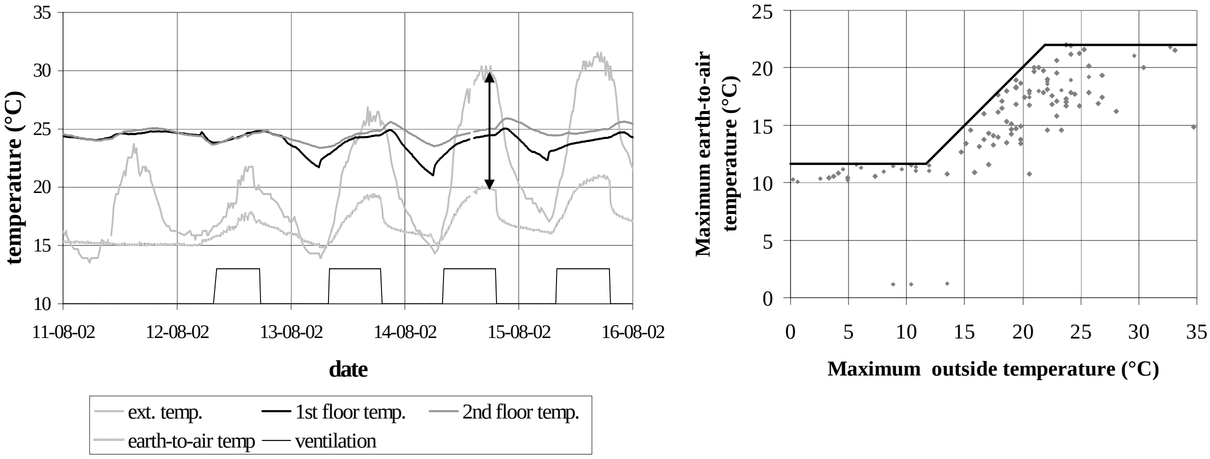

Figure 3: earth-to-air heat exchanger: operation (left) and cooling effect (right) (De Paepe, 2003)

Thermal summer comfort

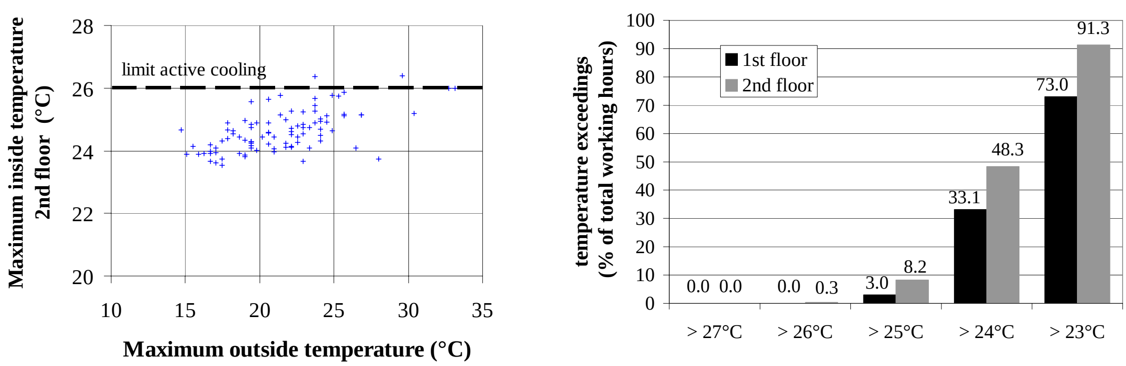

Figure 4: Maximum inside temperature at 2nd floor as a function of the maximum outside temperature (left) and temperature exceeding hours at both floors (right) from May 15 to September 30, 2002 (De Paepe, 2003)

Figure 4 discusses the thermal summer comfort. The maximum temperatures at the 2nd floor are mostly between 23.5°C and 26°C. High temperatures are more frequently monitored at the second floor. The inside temperatures exceed 23°C during respectively 73% and 91% of the working hours on the 1st and 2nd floor. 26°C is only exceed 10 hours at the 2nd and never at the 1st floor. A cooling battery is installed as back-up and starts working from an inside temperature of 26°C, but never operates during the summer 2002 (De Paepe, 2003).

SIMULATIONS: IMPACT OF PASSIVE COOLING

A coupled thermal and ventilation simulation model, which iterates the mass and energy balance per zone till convergence, is necessary to simulate natural night ventilation (Breesch and Janssens, 2002). 'SD Worx' is simulated by coupling TRNSYS (Klein et al., 2000), a transient multi-zone thermal simulation model, and COMIS (Haas et al., 2002) (Dorer, 1999), a multi-zone infiltration and ventilation simulation model.

The building geometry is simplified and consists of two landscape office zones and the circulation zone. Weather and building data are given in Table 1 and Figure 5. Solar radiation and wind direction data on site aren't available. Consequently, the weather data of the Test Reference Year of Ukkel are used in the simulations. Figure 5 (right) shows the external temperatures in both weather data are comparable. Due to the application of a control system, a small time step (6 min.) is chosen. The landscape offices are designed for an occupation of 24 persons each floor. At the moment of the measurements, 9 persons are working on each floor from 8 till 17h. The earth-to-air heat exchanger is modelled as shown in Figure 3 (right).

TABLE 1
Building data

Night ventilation building data							
zone	Reference height (m)	Dimensions H/D/W (m)	Louvres				
			from	to	height (m)	A (m²)	C_D
Office 1st floor	3.5	3/12.1/21.2	outside	office 1st	6.0	5.66	0.27
			office 1st	circulation	6.3	3.06	0.33
Office 2nd floor	7	3/12.1/21.2	outside	office 2nd	9.5	5.66	0.27
			office 2nd	circulation	9.8	3.06	0.33
Circulation zone	3.5	8.4/2.9/21.2	circulation	outside	11.4	10.65	0.33

Thermal building data					
g (window)	0.6	U (window frame)	3.5 W/m²K	U (external floor)	0.24 W/m²K
U (window)	1.1 W/m²K	U (roof)	0.28 W/m²K	U (internal floor)	1.61 W/m²K
g (window, horizontal, circulation)	0.28	U (ext wall)	0.28 W/m²K	U (external floor, circulation)	0.15 W/m²K
U (window, horizontal, circulation)	0.6 W/m²K	U (int wall)	0.93 W/m²K		

Wall composition			
External wall	reinforced concrete, embedded with brick panes	Flat roof, internal and external floor	hollow core concrete slabs false floor
Internal wall	wooden cupboards		

Internal heat gains				
		Radiant (%)	Convective (%)	diversity
people	80 W/pers.	50	50	1
PC + screen laserprinter	130 W/pers. 300 W	25 20	75 80	0.75 0.5
lighting	10 W/m²	25	75	0.6
Present occupation (9 pers): total		**929 W**	**2098 W**	
Max. occupation (24 pers): total		**1894 W**	**3795 W**	

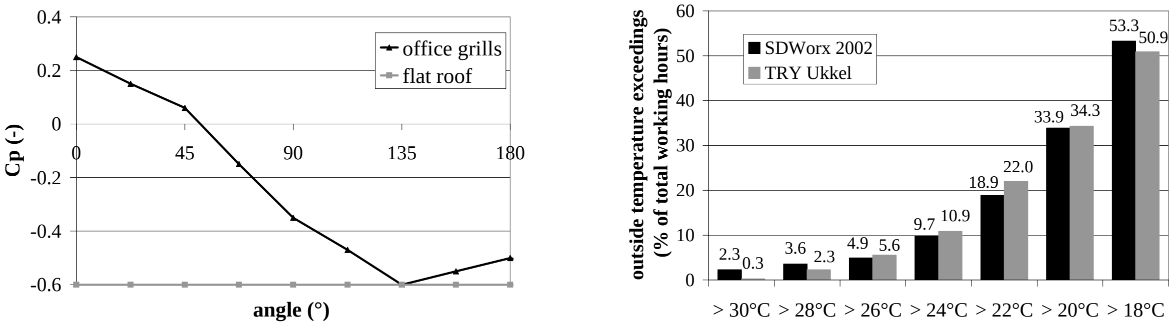

Figure 5: Wind surface pressure coefficient Cp varies with the angle between the wind direction and the normal on the surface (Orme et al., 1994) (left) and Weather data (May 15 till September 30): comparison outside temperatures exceedings on site - Test Reference Year Ukkel

Comparison to measurements

Simulation results need to be compared to the measurements to predict the impact of passive cooling on thermal summer comfort. The relationship between the simulated maximum indoor and outdoor air temperatures and the simulated temperature exceeding hours in Figure 6 are compared to the measured temperatures in Figure 4.

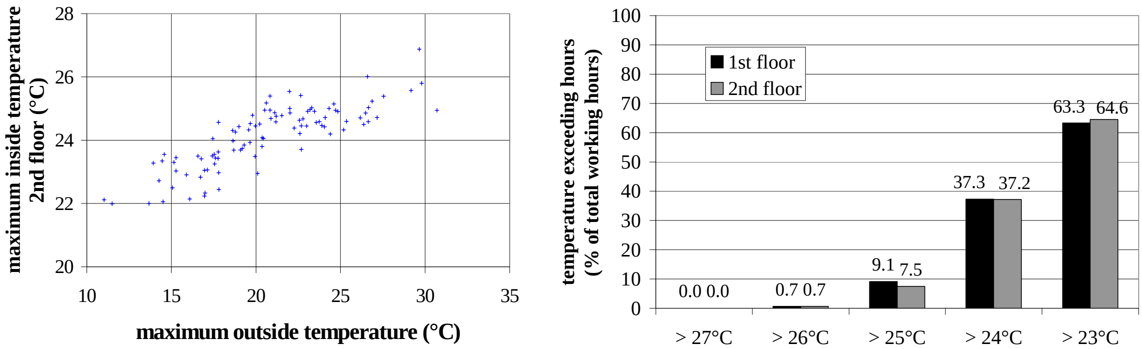

Figure 6: Maximum air temperature at 2nd floor as a function of the maximum outside air temperature (left) and temperature exceeding hours at both floors (right) from May 15 to September 30, 2002 (TRY Ukkel)

The following conclusions can be drawn. Unlike the measurements, the simulated temperatures at both floors hardly differ. The air temperature peaks (T_i >25°C) at the first and the second floor respectively are a little bit over- and underpredicted by the simulation model. Both differences are caused by assumptions made by the user (isothermal wall between the first and the service floor and a over-isolated roof at the second floor) and properties of the multi-zone model (one temperature in the vertical circulation zone underestimates thermal stratification). The measured and simulated relationship between maximum indoor and outdoor temperatures agree very well, except for chilly summer days (T_e < 18°C). The maximum simulated temperatures at the 2^{nd} floor are less than 23.5°C, while the measured temperatures exceed 23.5°C. Comparing the hours exceeding 23°C in both figures, proves the same. Underestimation of the heat recuperation on the ventilation supply air explains the difference.

Impact of passive cooling

To estimate the impact of natural night ventilation and the earth-to-air heat exchanger on the thermal summer comfort, the weighted temperature exceedings hours (GTO) (ISSO, 1990) in four different cases (night ventilation, earth-to-air heat exchanger, combination of both techniques, no passive cooling) are compared for 2 types of occupation (current i.e. 9 persons and maximum i.e. 24 persons) in Figure 7.

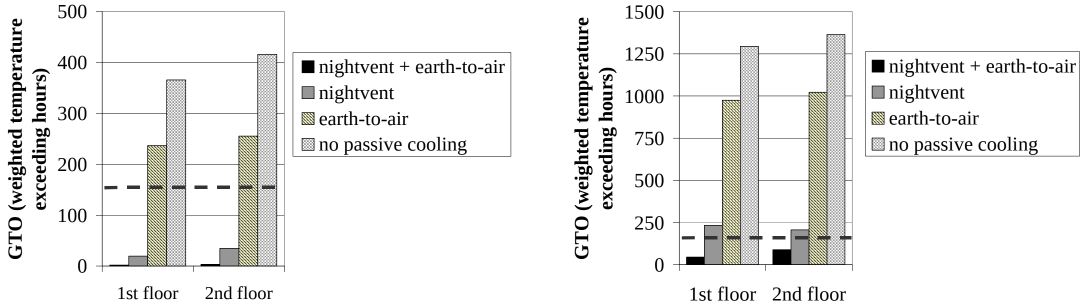

Figure 7: Weighted temperature exceeding hours (GTO) from May 15 to September 30, 2002 (TRY Ukkel) at current (left) and maximum occupation (right)

In case of present occupation, night ventilation alone or combined to an earth-to-air heat exchanger deliver an excellent thermal comfort (GTO << 150, i.e. treshold for good thermal summer comfort, see (ISSO, 1990)). With maximum occupation, only the combination performs very well. Earth-to-air heat exchanger alone and lack of passive cooling techniques perform poorly in both occupancies. As a result, passive cooling has an important impact on thermal summer comfort in 'SD Worx'. Secondly, night ventilation affects thermal comfort much more than an earth-to-air heat exchanger, with the present modelling assumptions.

CONCLUSIONS

Natural night ventilation and an earth-to-air heat exchanger are applied in the low-energy office building 'SD Worx' in Kortrijk (Belgium). Measurements during summer 2002 show these passive cooling techniques perform well and cause a good thermal summer comfort. Simulations with the coupled thermal and ventilation simulation model TRNSYS-COMIS demonstrate night ventilation is more efficient to improve thermal summer comfort in this project than an earth-to-air heat exchanger.

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