Achieving thermal comfort using natural ventilation – Effect of internal finishing

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ABSTRACT

Thermal mass activation (TMA) can assure, in certain cases, thermal comfort conditions without the need of air conditioning systems. Even if other cooling systems have to be used, night ventilation significantly reduces the duration of the working time of additional cooling systems.

The desired night ventilation rate (NVR), could be achieved using either mechanical ventilation, natural ventilation or a combination of these two methods (hybrid ventilation system).In this paper, we will investigate the feasibility of night cooling using natural ventilation for a residential building in a hot region of France: Cargèse. We will develop a model that calculates the internal temperature according to the heat balance and the combined effects of buoyancy and wind forces.

Besides, we will study the effect of the internal finishing on the effectiveness of TMA. What type should we choose? And if we decide to use a suspended ceiling, a raised floor or a gypsum board in front of a concrete wall, what impact will this choice have on summer comfort?

1. INTRODUCTION

Thermal mass activation is a passive cooling technique were the building can itself work as thermal storage and improve the daily indoor conditions by reducing the pick indoor air temperatures, lowering the temperature of the walls and creating a time lag between the external and internal maximum temperatures (Corgnati 2006). To increase the effectiveness of thermal mass activation (TMA), the following parameters should be carefully considered: the material properties, building orientation, location and distribution of thermal mass, thermal insulation and the ventilation rate. However another design condition - not well elucidated before – appears to be of great importance for TMA effectiveness: the internal finishing. In practice, architects may use a gypsum board in front of a concrete wall thus creating an air gap of different size depending on the way the gypsum board was installed. Besides, the use in certain applications of false ceilings or raised floors, induce an air gap and hence reducing the heat exchange between the indoor air and concrete slabs. In this work, we try to evaluate the effect of these internal finishing on summer comfort.

As for the desired night ventilation rate (NVR), natural ventilation appears as an attractive and suitable strategy for many types of buildings, such as low-rise dwellings, schools, small or medium-sized office… However, ‘natural’ means that the natural ventilation potential (NVP) will be random and will depend on many criteria, which are generally divided into three parts: outdoor meteorological criteria (wind speed distribution and orientation, temperature distribution …), urban criteria (outdoor air quality, noise level, urban topology…) and building criteria (building layout, building height, indoor pollutant sources…) (Zhiwen Luo 2006). In our study, we develop a model for predicting the NVP as a function of wind speed and orientation (Sharag-Eldin, 1998), temperature distribution, urban topology, building layout and building materials (Yuguo Li, 1999). Besides, the developed model no longer sets the indoor temperature to a constant value but calculate it according to the heat balance and the combined effects of buoyancy and wind forces. Finally, this model is used to investigate the feasibility of night cooling using natural ventilation for a residential building in a hot region of France: Cargèse.

The dynamic simulations were done using the SIMSPARK platform. This platform is based on SPARK, an object-oriented equation based algebro-differential solver.

2. APPLICATION

The developed model was used to evaluate the natural ventilation potential for a residential building in Cargèse (FRANCE), a village located 50 km north of Ajaccio, on the west coast of Corsica (fig.1). And the result is used to investigate if night cooling using natural ventilation can secure thermal comfort conditions.

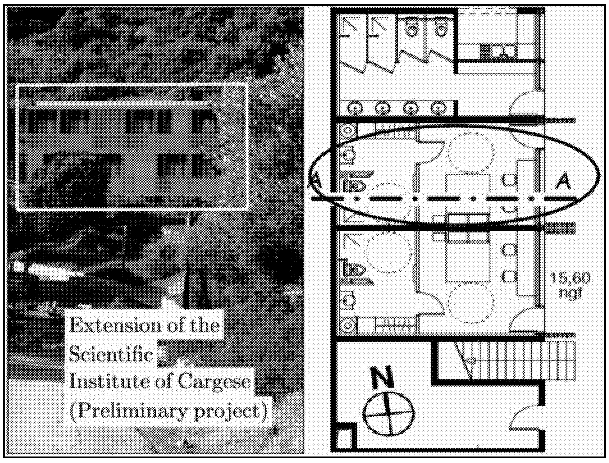

Figure 1: On site view of the future building and a plan view of a typical floor of the building

2.1. Meteorological and technical data

Following are the basic considerations (meteorological and technical) that will be used as an input for our different simulations:

- *Weather station:* The meteorological data for our simulations were measured at site (wind speed and orientation, external temperature, relative humidity, direct and diffuse solar radiation),
- *Room dimensions*: 7m x 4m,
- *Eastern and western glazing*: Low emissivity double glazing,
- *External walls*: 15 cm heavy weight concrete, 15 cm insulation external insulation
- *Vertical openings*: We will consider an opening on the eastern wall and another one on the western wall (40cm*15cm).

2.2. Dynamic simulations:

In order to quantify the NV effect, we will consider a basic case (case 1) where the ventilation rate is constant and equal to 0.5 Vol/h. However, in the other case (case 2) the ventilation rate is set to the constant value of 0.5 Vol/h during the day, and at night, when the internal temperature is greater than 25°C and the external temperature is lower than the room air temperature, the ventilation rate is set equal to the calculated natural ventilation rate using the method discussed previously.

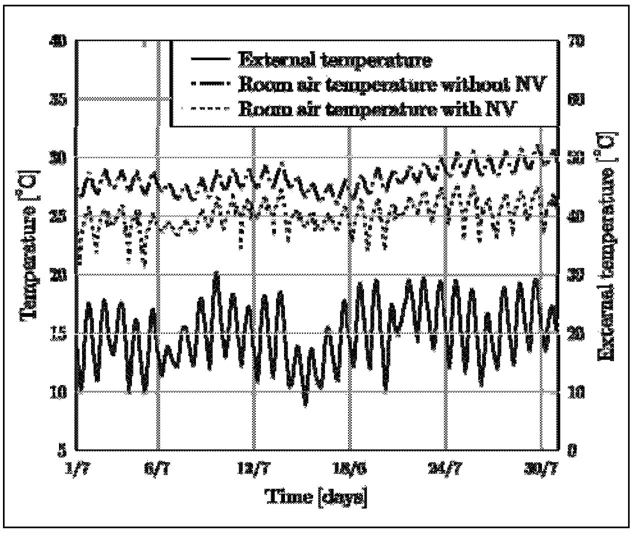

Figure 2: Room air temperature for july

The results of room air temperature variation for case 1 and case 2 where plotted along with the measured external temperature for the month of July (fig.2). As we can see, for case 1, internal temperatures of 31°C could be reached while in case 2, we notice that night cooling using natural ventilation can significantly reduce the peak indoor air temperature. This could be explained by the important temperature difference between day time and night time even for the hottest summer period (fig.2, 3).

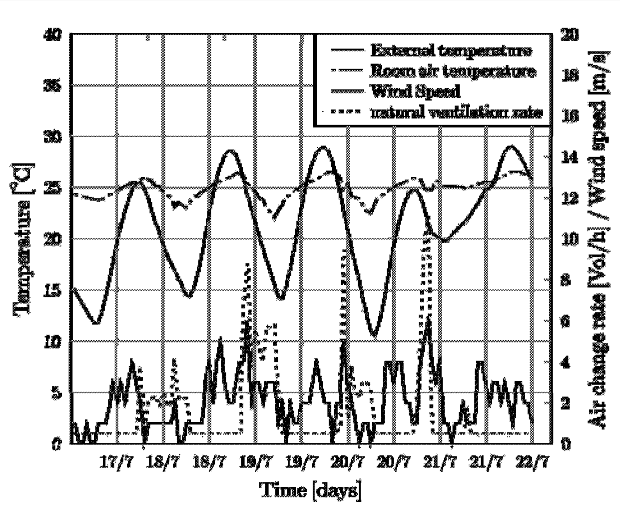

Figure 3: Room air temperature 17→ 21 July

We will now focus our study on a four days period (17 → 21 July). The results shown in figure 3 prove that a convenient night ventilation rate could be achieved using natural ventilation. Besides, the peak in air change rate coincides with the peak in wind speed which confirms the good choice of the openings positions.

2.3. Comfort Analysis:

To evaluate the performances of natural night ventilation, i.e. the achieved indoor climate, the indoor air temperature as well as the internal humidity where simulated. However, the way people react with the thermal indoor environment depends on more conditions. All these parameters are included in the concept 'thermal comfort' defined as "the condition of mind which expresses satisfaction with the thermal environment" (ISO, 1996).

Comfort analyses of indoor environments are covered by ISO 7730 (1994), based on the well-known Fanger theory (1970). However, thermal comfort field studies in warm climates for buildings without air-conditioning have demonstrated that the Predicted Mean Vote (PMV) model predicts warmer thermal sensation than the occupants actually feel. In fact, ISO 7730 in its present form can be seriously misleading when used to estimate thermal comfort conditions in buildings (Humphreys and Nicol, 2002). Besides, Ole Fanger introduced an extension of the PMV model that includes an "expectancy factor" for use in non-air conditioned buildings. It should be noted that the new PMV predicts a higher upper temperature limit when the expectancy factor is low: People with low expectations can tolerate warmer indoor environment. The "expectancy factor" was estimated to be 0.9 for Brisbane, 0.7 for Athens and Singapore and 0.6 for Bangkok (Ole Fanger, 2002).

Another way to assess the thermal comfort is the use of the "adaptive model" where comfort temperature is closely related to the prevailing outdoor ambient temperature, and could be expressed by an equation of the form (McCartney 2002):

$$T_c = aT_{out} + b$$

Where:
T_C: Comfort temperature (°C)
T_{OUT}: Outside temperature index (°C)
a, b: Constants evaluated experimentally.

In a recent EU-funded research project, Smart Controls and Thermal Comfort (SCATs), an adaptive control algorithm was developed and data were provided for the evaluation of constants "a" and "b" and it was found out that for France (McCartney 2002):

$$T_c = 0.049 T_{RM} + 22.58 \qquad T_{RM} \le 10°C$$

$$T_c = 0.206 T_{RM} + 21.42 \qquad T_{RM} > 10°C$$

Where *TRM* is running mean temperature given by:

$$T_{RM_n} = 0.8 T_{RM_{n-1}} + 0.2 T_{DM_{n-1}}$$

TDM is the daily mean temperature on day n-1 (°C)

A more simplified method consisting of using the Building Bio-Climatic Charts (Givoni 1976) could be applied to compare the internal conditions to thermal comfort conditions. The limits for the comfort zone are determined based on relative humidity, temperature and wind speed inside the room. For example, if we consider a room air speed of 0 m/s, the comfort limits are:

$$19.5°C < T_{\text{int}} < 27°C \quad \text{and} \quad 20\% < RH < 80\%$$

As we have seen, there are several methods that have been developed for defining comfort zone however looking to the models indicates that there may be a combination of comfort zone definition models, like Fanger or adaptive with design advise models like Givoni's for architects. The new climatic design model will need more flexible comfort conditions with different clothing and activity level together with improved number of design advices to cover more parts of architectural design process. For this study we will represent our results using the three different approaches described earlier in this paragraph. As for the percentage evaluation, we considered the following months: June, July, August and September.

Table 1: Percentage of points outside the comfort conditions (PMV)

PMV	*Expectancy factor = 1*		*Expectancy factor = 0.7*	
	Case 1	Case 2	Case 1	Case 2
> 0.2	30 %	10 %	14 %	0.8%
> 0.5	19 %	1.5 %	2.8 %	0 %
> 0.7	11 %	0.6 %	0.3%	0%

The results obtained with these three methods (table 1, table 2 and fig.4) clearly proves that changing from case 1 to case 2, i.e. using night natural ventilation, could help insuring thermal comfort conditions and we can go from category 3 down to category 2 or 1 (prEN 15251)-depending on the method used to evaluate comfort.

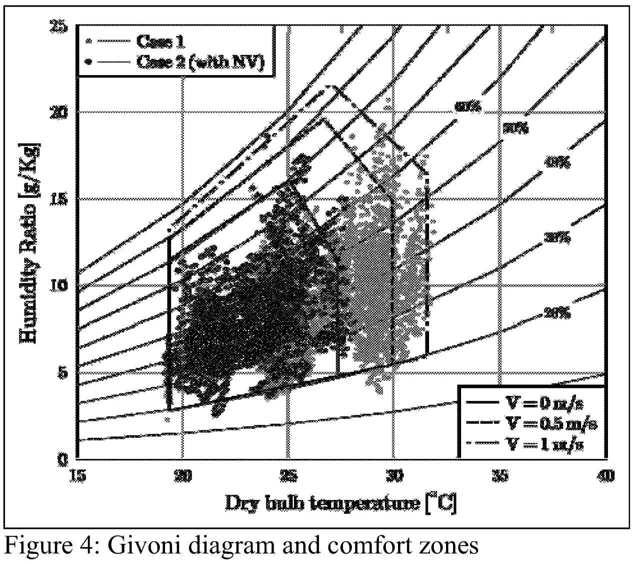

Figure 4: Givoni diagram and comfort zones

However we can notice that if the PMV was extended considering an "expectancy factor", the results obtained are closer to the ones predicted by the adaptive principle. Besides we can clearly see, on Givoni's diagram how the internal conditions points moved towards higher comfort situations (fig.4).

Table 2: Percentage of points outside the comfort conditions (adaptive model)

	Room air temperature			
	$>T_c$*	$>T_c + 2$	$>T_c + 3$	$>T_c + 4$
Case 1	23 %	16 %	13 %	7 %
Case 2	14 %	1 %	0 %	0 %

* Comfort temperature

We can also say that if the high and low limits are well determined, this graphical representation can be a very simple and very useful way to compare different solutions.

2.4. *Influence of internal finishing:*

In this section, we will try to study the possible influence of internal finishing on summer comfort. For this purpose, two cases were studied:

- *Case 2-bis:* based on case 2 with the addition of gypsum boards in front of the concrete walls (1 cm air gap).
- *Case 2-ter:* based on case 2-bis with the addition of a false ceiling

The natural convection, radiative and convective heat transfer models were developed and added to the previous model (fig.5).

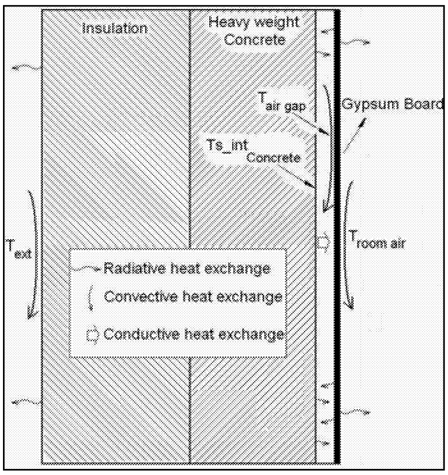

Figure 5: Graphical representation of the modeled system

The results of our simulations were resumed in terms of the variation of the number of hours where the internal temperature is greater than 26, 27 or 28°C (table 3).

If we take case 2 as a base for our comparison, we can see that in case 2-ter, the numbers of hours where room air temperature (T_int) surpasses 27°C is almost multiplied by four and that (T_int) could exceed 28°C.

Table 3: Variation of maximum internal temperatures

T_int	*Case 2*	*Case 2-bis*	*Case 2-ter*
> 26°C	209 hrs	300 hrs	400 hrs
> 27°C	30 hrs	68 hrs	111 hrs
> 28°C	0 hrs	1 hrs	9 hrs

Furthermore, we observe that if we only add the gypsum boards in front of the concrete walls we double the number of hours where (T_int) is greater than 27°C. This result could be explained by the fact that this type of internal finishing introduces an air gap that acts as an insulation thus reducing the heat exchange between the room air and the concrete wall.

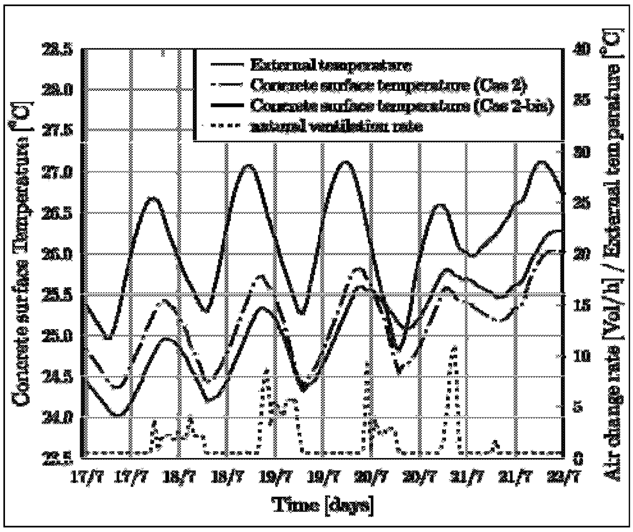

Figure 6: Variation of the concrete surface temperature

Consequently, at the end of the night ventilation period, the temperature of the concrete wall, in case 2, is lower than the one in case 2-bis and hence, a higher phase shift is assured. On the other hand, a higher heat exchange with the concrete wall helps store more heat in the walls and reduce the peak room air temperature (fig.6).

3. CONCLUSION

In this work, we tried to evaluate the feasibility of night cooling using natural ventilation for a residential building in Cargèse (FRANCE). We developed a simple and easy implementation method for natural ventilation calculation. The on-site meteorological measurements as long as the selected material properties, building orientation and configuration, were used as an input for the model. The resulting simulations proved that:

- *Thermal mass activation* could assure, in this case, thermal comfort conditions without the need of conventional air conditioning systems.
- *The desired night ventilation rate* could be achieved using natural ventilation during the whole summer period.

Besides, we studied the effect of internal finishing on summer comfort. For this purpose, two types were considered: a gypsum board in front of a concrete wall and a false ceiling. The simulations showed that these finishing can result in higher internal temperatures and therefore they should be avoided whenever it is possible.

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