# Flow Patterns Effects on Night Cooling Ventilation

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**ABSTRACT**
The passive cooling techniques such as night time cross ventilation is potentially an interesting strategy to provide substantial cooling energy savings in warm climates. The efficiency of the night cooling ventilation is determined by three main factors: the external air flow rate in the room, the flow pattern and the thermal mass distribution. Most of the software used to simulate building thermal performance assumes natural convection in the enclosure; therefore the convective heat transfer coefficients for internal room surfaces are underestimated. The aim of this paper is to analyse the effect of the enclosure shape and the inlet/outlet openings situation on these convective heat transfer coefficients. This analysis allows a comprehensive sample of typologies to generate guidelines which can help the designer with the distribution of the thermal mass and inlet/outlet openings in the enclosure. The approach will combine a theoretical analysis to characterize globally the enclosures getting charge/discharge time constants with simulation studies based on computational fluid dynamics software.

Keywords: Night Cooling Ventilation, Computational fluid dynamics, Heat transfer coefficients

## INTRODUCTION

Night ventilation has been used from the ancient times, lots of authors (Kimura, Allard et al, Santamouris, Lunardini) has been involved in the developments of design guidelines in order to promote and extend its use. However, they have not done an approach to the assessment using computer fluid dynamic simulation software. This is the goal of this article. Concretely, the use of this program to study the influence of the air flow pattern on night cooling ventilation.
Regarding the use of this technique, only from 90’s the designers begin to take in consideration the night ventilation as a, properly said, cooling technique. In fact, during the architectural competition Zephyr during the year 1994, most of projects used the natural ventilation as passive cooling technique.
Moreover, natural ventilation seems to give an answer to the requirements of mechanical ventilation systems regarding to the level of noise, health problems, needs of periodic maintenance jobs and energy consumption.

**Thermal sensation and comfort.**

Thermal sensation takes an important role in the comfort perception; and, as any comfort parameter it is very subjective. A exhaustive revision of thermal comfort is done in the chapter 8 of ASHRAE Fundamentals (1993). Human thermal comfort is defined as the conditions where a person would not like a colder or heater ambient. It is a complex concept as it depends of several parameters that can be sorted in next types:

- Physic parameters.
- Phisiologic parameters.
- External parameters.

Between these variables, the dry bulb temperature, humidity and wind velocity are the most important ones. To modify the air movement between persons can contribute to control their level of comfort. Air movements determine the convective heat flux and the mass exchange between each person and the air in contact with him. In summer, high air velocities would lead to an increase in the evaporation rate over the skin surface, and consequently, an improvement in the thermal comfort.

**The ventilation effect over the internal gains of heat.**

The second direct effect of the ventilation over the comfort conditions is the reduction of internal heat gains by removing the heat generated in the interior. At mild climates, usually buildings are well ventilated permitting a low difference of temperature between the exterior and the interior. This strategy typically is employed in buildings with low thermal inertia and has to be combined with solar radiation control in order to be effective.

**Ventilation and structural thermal storage.**

Another strategy is to chill the structural components of the building when it is unoccupied, normally in the night. This technique is known as night cooling ventilation. The objective is to use the building itself as a heat sink during the day, and in the night, the energy stored in the structure is taken by the circulating air that carry out this energy, cooling the building, and allowing it to be use again as a heat sink, closing the cycle. This introduces concepts of energy offer and energy requirement. The energy offer is the storage heat capacity of the building, and the energy requirement is the heat necessary to assure the comfort conditions in the building. Under this viewpoint, three situations can occur:

- Energy offer higher than energy demand.
- Energy offer equal than energy demand.
- Energy offer lower than energy demand.

It can seem that in the second of the related cases, the requirements of energy of the building would be null. Nevertheless, making an analysis, we will be able to understand that all the energy stored in the structure will not be able to satisfy the demand. To explain this, the concept of restored heat, can be employed. As is known, this is defined as the fraction of stored energy that is used to reduce the energy demand of the building. Only in very special situations the total storage

energy can be used to reduce energy demand, normally a portion of the storage energy will be loosed to the exterior. In order to understand the characterization of this technique of natural refrigeration it will be necessary to understand the particularities of this one.
In general we can say that the natural ventilation will depend on the speed of air at the entrance of the enclosure at issue, on the air movement –flow pattern—inside the enclosure, on the construction typology, on the climate, and on the set point temperature. Without considering the last two items we can graphically show the dependency with the factors previously mentioned by means of the following graphs.
In figure 1, the streamlines of one enclosure are shown, being element “1” the floor, element 2 and 4 walls and element 3 the ceiling. The inlet of the air is at floor level and the outlet at ceiling level .

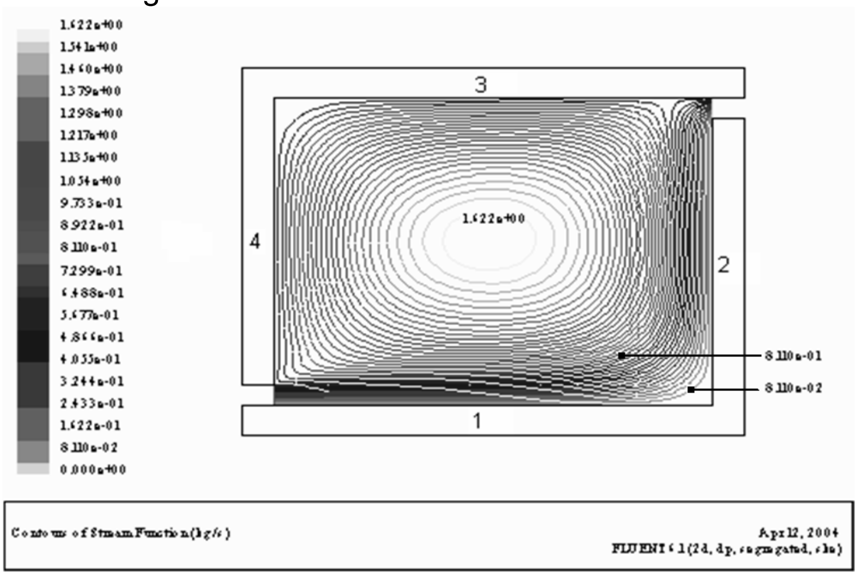


Figure 1- streamlines for configuration 1.

The flow pattern can be divided in two regions, one on the floor and on the wall 2, and the other formed by the remaining space. On the first region the air is in movement from the inlet to the outlet, on the second the air keeps turning and stagnant. As consequence the convective heat transfer coefficients are different on each element of the room, because they are air velocity dependant. This flow pattern produces direct cooling on elements 1 and 2, while elements 3 y 4 are cooled by the stagnant air, which is in contact whit the region 1, this is an indirect cooling.
The superficial temperatures evolutions for the elements are shown in figure 2.

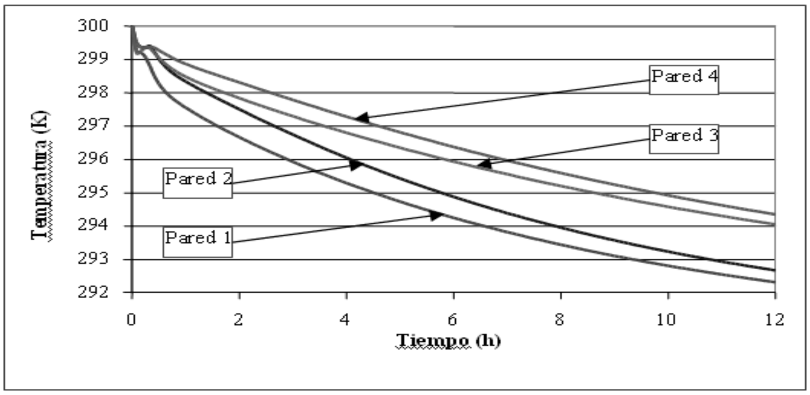


Figure 2- Hourly evolutions of temperatures for the elements of configuration 1.

Each element has its own evolution depending on the temperature of the air that is in contact with it, on the convective heat transfer coefficient, and on the thermal inertia of it.

## GLOBAL CHARACTERIZATION OF ZONES.

In this section, the influence of the flow pattern over the capacity of storage energy of the enclosure will be studied. This study will be developed using the Storage Efficiency (SE) defined as the actual amount of energy absorbed by the fabric divided by the maximum amount of energy potentially absorbed. In numerical terms:

$$SE = \frac{T_{storage}(0) - T_{storage}(t)}{T_{storage}(0) - T_{outdoor}}$$

### The influence of air flow pattern over the storage efficiency.

The enclosure geometry affects the air flow pattern, and this one as well, the storage efficiency.  The designer normally creates the spaces of a building taking care of some fundamental reasons, in which the air flow pattern is not included. But he can have some degree of freedom to select the positions of the openings.
El diseñador normalmente crea los volúmenes atendiendo a otras razones primordiales, pero puede disponer de algún grado de libertad al seleccionar las posiciones de las aberturas. These openings, in the case of natural ventilation, can be windows or grids that allow the movement of the air from and towards the interior of the enclosure.
Figure 3 shows a summary of usual typologies that can be found in most of buildings. These typologies are bidimensional, it supposes that the third dimension does not change the air flow pattern greatly. In general it is true, if the length of the volume in the third dimension is larger than the other two lengths, or, if there is not possibility of flow in a third dimension. Under these considerations, the figures can be understood as sections of spaces that can be in horizontal or vertical position. The lengths of the elements 1 and 3 are four meters, and elements 2 and 4, are three meters.

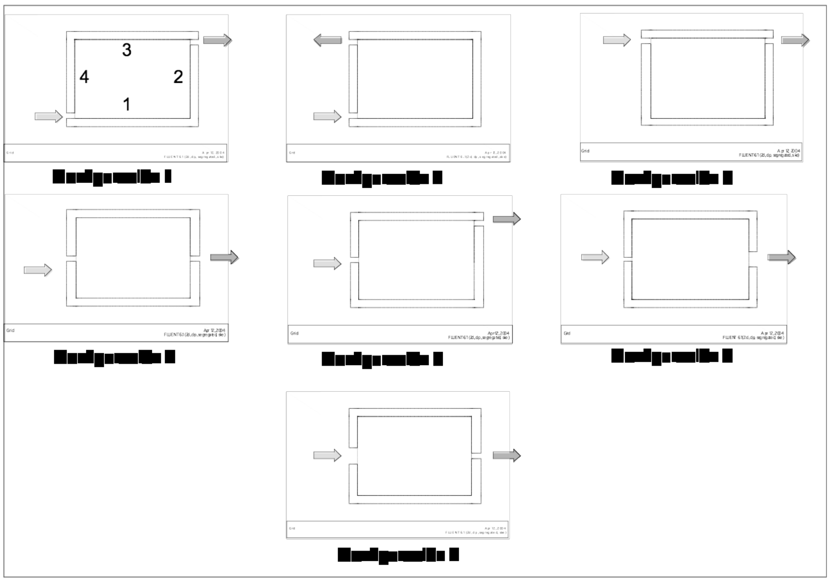


Figure 3- Usual typologies for natural ventilation in buildings.

The existence of a pressure differential between the inlet and the outlet has been assumed, being this one, the impelling force for the airflow.

For a constant pressure differential between the inlet and the outlet, the values shown in figure 4 of the storage efficiency based on the duration of the period of load have been obtained.

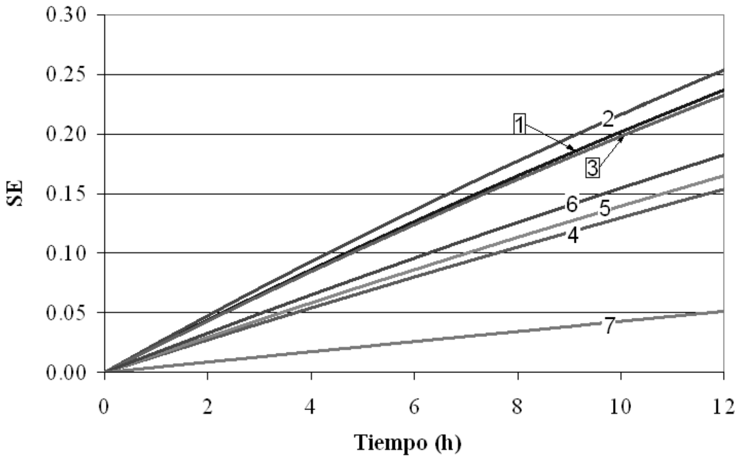


Figure 4- storage efficiency based on the duration of the period of load for all the typologies.

Between the proposed configurations, the number two is the best, while the worst is the number seven, the configurations one and three are close to the best, and configurations four, five, and six, are in a middle area.
If the charge period is eighth hours, the storage efficiency on configuration two, is 18%, while on configuration seven is only 3% (Salmerón, J.M., 2005). It is a remarkable result, because with same geometry of the room, same thermal inertia of the elements, and same initial interior temperature, is possible to storage in the same time interval, until six times more energy, depending only of the position of the air inlet and outlet; and in the consequences over the flow pattern.
An analysis of the different typologies shows that the best ones, are those having an air flow pattern in which the main flow current is in contact with more elements in the room. For example, on typology two the main current of the air flow is in contact with the elements 1, 2 and 3; while on typology seven a short circuit is presented. Typologies four and six are in shot circuit also, but they are not as bad as seven because in this last one, the inlet is bigger than outlet, generating an acceleration of the air flow that make it to exit quickly without making contact with the room walls; while on configuration four and six, the outlet is equal or bigger than the inlet permitting the air to be in contact with the walls.
Some guides of ventilation design, recommends bigger inlets than outlets, in order to accelerate the air in the room for increase the comfort sense of the occupants. It looks a correct consideration from the thermal viewpoint, but making the reservation of which the inlet and outlet are not faced.
On typology three, a short circuit is presented too, but in this case, the main air flow pattern is in strongly contact with the element 3, allowing to remove a big amount of store energy in this wall.

## CONCLUSIONS

We can synthesize the results obtained in the article by means of the following affirmation: “It is very important for the correct quantification of the demand of refrigeration satisfied by the nocturnal ventilation to consider the disposition of the inlets and outlets of air in the enclosure”.

In quantitative form we have demonstrated that with a correct configuration it is possible to store and restore to the space five times more energy than with an unfavourable configuration like the short circuit.

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