Cold storage in the thermal mass of buildings using night ventilation. Experimental analysis

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ABSTRACT

An experimental analysis of the night ventilation technique for cooling in buildings, was performed in a test cell with the aim of establish the potential of this technique in two scenarios: a) when the air-stream is in poor contact with the thermal mass and b) when the air-stream is in close contact with the thermal mass of the test cell. The test cell is a small one-room building equipped with instrumentation for measurement and control the night ventilation following a strategy based in the values of indoor and outdoor temperatures.

The results showed that similar mean daily temperatures are reached when the air stream is in poor contact with thermal mass and when is in good contact. Nevertheless, lower variation in the interior temperature is obtained when the air stream is in good contact with thermal mass, producing better comfort conditions since no very high and low temperatures are achieved in this case.

KEYWORDS

Night ventilation, Thermal mass, Mediterranean Climates, Free cooling

1 INTRODUCTION

In this paper we present experiments conducted within the framework of the project "Analysis of the energy performance of concrete envelopes based on maximizing the benefits of its thermal inertia" (Análisis del comportamiento energético de los cerramientos de hormigón en base a la maximización de las ventajas derivadas de su inercia térmica). The experimental setup consists of a test cells representing a building of concrete that has been instrumented with sensors to record the evolution of the surfaces and air temperatures in the interior; and weather station for recording external conditions. The test cell is located in Alcala de Guadaira, a little town near to Seville Spain.

Night ventilation potential for improving comfort has mainly been investigated by numerical means(Pfafferott et al. 2003). (Artmann et al. 2007) evaluated the potential of passive cooling by night-time ventilation in Europe; they conclude that in the Northern Europe the potential of passive cooling is very significant and it decreases with the latitude being a limited potential in the southern Europe. Nevertheless, several studies shows that this technique can be useful in Mediterranean climates (Irulegi et al. 2014), (Macias et al. 2006), and some of them indicate that the use of the thermal inertia is a key variable in order to obtain a significant reductión of temperatura and cooling loads (Corgnati & Kindinis 2007), (Kolokotroni & Aronis 1999), (Geros et al. 1999).

Experiments performed in the test cell are focused to evaluate the importance of the thermal mass in the effeteness of the night ventilation technique. .

2 EXPERIMENTAL SETUP

The experimental setup consists of a stand or test cell, made of concrete, located in the premises of a cement factory near the city of Seville, Spain, (37º21'35 "N, 5º51'50" O) about 40m altitude. This town is classified as extreme summer and mild winter in Spain.
The interior dimensions of the cell are 2.9m wide, 2.40m deep and 2.40m high. The walls of the north facade, east and west have two layers: the outer concrete is 2500 kg / m3 density and 12cm thick; the inner polystyrene layer is 8 cm thick. The door is located on the north side and is internally insulated by a layer of polystyrene of the same thickness as the walls. The cover is made of concrete with a layer of expanded polystyrene insulation inside 5cm thick.

Ventilation is carried out by mechanical fans drive where 8 147 m3 / h peak flow each, are located in the door of the test cell by way of extraction as shown in figure 1. The consumption of these fans is 140W, though It has confirmed that exist in the market more efficient options that can lower the power consumption to about one tenth.

figure 1 Exhaust fans installed at the door of the test cell

figure 2, schematically shows the outside air, passes first air chamber of the south wall upwards until holes on top communicating with the inside of the building, where the air runs inside of it out by fans located in the rear door (north side).

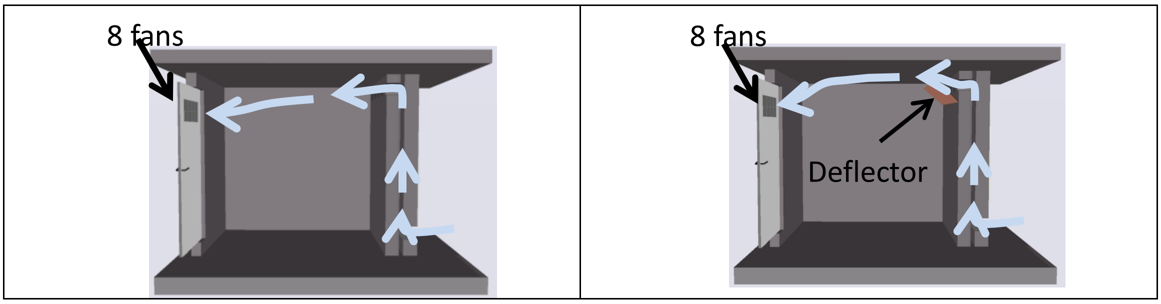

figure 2. Two flow-patterns considered in order to evaluate tye effect of the thermal storage in the roof

In order to evaluate the effect of thermal storage in the concrete slab, two flow patterns were tested: one in which the air enters through the holes directly, and another in which a baffle is positioned to enhance contact between the fresh air and the concrete slab. The baffle was constructed of plywood and installed as shown in figure 3.

The main points of temperature measurement are shown in figure 3. In each of these points a T type thermocouple was connected to a CompactDAQ data acquisition system which provides an accuracy of +/- 0.5 ° C.

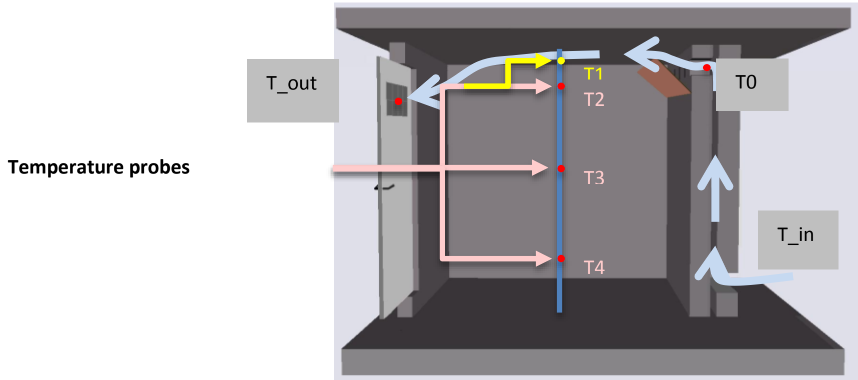

figure 3 Temperature sensors to measure the effect of night ventilation

The starting and stopping of ventilation was controlled by the difference of temperature between the indoor and outdoor temperature, if this was with a value higher than 4ºC, the fans start operation, and stop when the outdoor temperature is inferior to 2ºC.

3 METHODOLOGY

The experiments were performed between 02.09.2014 and 06.10.2014, and consisted of observing the indoor temperature, under different operation modes.

The first experiment, was to let the test cell temperature swings freely without the presence of any forced night ventilation. This took place between 09.02.2014 and 08.09.2014. The purpose of this experiment was to determine the performance of the test cell without night ventilation to evaluate later the effect of ventilation.

The second experiment was to operate the cell at night ventilation scheme without deflector. Under this scheme, air enters and leaves the test cell without having a good contact with the inner surfaces. This experiment took place from 08 to 15 September 2014.

The third experiment is identical to the second except for the placement of a deflector to forces the air stream have a better contact with the ceiling. This experiment was conducted 15.09.2015 and 06.10.2015. The objective of this experiment was to evaluate the effect of cold accumulation in the structure.

In this study, we used a single cell to perform each of these experiments. It has an obvious advantage of cost savings. The disadvantage of using a single test cell is that the excitation conditions are different in each experiment as can be seen in figure 4. The consequence is that the results cannot be compared directly. However, it has carried out an analysis and comparison of the results in relative terms, obtaining consistent conclusions.

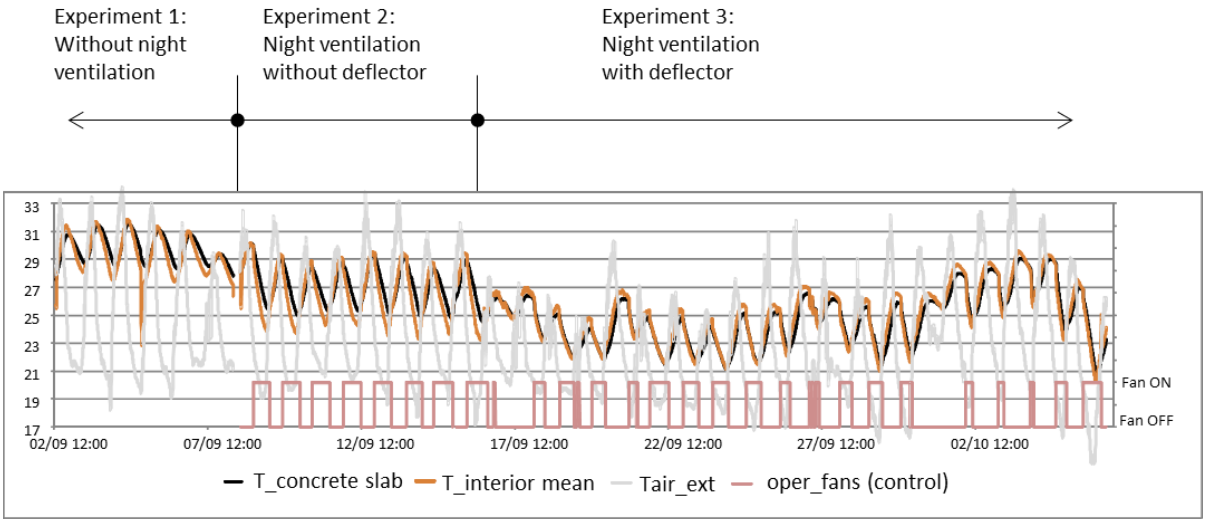

figure 4. Main temperatures of the three experiments performed, and fans operation

The method of analysis of the results was performed in two ways:

Analysis 1: Assessment of the difference between the outside temperature and the temperature inside the test cell

Analysis 2: Evaluation of the daily fluctuation of the temperature inside.

The first analysis gives an indication of the total heat quantity in evacuated form of each operation. Analysis 2 gives an indication of the amount of cold stored in the structure, since a low temperature fluctuation indicates that the cold is stored and transferred slowly during the day.

4 RESULTS AND DISCUSION

For each of the first two experiments, graphics corresponding to three days were selected. The selection of these days was done with the intention that external conditions were similar to each other.

For the third experiment, although the same similarity of external conditions was sought, it was not possible to find a nearby sufficiently clear and for that reason, two periods of three days are shown. In the first period the similarity with experiment 2 is that the operating times of ventilation are similar. With experiment 3, the similarity is that mean temperatures are approximately equal to those of the first two experiments.

4.1 Experiment 1. Without night ventilation

In this experiment the test cell works in free floating mode without any ventilation and air exchange with the exterior except infiltration.

It is worth mentioning that in this period of testing, it was necessary to enter the test cell for reasons of maintenance, resulting in a slight discontinuity in indoor temperatures, as will be seen in the graphs presented in this section. Still, the results are considered to be valid, because that the variations were very small.

The figure 5 shows that the average indoor air temperature and ceiling has an amplitude much smaller than the outside oscillation. This result is expected due to thermal inertia, which is also the one that occurs there is a delay between the highest and lowest points of the temperatures outside and inside.

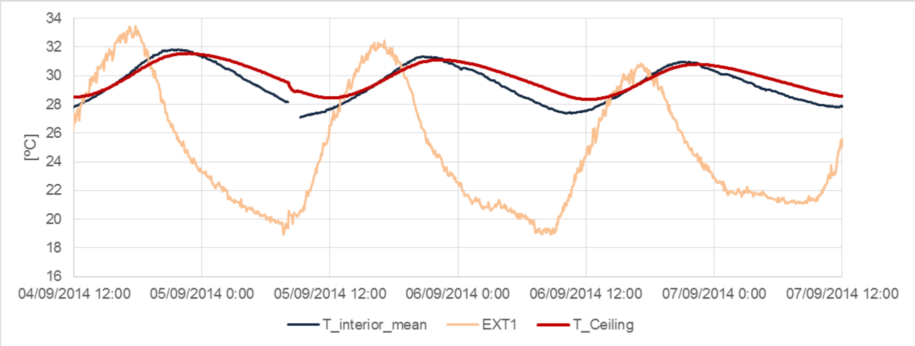

figure 5. Evolution of the interior, exterior and ceiling temperatures in the experiment without night ventilation

The temperature of the ceiling shows that almost always remains above the interior, indicating that the slab provides heat to the test cell, as a result, mainly, of solar radiation incident on its outer surface. It is also evident that the concrete slab has a high thermal inertia due to the thermal oscillation amplitude is less than the interior and their higher delay.

Furthermore, it was recorded in the cell a temperature stratification inside, as shown in figure 6, where it is seen that between the highest and nearest to ground sensor, T4 (0.4m) and T1 (2.32m) the difference is about 2 ° C to remain constant in all the registered period.

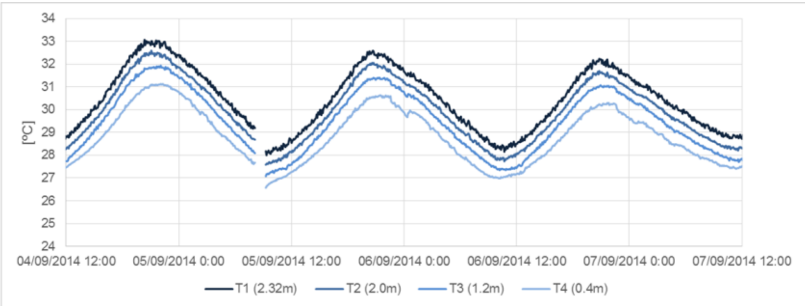

figure 6. Evolution of the interior temperatures at four levels

4.2 Experiment 2. Night ventilation without deflector

This experiment develops a night ventilation controlled by the temperature difference between the outside and inside of the test cell following the criteria mentioned above. The air stream in this experiment is not forced to come in contact with the ceiling.

The behavior of the temperatures shown in figure 7 displays that the average interior temperature descends significantly when fans works, but this also rise sharply when it stops working as result of internal gains produced by equipment inside the tests cell and heat gains through the envelope, where solar radiation plays an important role.

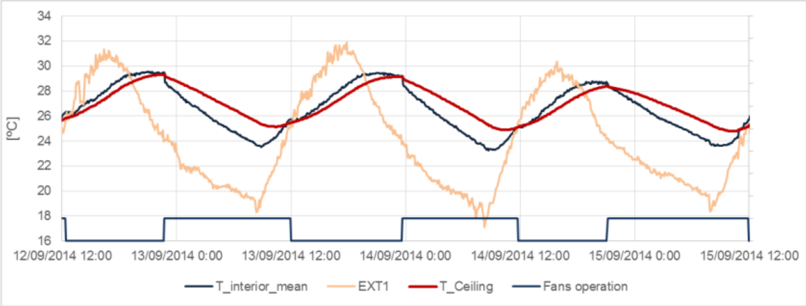

figure 7. Evolution of the interior, exterior and ceiling temperatures in the night ventilation experiment without deflector

The temperature of the ceiling shows a clear signal not to be being modified directly by the ventilation, which can be interpreted as the existence of a poor contact between the air stream and this surface.

From the behavior of air temperatures at different heights shown in figure 8, we can see that in the absence of ventilation, the behavior is similar to that in experiment 1, in other words, if the height is bigger, higher temperature. However, when there is ventilation, the temperature behavior is inverse, that is, the hottest area is the bottom and the cooler is higher; the temperature difference between the upper two points is negligible, it is suggesting that the air stream passes through these two points.

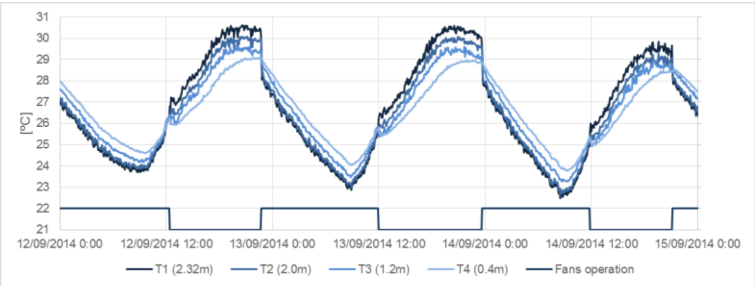

figure 8. Evolution of the interior temperatures at four levels

4.3 Experiment 3. Night ventilation with deflector

The only difference between this experiment and experiment 2 is the installation of a deflector to force the airflow to come into contact with the ceiling.

As stated earlier, it was not possible to find a sequence of three days similar to those of the first two experiments conditions. In this case, two sequences of three days each were selected.

The similarity of the first selected set of three days, is that the periods of night ventilation operation are similar to those of Experiment 2. In this case, the temperature of the ceiling is lower than the mean indoor temperature (figure 9) when the ventilation is off, indicating that cold is accumulated in the slab; and not as in experiment 2 in which the temperature of the ceiling were superior.

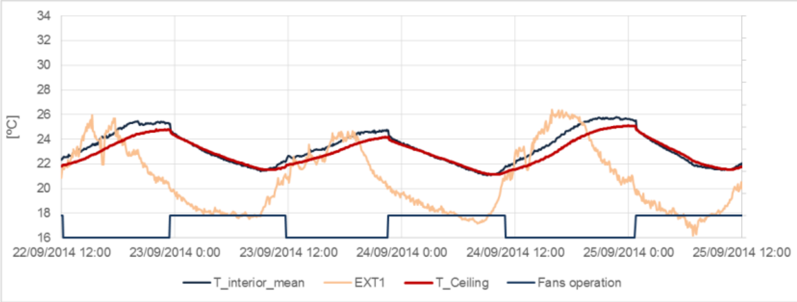

figure 9. Evolution of the interior, exterior and ceiling temperatures in the night ventilation experiment with deflector. First series of days selected in experiment 3

Regarding the temperature stratification shown in figure 10, having a similar behavior of experiment 2 (figure 8), with the difference that in this case the sensor (T1) shows a temperature below the other sensor (T2), which means that the air stream passes to greater heights in this case, as expected.

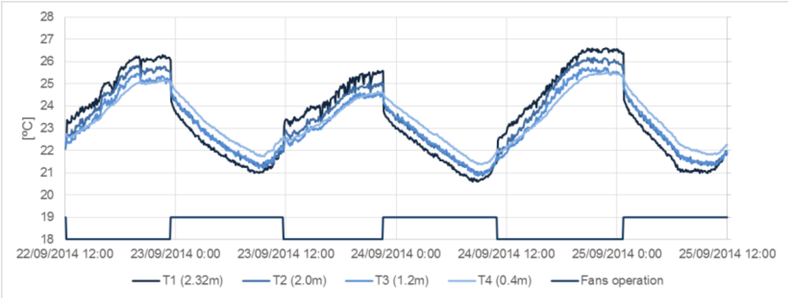

figure 10 Evolution of the interior temperatures at four levels in the first series of days selected in experiment 3

In order to search for lower power consumption of the fans, the value of the temperature difference widened so that it would began to ventilation, the initial value of 4 ° C was passed to 6C, that is, the fans only turned on if the outside temperature was 6 ° C lower than the interior.

The behaviour of the average test cell temperature and ceiling with the new mode of operation is shown in figure 11. It is noted that the operation time of cooling is strongly reduced, but also the decrease of the indoor temperature when ventilation works, is much lower than the previous cases. The oscillation amplitude of the indoor temperature is similar to the case of Experiment 1, namely, without night ventilation values.

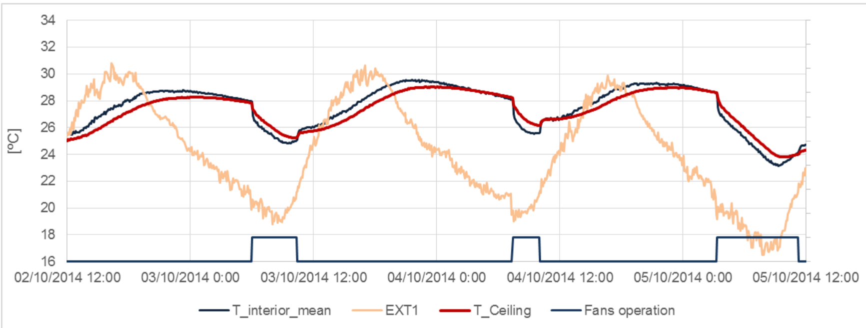

figure 11 Evolution of the interior, exterior and ceiling temperatures in the night ventilation experiment with deflector. Second series of days selected in experiment 3

The stratification of indoor temperatures shows an analogous behavior to that obtained in the case where the control strategy kept the start of fans set for a 4 ° C difference between outside and inside, as can be seen in the figure 12.

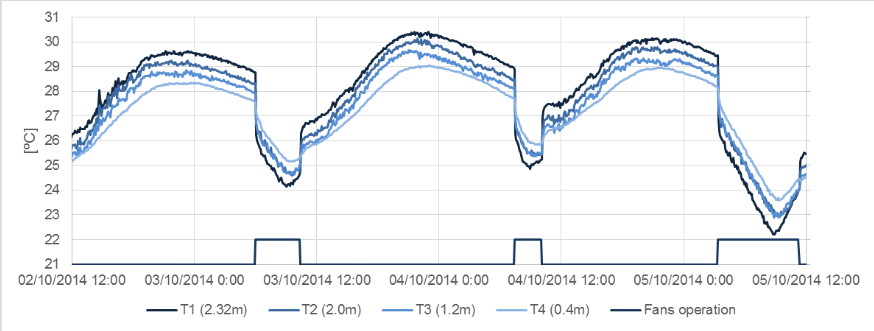

figure 12 Evolution of the interior temperatures at four levels in the first series of days selected in experiment 3

4.4 Summary of the three experiments

In order to obtain an overview of the three experiments and their results, we have condensed the data of the most relevant variables to daily values.

Daily exterior and interior average temperatures are shown in figure 13. The first and obvious observation was that the average temperature of the interior test cell is always higher than the outside. This is because the internal and solar gains through walls and roof are greater than the heat removed by ventilation. Therefore, the smaller the difference between the mean outside temperature and the inside, the better the comfort inside the test cell.

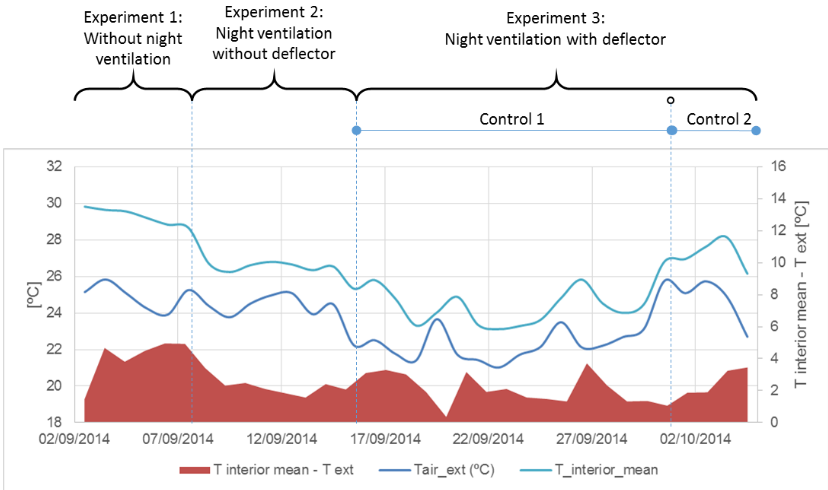

figure 13. Daily mean interior and exterior temperatures

figure 13 also it shows the difference between indoor and outdoor temperature. This temperature difference is lower when night ventilation is applied. In this figure there is not clear difference between the average results of Experiment 2 and Experiment 3, which means that the average daily temperature obtained with and without deflector (with and without thermal inertia) is very similar.
In figure 14, the daily average temperatures of ceiling and interior the test cell is show. In this case, the temperature of the ceiling in experiment 1 and experiment 2 shows higher values than the indoor air. In experiment 3, the ceiling temperature is inferior than that of air. This indicates two things:

1. In experiments 1 and 2, the ceiling is an element that provides heat to the interior while in experiment 3 the cover removed heat.

2. The only plausible explanation for the roof show a lower temperature than that shown in the interior of the cell in Experiment 3, it is that the cover has cooled during the hours of night ventilation. On another hand, because on Experiment 1 is impossible the cold accumulation, and because in Experiment 2 the temperature difference between ceiling and indoor is similar, we can say that the cold storage in experiment 2 is very poor.

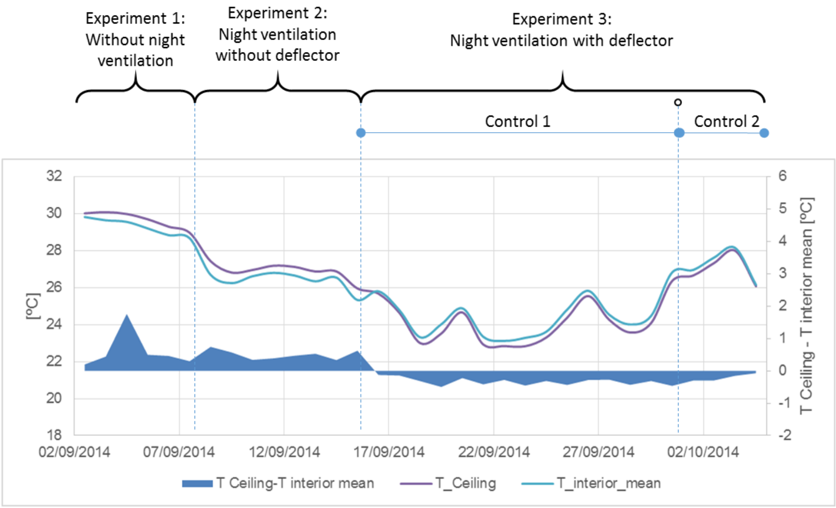

figure 14. Daily mean interior and ceiling temperatures

An extra benefit of the ceiling having inferior temperatures than the indoor air, is the increased comfort conditions, since the operating temperature of the building would be lower in the case of Experiment 3.

An overall summary of three experiments is shown in Table 1. These data ratify the observations done before, that is, the mean temperature in the test cells is lower with night ventilation and this temperature is approximately the same with or without cold storage on the slab. Also, with the experiment 3. The ceiling temperature is lower, indicating that there has been cold storage and in experiment 2, this storage is poor.

Table 1. Global summary of mean temperature differences and temperature oscillation for the three experiments carried out

	Mean Text - Tint	Mean Tceil - Tint	Mean exterior daily temperature oscillation	Mean interior daily temperature oscillation
	[ºC]	[ºC]	[ºC]	[ºC]
Without night ventilation	4.6	0.7	12.6	3.7
Night ventilation without deflector	2.1	0.5	12.5	5.4
Night ventilation with deflector (control 1)	2.2	-0.3	10.2	4.0
Night ventilation with deflector (control 2)	2.3	-0.3	12.7	4.5

However, observing the daily variation of indoor temperature, we see something that had not been evident previously, is that the temperature variation with cold storage on the slab (experiment 3), is significantly lower than without this storage. This is verified by observing Figures 7, 9 and 11. Therefore, although the daily mean indoor temperature is similar with and without cold storage, the difference between the minimum and maximum indoor temperature is lower when cold is storage, producing higher comfort in the occupants.

5 CONCLUSIONS

Three experiments performed in a tests cells located near to Seville Spain, has shown that night ventilation is useful to reduce the daily mean interior temperature approximately 2ºC and this value is independent of the activation of the thermal mass. Nevertheless, when the air stream allows to activate the thermal mass, the mean daily oscillation temperature is approximately 1ºC lower, indicating that daytime temperatures are around 0.5ºC inferior compared with the case in which thermal mass ion not activate.

6 ACKNOWLEDGEMENTS

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