HYGROTHERMAL STUDY OF DWELLING SUBMITTED TO PASSIVE COOLING

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A significant portion of energy consumed in buildings is due to energy usage by heating, ventilation, and air conditioning (HVAC) systems. Free cooling is a good option for energy savings in (HVAC) systems.

In recent years, scientists, engineers, and architects designed successful and innovative buildings which use passive cooling techniques, such as natural ventilation. The house studied in the present work, is a pilot project undertaken jointly by the Centre for Development of Renewable Energies (CDER) and the National Centre for Studies and Research of the integrated building (CNERIB) in the framework of the MED-ENEC project (Mediterranean Energy Efficiency in Construction structure). The house under consideration has a surface area of 65 m² and is located in the region of Algiers which characterized by a Mediterranean climate with relatively mild winters and a hot and humid summer. The aim of this work is to study the thermal comfort inside the house in summer without air conditioning systems, only ventilation is considered. The aim of this work is to study the effect of natural ventilation on both thermal and hygrometric comfort inside the house during the summer period. Numerical simulation is made using the TRNSYS software and the results obtained are in good agreement with measured values. The prototype home is designed in a way that natural ventilation allows thermal comfort which induced energy saving from air conditioning. The mean temperature measured in the interior of the house is 26 ° C. The relative humidity reaches about 70% in August. Thermal comfort is related to relative humidity that are the essential parameters of the feeling of comfort. Humidity is an important parameter in thermal comfort, it is why we can conclude that we have reached a relatively good hygrothermal comfort.

Keywords: bioclimatic housing, comfort hygrothermal, natural ventilation, TRNSYS.

1. Introduction

The rapid growth of energy use in the world has raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts (ozone layer depletion, global warming, climate change, etc.). The global contribution from buildings towards energy consumption, both residential and commercial, has steadily increased reaching values between 20% and 40% in developed countries, which has exceeded the other major sectors: industry and transportation. The growth of the population, the increasing demand for building services and comfort levels, together with the rising in time spent inside buildings, assure the continuity of the upward trend in energy demand the future. For this reason, energy efficiency in buildings is today a prime objective for energy policy at regional, national and international levels. Among building services, the growth in HVAC systems energy use is particularly significant (50% of building consumption and 20% of total consumption in the USA) [1]. More than 90 million people live in the twenty most populated Mediterranean metropolitan areas; according to the actual trend other 70 million people are expected to move leaving the countryside towards the urban area by 2025 [2]. The global warming and the urban sprawl causes a number of environmental hazards, the urban heat island (UHI) are one of these.

This phenomenon is defined as the air temperature increase in a densely built environment with respect to the countryside surroundings.

The main cause of this phenomenon is the modification of the land surface in the urban area, where the vegetation is replaced by extensively built surfaces (typically paved roads and buildings surfaces), characterised by a high solar absorption, a high impermeability and favourable thermal properties for energy storage and heat release, as well as several anthropogenic. The UHI was first monitored in London back to the 19th century [3]; many studies were performed over the last decades [4, 5, 6, 7, 8, 9, 10], showing the quantitative effects of the phenomenon and the correlation with the previously cited causes. The daily mean UHI ranges typically between 2 and 5 °C, while UHI intensities (defined as the maximum difference between urban and background rural temperatures) up to 12°C were measured under particular conditions. This UHI impacts important issues such as the quality of life; the public health (especially for the most vulnerable population); and the environmental hazards.

Construction is one of the most important and significant economic sectors worldwide and represents a global world’s annual close to $3 trillion. This corresponds almost to 10% of the global economy [11]. However, as reported by the United Nations [12], more than one billion people live in squats, slums, and inappropriate houses, while in many cities in the less developed countries, between one and two third of the population live in overcrowded houses of poor quality [13, 14].

Based on a validated building thermal model, dynamic analysis is carried out in order to evaluate the impact of thermal mass, eaves and night ventilation [15]. The results demonstrate that cooling energy demand is more affected by thermal transmittance values than by the envelope thermal mass. A recommended guideline for the optimum overhang length for south facing windows is proposed. Ultimately, it is found that the combination of both natural ventilation and horizontal shading devices improves thermal comfort for occupants and significantly reduces cooling energy demand.

At the new institute building of Fraunhofer ISE, both mechanical and free night ventilation is used for passive cooling of the offices [16]. The results from a long-term monitoring show that room temperatures are comfortable even at high ambient air temperatures. In two offices, experiments were carried out in order to determine the efficiency of night ventilation depending on air change rate, solar and internal heat gains. The aim is to identify the characteristic parameters of the building and also the night ventilation effect with these parameters. The experiments (one room with and one without night ventilation) are evaluated by using both a parametric model and the ESP-r building simulation program. Both models are merged in order to develop a method for data evaluation in office buildings with night ventilation and to provide a simple model for integration in a building management system.

The effectiveness of natural night-ventilation in the urban environment depends on local climate characteristics [17], but also on solar shading and wind shielding effects of the surrounding buildings. However, the impact factor of the latter on the effectiveness of night-ventilation is often disregarded, altering the predicted building energy performance. Building Energy Simulation tools coupled with Air flow Network models allow the estimation of the effect of the urban environment on the cooling energy savings due to night ventilation. Nevertheless, external sources of wind flow data are needed to take into account the wind shielding effect of surrounding buildings. In this paper, the cooling effectiveness of night-ventilation for an office building placed in the center of urban areas of increased density is analyzed for three European locations. The energy demand of the unventilated building is first assessed, with the consideration of the effect of environmental albedo and a simplified Urban Heat Island scenario. Then, night-ventilation rates and energy savings for the ventilated building are calculated to estimate the variation of the cooling effect of night-ventilation. Results show a strong reduction of the energy savings in high-density urban areas and point out that a detailed description of the surroundings is crucial to assess the suitability of passive cooling solutions.

Passive cooling in the built environment is now reaching its phase of maturity [18]. Passive cooling is achieved by the use of techniques for solar and heat control, heat amortization and heat dissipation. Modulation of heat gain deals with the thermal storage capacity of the building structure, while heat dissipation techniques deal with the potential for disposal of excess heat of the building to an environmental sink of lower temperature, like the ground, water, and ambient air or sky.

Among the forms of passive cooling, night ventilation (NV) has been proven to be effective improving the building energy performance [19]. However, in previous studies, fixed NV operating strategies were usually pre-defined, ignoring the weather condition variations over the whole operation process, the influence of outdoor humidity on NV's efficiency, and NV's integrated performance with active air conditioning systems. Such strategies may have potentials for further improvements.

An investigation was conducted in a house dating from the colonial period in Guelma in order to estimate the role of inertia on the hygrothermal comfort [20]. For comparison purposes, a contemporary villa was chosen to assess the impact of thermal inertia on the energy consumption of buildings. The results show that the use of a material adapted to the local climate of the region has led to a good hygrothermal comfort and reduced energy consumption. The validation these results through a simulation using the software TRNSYS.V14 reaffirms the role of the thermal inertia in maintaining the humidity balance inside the house. Although, according to the results, the inertia of materials must be associated with heating means (booster) and natural cooling (night ventilation) in the most unfavorable.

Several works are done on passive cooling by night ventilation and only a few have studied the effect of natural ventilation of moisture in the house. In this article, we analyze the night ventilation effect on the temperature and humidity inside the house studied.

In this work, we give a description of the pilot house; we also explain how the experimentation work is performed. In addition, the mathematical model of our study is presented and how the numerical model is defined. A detailed analysis of the results is presented particularly in terms of temperature and relative humidity in the house and outside the home study. Finally, we give a summary and a conclusion concerning our study.

2. Scope of the research

The studied house [15] which has an area of 65 m², is built in accordance with Algerian building code [21, 22].

The home is located at Souidania (20 km southwest of Algiers, latitude 36_7N, Longitude 03_2E)[15]. The location is characterized by a temperate of a Mediterranean climate with rainy and relatively mild winters and hot-humid summers. The dwelling is designed for good energy efficiency based on optimal insulation of the envelope and the use of solar energy for space heating and domestic hot water production. Its enhanced thermal efficiency reduces energy demand for heating and cooling.

The house is equipped with four thermal solar collectors with a total area of 8 m2. This solar system provides domestic hot water and space heating through the floor. The house has a compact shape and is oriented along the EeW axis. The living room and bedroom have medium size windows (12% of floor area) oriented south in order to gain heat from the winter sun in cooler months. A roof overhang of 75 cm is provided for south-facing windows in order to prevent direct solar radiation during summer. All openings are high efficiency double glazed PVC windows 4/6/4 (4 mm clear glass + 6 mm airgap+4 mm clear glass) with an overall specific heat transfer coefficient of 2.6 W/(m2 °C). The wall facing west has no openings in order to prevent overheating. On the other hand, the house is cooled by passive techniques combining natural ventilation and high thermal inertia walls and ceiling slabs. Prevailing summer winds (sea breeze) are oriented NeE. Accordingly, openings are oriented for optimal exploitation of natural ventilation in accordance with the prevailing wind pattern. Moreover, occupants have the possibility of controlling the ventilation rate by operating windows.

Fig.1. the house investigated [15]

The data acquisition system consists of a computer and a Keithley digital multi-meter 2700. A set of type-K thermocouples is used to measure temperatures at several locations.

Thermo-hygrometers (TESTO 175-H1) are installed at 1.5 m from the ground for measuring internal ambient air temperature and relative humidity.

The temperatures and relative humidities are measured and recorded every 30 min. During the monitoring period, the prototype dwelling remained unoccupied. During the summer season, to control night ventilation, the windows are open from 9:00 pm until 7:00 am. The shutters are closed during the day to avoid heat gains due to solar radiation.

3. Dynamic hygrothermal model

The dwelling is modeled using TRNSYS with Type 56 [25]. Before discussing the impact of passive techniques on the reduction of energy demand, simulation results are first compared with experimental measurements.

In the present study, we investigate the effect of natural ventilation on hygro-thermal comfort inside the house. Thermal comfort aims to achieve a set temperature bearable by people, but also moisture is an important parameter in the thermal comfort conditions.

Heat balance and mass of ambiance

The temperature and the relative humidity of the atmosphere inside the habitat are assessed taking into account the heat gain and moisture through the building envelope, the internal sources and HVAC equipment. Equations 1 and 2 govern transfers in the ambiance [23,24]. The heat balance is assumed in a way that: (1) the air temperature is uniform, (2) all the radiations are distributed so that the surface absorption per unit area is constant, (3) the convective and radiative exchange coefficients of are the same for all surfaces. The heat balance can be described as follows:

$$\rho.C_P.V.\frac{\partial T}{\partial t}=\sum_j A_j\alpha_j\left(T_j-T_i\right)+Q_{sol}+Q_{in}+n.V.\rho.C_P.\left(T_0-T_i\right)+Q_{ven} \tag{1}$$

The moisture balance can be expressed as follows:

$$V\frac{\partial \nu_i}{\partial t}=\sum_j A_j g_{m,j}+M_{prod}+M_{HVAC}+n.V.(\nu_0-\nu_i)+M_{ven} \tag{2}$$

4. Results and Discussion

The data concerning different parameters measured inside and outside of the house are represented in graphical form as follows:

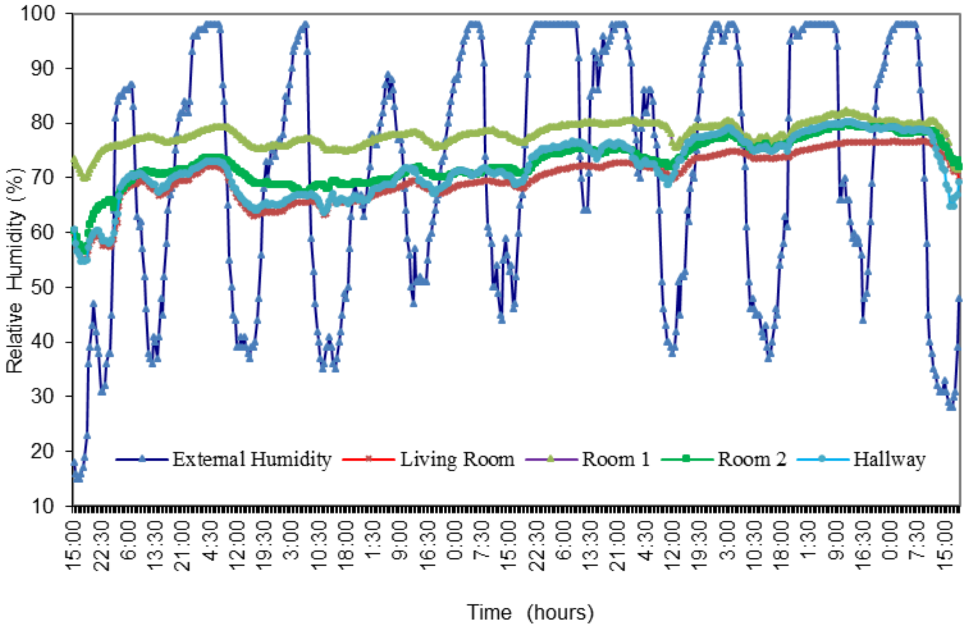

Fig.2. Variation of relative humidity in the dwelling from august 12th to august 22th

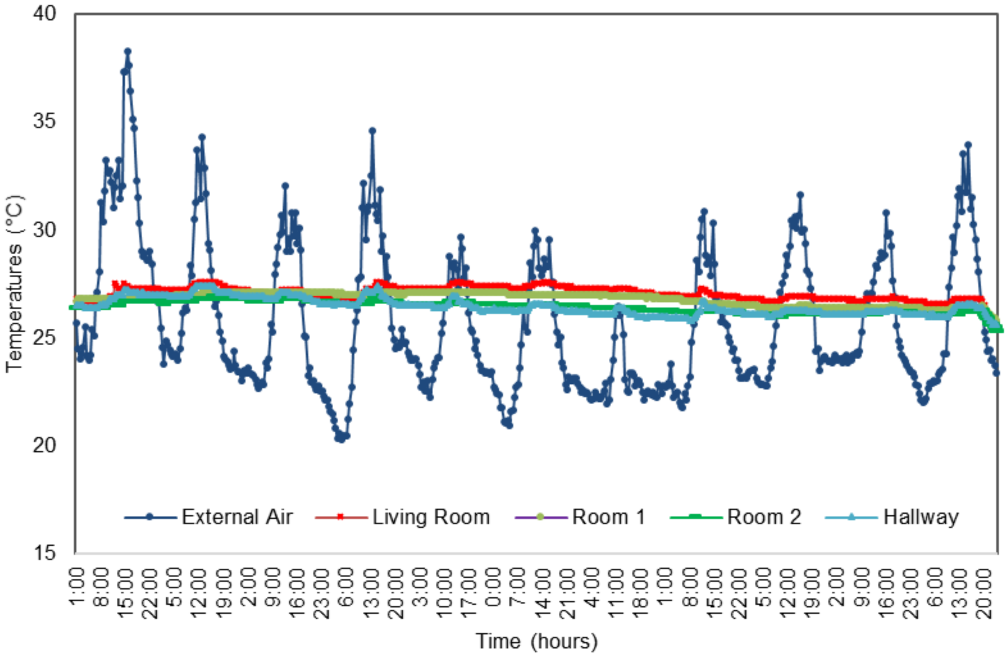

Fig 3. Temperature measured inside the house

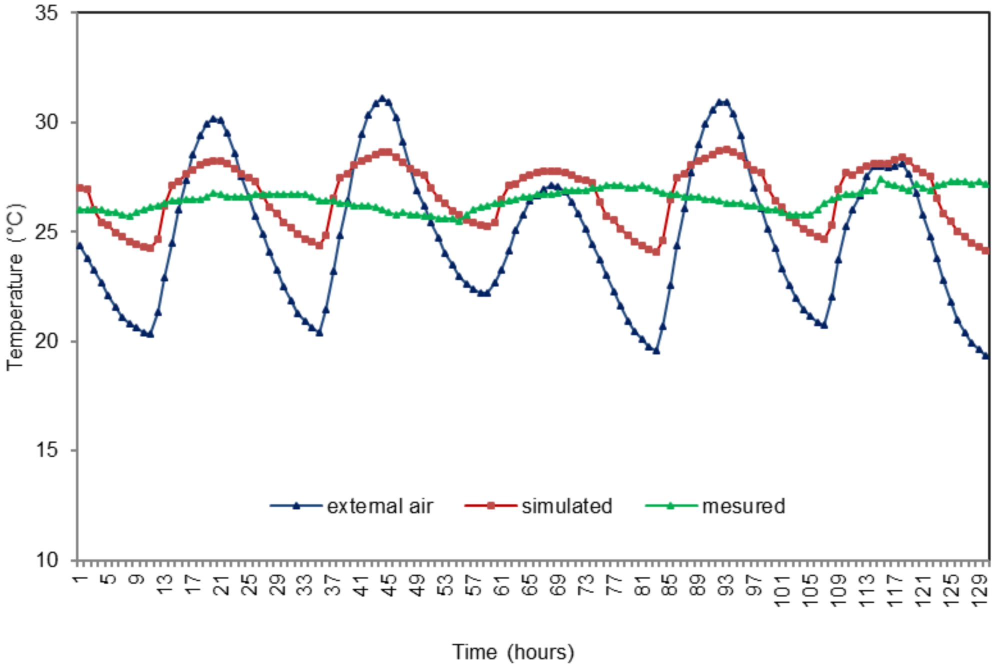

Fig 4. Temporal Evolution of the outdoor temperature and the temperature inside the house

Variation of the relative humidity

The humidity is an important parameter for thermal comfort, for this, it has been measured and analyzed. Figure 2 illustrates the variations of the relative humidity inside the house. The measurement campaign presented is chosen between 12 and 22 August.

This period represents the warmer part of the season. Values range between 55% and 70% in the living room, room 2 and hallway.

For the Room 1 which is located on the south-west side, the relative humidity is between 73% and 77%.

Outside, the relative humidity varies between 18% and 98%.

Temperature variation

The outside temperature during this period is between 20.44 ° C and 38.26 ° C.

In the house, the temperature hovers around 26 ° C, which is quite comfortable.

Fig 3. Illustrates the changes of temperatures measured in the bedrooms, the living room, and hallway, and are almost constant around 26 ° C.

Comparison of measured values with those obtained from simulation using TRNSYS [25].

The temperature measured in the house during a week of August is almost constant about 26 ° C (see fig4.).

The values obtained via simulation using TRNSYS range between 24 ° C and 27 ° C.

On the same figure is shown the outside temperature, it ranges from 20 ° C to 32 ° C for the same period.

We plotted the temperatures measured in the house during a week of August, which the hottest month in Algeria, and compared with the simulation results obtained from the TRNSYS software.

We conclude that the measured temperatures are comfortable and constants. Simulated temperatures are unstable to plus or minus 4 ° C; this is due to other factors which will be explored in the future.

Calculation error

Maximum absolute error(°C)	Minimum absolute error(°C)	Mean absolute error(°C)
2,03	0,2	1,29

The maximum error is 2,03 ° C, which is acceptable to validate our model.

5. CONCLUSION

Natural ventilation is one of the passive cooling techniques used in buildings.

We adopted this technique to study the effect of natural ventilation on both thermal and hygrometric comfort inside the house during the night in the summer period. It was found that the temperature can be as close as 26 ° C and the relative humidity fluctuates between 60% and 70%. This improves greatly both thermal and hygrometric comfort. However, concerning the hygrometric comfort, the relative humidity is slightly higher than the desired value which is about 50%. One way to reduce this value is to add a passive dehumidifier in the house. This opens up an additional possibility to improve the hygrothermal comfort in the building using passive and free systems, which we will investigate in a future work.

6. Nomenclature

Aj : exchange area [m²]
Cp : specific mass capacity [m3.kg-1]
gmj : moisture flow [kg.s-1.m-2]
M: rate of moisture production [kg.h-1]
β: air change rate [h-1]
Q: heat flow [W]
V: volume [m3]
T: temperature [K]

Greek symbols

ν: vapor content [kg.m-3]
νo: vapor content of the air outside [kg.m-3]
νi: Vapor content of the air inside [kg.m-3]
ρ: Density [kg.m-3]
αi: coefficient of convective exchange [W.m-2.K-1]

Indices and exponents

in: internal, interior
prod: production
sol: solar radiation
ven: ventilation

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