PASSIVE COOLING OF HOUSING BY NATURAL VENTILATION

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Abstract

The building's form and thermal characteristics largely govern the amount of energy consumed by a building. To avoid major flaws of the design, an architect needs to include the evaluation of the building's energy consumption in the earlier stages of the design process. If energy efficiency is not adequately considered during these stages, higher operating cost will accrue over the life of the building. In recent years, scientists, engineers and architects designed successful innovative buildings that use passive cooling techniques, such as natural ventilation. The house studied is a pilot project undertaken jointly by the Centre for Development of Renewable Energies (CDER) and the National Centre for Studies and Research of integrated building (CNERIB) under the MED-ENEC project (Mediterranean Energy Efficiency in Construction structure). The house subject of study is 65 m² surface area, located in the Algiers region characterized by a Mediterranean climate with relatively mild winters and hot, humid summer. This work is to study the comfort inside the house in the summer without air conditioning, ventilation only is considered. Numerical simulation is made under TRNSYS, the results compared with measured values are conclusive.

Keywords: bioclimatic housing, natural ventilation, TRNSYS, energetic efficiency in the building

1 Introduction

The effects of global warming and climate changes are of relevant concern for environment and human activities in the Mediterranean area. The average air temperature rise of 2 ◦C represents a critical limit beyond which dangerous climate changes should occur by 2030 [1]. More than 90 million people live in the twenty most populated Mediterranean metropolitan areas; according to the actual trend other 70 million of people are expected to move to leave 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) is one of these.
This phenomenon on is defined as the air temperature rise in densely built environments respect to the countryside surroundings.

The main cause 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 high solar absorption, 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 during the past decades [4–10], showing the quantitative effects of the phenomenon and the correlation with the previously enounced causes. Daily mean UHI typically ranges between 2 and 5 °C, while UHI intensities (defined as maximum difference between urban and background rural temperatures) up to 12°C were registered under particular conditions. This UHI impacts important issues such as: the quality of life; the public health, especially for the most vulnerable population; the environmental hazards.

Construction is one of the most important 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 of people live in squats, slums and inappropriate houses, while in many cities in the less developed world between one to two third of the population live in overcrowded poor quality houses [13,14].

Based on a validated building thermal model, dynamic analysis is carried out in order to evaluate the impact of thermal mass and of 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 dependent on air change rate, solar and internal heat gains. The aim is to identify characteristic building parameters and to determine 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 programme. 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 of the latter factors 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 estimating 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 account for 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, also considering 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 is 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.

As one form of passive cooling, night ventilation (NV) has been proven effective to improve the building energy performance [19]. In previous studies, however, 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. This paper presents a systematic approach to address the dynamic optimization of integrated operation of NV and active building air conditioning using typical variable–air–volume (VAV) systems as the case. In the optimization scheme, the physical model is developed per differential algebraic equations (DAEs). The simultaneous collocation method is introduced to translate the dynamic optimization into a nonlinear program, which is then implemented in the GAMS platform and handled by IPOPT solver.

2 Description of the pilot dwelling

The pilot dwelling is a low-energy house [15] with 65 m² net floor area; 3 rooms, 1 kitchen, 1 bathroom, and lavatories. The prototype (Fig. 1) is designed as a typical single family home; it is built in accordance with Algerian building code [20,21]. The home is located at Souidania (20 km southwest of Algiers, latitude 36°7N, Longitude 03°2E). The location is characterized by a temperate 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 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.

Figure 1: The prototype dwelling [15]

3 Experimental study

Description of the monitoring system
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.

A weather station WMR918 is installed near the prototype at 7 m from the ground. This station is used to measure wind velocity, external air temperature and external relative humidity. Horizontal global solar radiation is measured with a CM3 KIPP&ZONEN pyranometer. All temperatures are measured and recorded every 30 min. During the monitoring period, the prototype dwelling remained unoccupied and shutters were closed.

4 Analytical study

The prototype dwelling is reproduced as virtual model using TRNSYS Version 16 (a transient thermal energy modeling software developed at the University of Wisconsine Madison). The dwelling is modeled in TRNSYS with Type 56 using 8 zones: 3 rooms, kitchen, bathroom, lavatories, hall, and attic. Before discussing the impact of passives techniques on the reduction of cooling energy demand, simulation results are first compared with experimental measurements.

In the present study, we studied the effect of natural ventilation on thermal comfort inside the house.

Natural ventilation

Night ventilation can be considered as the lowest-cost cooling technique contributing to the reduction of the cooling load of buildings and to the improvement of thermal comfort of occupants.

This technique takes advantage of the cool outside air during night by opening windows; this decreases indoor air temperature as well as the building structure temperature. Ventilation is due to the pressure difference between the inside and the outside of the building caused by wind flow and air temperature difference. De Gids and Phaff [22] propose an expression for the ventilation airflow rate 'Q' (in m^3/s) for a single-side ventilated building which developed through experimental measurements. Although this expression does not take into account the wind incidence angle, it can be adopted for low-rise buildings [23].

$$Q = \frac{A}{2}\left(c_1 U_{10}^2 + c_2 H \Delta T + c_3\right)^{\frac{1}{2}} \quad (1)$$

Where c_1 (c_1 = 0.001) is a dimensionless coefficient, c_2 and c_3 account for buoyancy (c_2 = 0.0035 m/s^2.K) and wind turbulence (c_3 = 0.01 m^2/s^2). A (m^2) is the opening area, U_{10} (m/s) is the mean wind speed at 10 m high and ΔT (K) is the mean temperature difference between inside and outside. Calculations yield a value of average fresh air volume flow rate entering the room reaching up to 0.1 m^3/s correspondent to an air-change rate (ach) of 8 h^{-1} if the window is entirely open. If windows are open with shutters closed, it is supposed that the average fresh air volume flow rate entering the room would be divided by two (ach = 4 h^{-1}).

5 Interpretation of results and discussion

The outside temperature varies sinusoidally between 26 and 31 ° C during the week of August (see figure 2). The house remains at a comfortable temperature ranging between 25 and 27° C. measures are consistent with the simulation.

The temperature inside the house are measured in the three bedrooms and in the living room, the temperatures are almost the same and vary from 24 to 28 ° C for an outside temperature of 19-31° C(see figure 3).

According to figure 4, the global solar illumination in a plane sensor reaches 800 W / m² for a day of August in Algiers. The outdoor temperature is approaching 35 degrees or more.

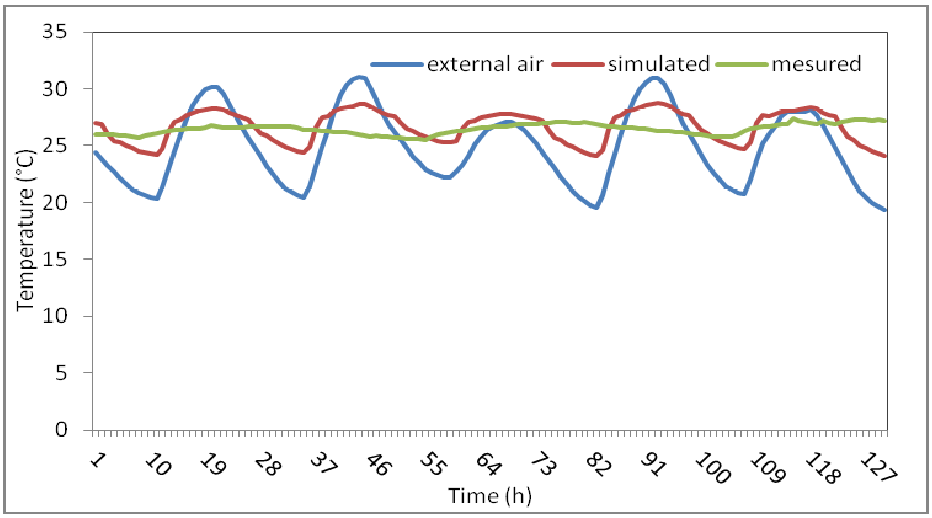

Figure 2: Evolution of the outdoor temperature and the temperature inside the house

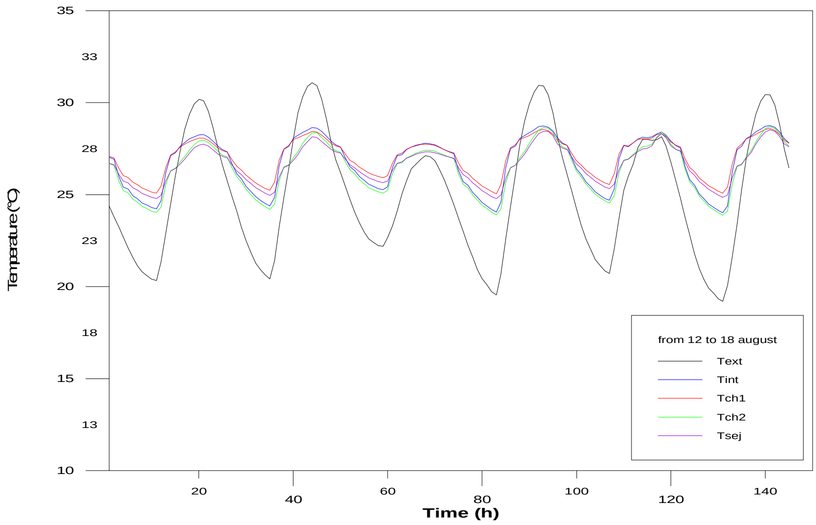

Figure 3: Evolution of inside temperatures of house and external temperature during one week of august

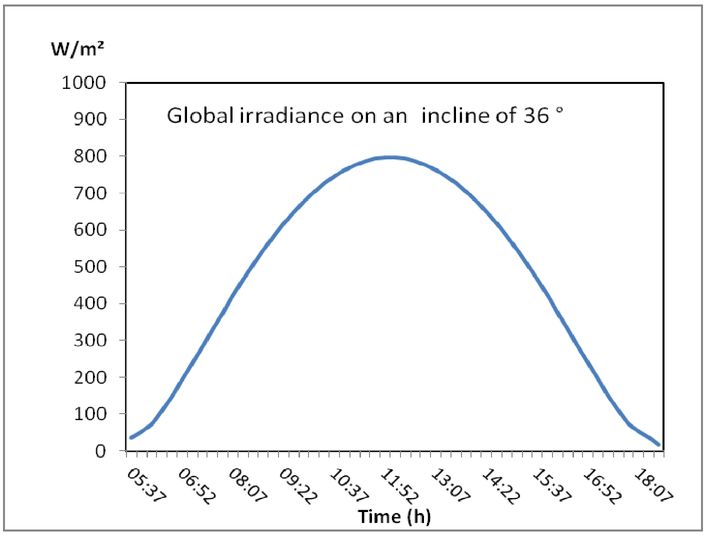

Figure 4: Average daily solar irradiance for August

6 Conclusion

A significant portion of energy consumed in buildings is attributed to energy usage by heating, ventilating and air conditioning (HVAC) systems. Free cooling is a good opportunity for energy savings in air conditioning systems [24].

The prototype home is designed such that natural ventilation allows thermal comfort which saves us air conditioning. The temperature measured at the interior is 25 ° C. we can say that we have a bioclimatic habitat [25].

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