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Natural cross ventilation in buildings on Mediterranean coastal zones

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ABSTRACT

Natural ventilation of buildings is a common way to improve indoor air quality, thermal comfort in summer and reduce energy consumption due to air conditioning. However, efficiency of such a system is highly dependent on climatic conditions. This paper investigates the use of thermal breezes, characterized by moderate speeds and well-defined direction, to improve natural cross ventilation technique on Mediterranean coastal zones. The interest of this phenomenon is highlighted by the development of climate indicators with meteorological data from various places in Corsica (France). A statistical wind rose is used to give more information on main wind sectors and speed fluctuations. The natural ventilation potential is assessed by a radar plot which groups the main climate indicators for comfort ventilation and passive cooling. Tracer gas measurements on a seaside building in Corsica show that high air change rates are reached by cross ventilation during day (higher than 25 ACH). Night ventilation gives more moderate results for passive cooling with air change rates close to 10 ACH. As the comfort in building is related to the airflow, it is necessary to be able to control it. The issue of controlling openings to maintain a satisfying airflow is treated with the help of an empirical model. Due to the regularity of thermal breezes, it shows that even if the airflow varies greatly during the day, a minimal control on opening surface is sufficient to maintain the airflow rate on a comfortable range.

1. Introduction

In France, the building sector is the largest energy consumer, accounting for over 45% of the total energy consumption. It is also the sector where the most important energy savings can be done. Rehabilitation or conception of a building must take into account the environment in which the building is or will be located: evolution of temperatures and relative humidity, wind profile, solar resource, shadings, etc. As shown in the French research project VALERIE [1], energy consumption of a building can be greatly reduced if it effectively exploits the resources of the environment. The design of typical low energy buildings, usually focused on thermal insulation, deprives them of these resources. It is therefore necessary to focus on the availability of these resources accorded to the needs of the building, which are different depending on the building location and evolve throughout days and seasons.

France has a great climatic diversity. As defined in the thermal regulation of buildings (RT2012), it is composed of eight climate zones. Joly et al. also propose a map based on an abstract partition of the factorial space organized by order structure [2]. Using a local interpolation method performed on a time series of 30 years, eight climates have been identified and mapped on the French territory. A coefficient involved in regulatory calculations to obtain labels such as the BBC (low-energy consumption building), varying the maximum consumption of primary energy between 40 and 75 kWh m^{-2} $year^{-1}$ depending on the climate zone. This significant variation shows the impact of climate on the energy consumption of buildings and the will to take it into account. However, even within the same climate zone, all regions are not subject to the same climatic conditions and therefore cannot benefit from the same resources. This diversity shows the great importance of adopting a bioclimatic approach [3].

Mediterranean climate is a temperate climate, characterized mainly by hot and dry summers and mild and wet winters. It induces specific energy needs in buildings, air conditioning needs being the most important. Consideration of this climate during summer and its consequences in terms of comfort is a characteristic of Mediterranean buildings [4,5]. For this purpose, we focus on natural ventilation which exploits free resources to improve summer comfort in buildings [6,7].

This work has different objectives. First we investigate the interest of wind resource by developing climates indicators which use standard meteorological data without the need of complex and time-consuming building simulations. These indicators give wind

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characteristics of a site and highlight the capabilities of natural ventilation for a given building. This study focuses on coastal thermal breezes which appear to be interesting for cross ventilation. The second objective is to assess the airflow reachable by cross ventilation on a seaside building. Both tracer gas measurements and empirical modelling are used to get an estimation of the airflow rate. The high airflow expected during day leads to the issue of how to limit it [8]. The use of operable windows which adapt depending on the airflow rate appears to be a relevant solution. As a first approximation, an empirical model allows to assess the technical effectiveness of this control system.

2. Natural ventilation in buildings

Building ventilation, both mechanical and natural, can occupy several roles such as ensuring the indoor air quality, improving thermal comfort in summer and reducing energy consumption due to air conditioning. Natural ventilation has the advantage of exploiting a free and abundant resource and remains easy to use. It improves occupant comfort by creating air movement in the building and by cooling the building structure at night with lowest outdoor temperatures. Neglected since the 50s for mechanical systems of ventilation and air conditioning they tend to disappear from constructive methods. However, natural ventilation fits perfectly with the current issue which is to design low-energy buildings with low emissions of greenhouse gases.

There are two types of physical phenomena which induce naturally an airflow in the building, one by wind effect and the other by stack effect. They can occur simultaneously but the effect of one of them generally predominates over the other. If there is wind, the wind effect is usually more important than the stack effect but the interaction between this two phenomena can be more complicated [9].

2.1. Natural ventilation by wind effect

Natural ventilation by wind effect is simply done by openings positioned on the axis of the wind. The pressure difference induced can be described by [10]:

$$\Delta_p = \frac{1}{2} C_p \rho v^2 \tag{1}$$

where C_p is the pressure coefficient, ρ the air density and v the wind speed.

Only one opening is needed to create an airflow inside the building, but higher flow rates are achieved with cross ventilation. Walls containing the openings do not necessary need to be exactly on the wind axis. According to Givoni [11] an angle between 30° and 60° to the building allows better ventilation. Potvin and Demers [12] also announced that a building at 45° relative to the prevailing winds will maximize high and low pressures improving natural ventilation. However, the effectiveness of such system depends strongly on the wind profile of the site, the design of the openings and the building geometry. Sobin [13] studied the effect of the shape of the openings and the wind direction on air velocities inside the building with wind tunnel experiments. Ji et al. [14] also studied the effect of fluctuating wind direction on natural cross ventilation. It appears that under real conditions these parameters fluctuate constantly and have a significant impact on airflow rates and therefore on the efficiency of the system.

2.2. Natural ventilation by stack effect

Natural ventilation by thermal buoyancy is due to the difference in density between the air inside and outside the building [10]:

$$\Delta_p = \rho_i g h \frac{T_i - T_o}{T_o} \tag{2}$$

where ρ_i is the internal air density, g the acceleration due to gravity, h the vertical distance between the two openings, T_i the inside temperature and T_o the outside temperature.

This method is possible as there is a temperature difference between the inside and the outside. However, it does not achieve the high ventilation rates obtained by wind effect. Moreover, the position of the openings must respect more accurate guidelines. Here, it is necessary to have a lower opening and a upper opening such as a roof evacuation.

2.3. Comfort ventilation

Natural ventilation can be used in two distinct ways: for comfort ventilation during day and for cooling the building at night. However, according to Givoni [15] these two techniques are not compatible. Comfort ventilation only improves the physiological comfort of the occupant by creating an airflow and does not allow to reach a set temperature. If the outside temperature is higher than the inside temperature, it will warm the room and the night ventilation will be less effective. For optimal use of day time comfort ventilation the building should not absorb and store heat, it must focus on lightweight structures (wood, lightweight concrete, perforated brick, etc.). In terms of climate, the maximum temperature should not exceed 28–32 °C depending on acclimatization of the occupants [16]. This strategy is preferred if the difference between day time and night time temperatures is less than 10 °C. It is used especially in tropical climate, characterized by a low thermal amplitude and thus with a low potential of passive cooling. The CSTB (Scientific and Technical Centre for Building) studied consideration of climatic parameters in the habitat on humid tropical climate [17]. It appears from this study that with wind speeds greater than 1 m/s at the openings of the building it is possible to effectively remove heat gain due to the sun and internal loads and improve the feeling of comfort. If the use of natural ventilation is not possible, a similar comfort can be achieved by using a fan. However, it will cause an additional cost due to power consumption and will not evacuate the internal loads (up to 9.1 kWh m^{-2} year^{-1} [18]).

2.4. Night ventilation

Night ventilation allows to cool the building structure by convection and store cold to ensure thermal comfort during the day. To optimize its efficiency the building must not be opened during the day to not let enter warmer air. It should also benefit from adapted solar protections to minimize solar gain. Furthermore, the structure of the building must allow cold storage (heavy structure) and have a good thermal insulation [15,19]. In terms of climate, the thermal amplitude should be the greatest possible for better efficiency. The use of this technique is very interesting for amplitudes of 10 °C and more. Many studies have shown the interest of night ventilation, based on experimental and numerical results [20–23]. According to a study performed in the UK this process allows up to 40% energy savings if the building is optimized for natural cross ventilation [22]. Blondeau et al. [20] are also interested in the impact of the set temperature on system performance. In this study, if natural ventilation is not sufficient, the set temperature is reached by a mechanical cooling system. The contribution of natural ventilation is only 12% for a set temperature of 22 °C but reaches 54% for a set temperature of 26 °C. Performances vary greatly depending on