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Judicious choice of the building compactness to improve thermo-aeraulic comfort in hot climate

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ABSTRACT

The geometric shape and arrangement of the buildings have a great influence on the indoor climate. Compactness is one of the most important factors, which reduces heating and cooling requirements. These parameters result from geometrical concepts, used to maximize the internal volume of the structure according to its shape. The present study aims at developing a new approach for transient thermal behavior simulation of multizone buildings in Saharan climate. Thermal nodal method was used to apprehend thermo-aeraulic behavior of air subjected to varied solicitations.

As result, this work proves that the compactness is better when the compactness index is lower. For this reason, we must privilege some urban typologies such as the rows of terraced houses, collective buildings and high-dimensional buildings.

1. Introduction

In desert regions, poor adaptation of the building design and its indoor environment can result in a greater need for active climatisation and, thus, increased energy use. In a warm and dry climate, the design and construction of a building involve the adoption of three elements: typology, shape and technology. The shape of a building is one of the keys to achieving the relationship between cost and performance. A building is an inhabitable volume delineated by an enveloping surface that separates it from the exterior. The relationship between this surface and the volume contained is usually called the shape factor or the compactness index of a building. This coefficient is responsible for the characterization of the contact mode of the building with the exterior [1–2], and it is considered only from the point of view of compactness. Thermal behavior analysis is very important both for the control of indoor comfort conditions and energy requirements. However, the relationship between shape and energy requirements is still an open question [3].

In the professional practice, the most used index is the shape coefficient defined as the ratio between the envelope surface of the building (i.e. the external skin surfaces) and the inner volume of the building [3]. In this field, several studies have been made. Depecker et al. [4] studied the relationship between shape and energy requirements during the winter season in two French localities with different climate conditions. In Ref. [5], energy consumption was analyzed according to building shape and mixed-use development through quantitative data and a review of the energy consumption characteristics of the residents through empirical surveys. Tsanasa and Xifarab [6] conducted a study on the effect of the relative compactness and other input variables on heating load and cooling load of residential buildings. Granadeiro et al. [7] mention that the architectural design variables which most influence the energy performance of a building are the envelope materials, shape and window areas. Designers require simple tools to obtain information about the energy performance of the building. The shape factor is one of those tools. However, in Ref. [8], it is noted that shape coefficient is a key factor to evaluate building energy efficiency. Heat transfer quantity through envelope is obviously different due to different building shapes. Aksoy and Inalli [9] also studied the building orientation and shape as practical passive parameters. They demonstrated the importance of building orientation and shape to extract solar energy effectively. Therefore, several elements, such as southern window and northern façade insulation, natural ventilation, zoning plan elements, should be considered and determined during the

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Nomenclature

S	surface (m^2)
j	number of the inner surface (wall, door and window) in zone i
$NW(i)$	total number of the interior surfaces (wall, door and window) in zone i
$T_{al}(n)$	air temperature of the zone n=air température entering the zone i (K)
T_{sij}, T_A	temperature of surface j in zone i (K)
$r_s(i)$	specific humidity: mass of water vapor contained in the unit mass of dry air (kg_{vap}/kg_{as} or %)
H_r	relative humidity (%)
P_{sat}	pressure of saturation vapor (Pa)
L_v	latent heat of vaporization of water ($J\ kg^{-1}$)
C_v	heat capacity at constant volume ($J\ kg^{-1}\ K^{-1}$)
C_{as}	heat capacity of the air mass ($J\ kg^{-}1\ K^{-1}$)
H_s, H_L	sensitive and latent enthalpy of the humid air (J)
$H^e(i)$	enthalpy of the humid air mass entering the zone i (J)
$H^{leav}(i)$	enthalpy of the humid air mass leaving the zone i (J)
$Q^{trans}_{mas}(n, i)$	mass flow transiting from zone n to zone i (kg/s)
$Q^{trans}_{mas}(i, n)$	mass flow of the dry air transiting from zone i to zone n (kg/s)
CI_s, CI_L	internal sensitive and latent powers due to appliances, occupants, lighting…(W)
P_s, P_L	sensitive and latent powers provided by the air-conditioning (W)
$V(i)$	volume of zone i
$v_s(i)$	specific volume of the humid air in the zone i
e	thickness (m)
n	number of node
α	absorption coefficient
ε	thermal emissivity
G	the incident global irradiation on the surfaces ($W\ m^{-2}$)
λ	thermal conductivity ($W\ K^{-1}\ m^{-1}$)
c_p	specific heat ($J\ kg^{-1}\ K^{-1}$)
ρ	density ($kg\ m^{-3}$)
F	form factor between the exchange surfaces
σ	Stefan–Boltzmann constant ($W\ m^{-2}\ K^{-4}$)
V_{vent}	wind speed ($m\ s^{-1}$)
h_{conv}	convective transfer coefficients ($W\ m^{-2}\ K^{-1}$)
M_{as}	molar mass of dry air ($g\ mol^{-1}$)
M_v	molar mass of water vapor ($g\ mol^{-1}$)
P	total pressure (Pa)
P_{vs}	saturated vapor pressure (Pa)
Gr	Grashof number
Pr	Prandtl number
h_{Conv}	the heat exchange coefficient by convection ($W/m^2\ K$)
ΔT	temperature difference between the wall and the surrounding air (K)
L	characteristic length (m)

schematic design phase. As these kinds of elements strongly influence building shape and size, they are directly related to construction costs as well as energy performance [10]. In [11] it is proved that generally, annual energy consumption increases as the courtyard building shape gets longer as a direction of prevailing wind.

A simplified thermal model for the prediction of the thermal performance of buildings is proposed by Mathews et al. [12]. In [13] a coupling between a building thermal simulation code and genetic algorithm was made to estimate the internal temperatures. However, the effect of the choice of thermal comfort model on the building's energy use is analyzed by Sourbron and Helson [14]. While Siddharth et al. [15] mentioned in their article that there are a limited number of available techniques for non-linear systems.

In these works, a method for reducing the order of dynamic models of temperature and humidity in multi-zone buildings is proposed. With the present studies, we can aim the advantage of a proposed new approach to the description of the thermo-aeraulic behavior in a multizone building. The evaluation is derived from a series of computer simulations. The most of current building simulation programs lack the capability to properly model emerging building energy systems due to the negligence of the humidity. Thermo-aeraulic modeling is essential for establishing overall thermal performance values and understand how different assembly designs perform under different interior and exterior climate conditions. This tool is used to evaluate the performance of a proposed architecture for a real building located in a very hot climate. We propose from a geometric analysis, an evaluation of the temperature and the specific humidity according the contact mode, geometric form, and making enlargement plans. Through the expected results, we can address a significant technical guide to the architect. Our contribution essentially allows us to offer the best technical solutions in terms of: dimensions intended to be used in the design of buildings, preferred building size and the most recommended geometric form for the realization of such building components.

2. Multizone building modeling

Developing a detailed thermal building simulation model may take several months if not a year of development time. Commercially available detailed building energy simulation programs, such as EnergyPlus [16], TRNSYS [17], and DOE-2 [18]. These software are powerful tools allow to introduce the input parameters to obtain output parameters without properly understanding the physical mechanisms of heat and mass transfer inside the habitat. It is in this context that we are obliged to program and understand in detail all existing phenomena in the solar system.

To determine the thermal comfort level in a thermal environment implies analyzing a complex interaction of many variables. Thus it is essential to constantly ensure the following parameters of thermal comfort:

- Ambient indoor temperature.
- The mean radiation temperature: this temperature is affected by all direct or indirect radiation that impinges onto the individual. In our case, we consider that the building is uninhabited. However, an acceptable approximation can be made by regarding only the thermal radiation given off by the walls [19]. This parameter depends on both the surface temperature and the surface area of walls. Our model can deliver these temperatures without any problems.
- Air velocity: it is directly related to the mass flow, therefore, it is considered in the proposed mathematical model.
- Specific or relative humidity, they are related by the Eq. (24) and are also taken into consideration.

One of the fundamental laws of physics states that mass can neither be produced nor destroyed, i.e. mass is conserved. Although energy can change in form, it can not be created or destroyed. These two laws of physics provide the basis for two tools which are used routinely in environmental engineering and science “the mass balance and the enthalpy balance”, knowing that