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Computational study and experimental validation of the heat ventilation in a living room with a solar patio system

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ABSTRACT

The numerical investigation of the heat ventilation and thermal comfort evaluation in a living room with a patio system was undertaken using a validated computational fluid dynamic (CFD) model. The Reynolds averaged Navier–Stokes (RANS) modeling approach with the k–ε turbulence model was used for the numerical investigations. The steady-state governing equations were solved using the software SolidWorks Flow Simulation. Based on the various flow simulations, the numerical results obtained for the temperature distributions, the airflow patterns and the turbulence characteristics inside the building were presented. Using the numerical results, it was noticed that the choice of the building design can improve comfort conditions by modifying the microclimate of the building and by enhancing the airflow in it. Indeed, it was found that patio system can be useful of a heat source in the building.

1. Introduction

Solar energy utilization is one of the main strategies used to provide buildings renewable energy. In fact, buildings require energy both in the form of heat during operation, which can be provided by solar thermal collectors. In this context, Han et al. [1] described the new designs and developments of illumination, heating and air conditioning systems and technologies for energy-efficient buildings. Important breakthroughs in these areas include high-efficiency and reduced cost solar system components, compact combined heat-power generation systems, and so on. To take advantage of these new technologies, hybrid or cascade energy systems have been proposed and investigated. A survey of innovative architectural and building envelope designs that have the potential to considerably reduce the illumination and heating and cooling costs for office buildings and residential houses is also included. Chan [2] investigated an appropriate floor level of a residential building above which balconies should be incorporated. A 21-story residential building was modeled using Energy Plus. Simulation results indicated that, for a west facing flat, only the flats located on 15/F–20/F can give acceptable environmental payback periods, ranging from 58.3 years to 40.7 years, i.e., within the lifespan (60 years) of a building. Homod [3] proposed the HVAC (heating, ventilating and air conditioning) systems go through rigorous coupling procedures as a result of indoor conditions, which are significantly affected by the outdoor environment. Hence, a traditional method for addressing a coupling setback in HVAC systems is to add a reheating coil. Rauf and Crawford [4] investigated the relationship between the service life and the life cycle embodied energy of buildings. The embodied energy of a detached residential building was calculated for a building service life range of 1–150 years. The results show that variations in building service life can have a considerable effect on the life cycle embodied energy demand of a building. A 29% reduction in life cycle embodied energy was found for the case study building by extending its life from 50 to 150 years. Boixo et al. [5] described the cool roofs which are an inexpensive method to save energy and to improve the comfort level in buildings in mild and hot climates. A high scale implementation of cool roofs in Andalusia, in the south of Spain, could potentially save 295,000 kWh per year, considering only residential buildings with flat roofs using electrical heating. Oliveira Panão et al. [6] developed a newly revised methodology arises including a few corrections in procedure. This iterative result is sufficiently accurate to calculate the building's cooling energy needs. Secondly, results show that the required conditions are insufficient to prevent overheating. The use of the gain utilization factor as an overheating risk index is suggested, according to an adaptive comfort protocol, and is integrated in the method used to calculate the maximum value for cooling energy needs. Marszaland and Heiselberg [7] recognized that in the long run, the implementation of energy efficiency measures is a more cost-optimal solution in contrast to taking no action. However, the Net

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Nomenclature

k–ε	Turbulence model (dimensionless)
$C_{2\varepsilon}$	Constant of the k–ε $C_{1\varepsilon}$ constant of the turbulence model (dimensionless)
C_μ	Constant of the k–ε turbulence model (dimensionless)
e	Internal energy (J kg^{-1})
F_i	Force components on the i direction (N)
h	The thermal enthalpy (J kg^{-1})
S_i	Mass-distributed (kg m^{-2} s^{-2})
G_k	Production term of turbulence (kg m^{-1} s^{-3})
H	Height (m)
k	Turbulent kinetic energy (J kg^{-1})
l	Length (m)
P	Pressure (Pa)
Pr	Prandt number
Q_H	Heat source or sink per unit volume (kg m^{-1} s^{-3})
q_i	Diffusive heat flux (J)
Re	Reynolds number (dimensionless)
t	Time (s)
u_i	Velocity components (m s^{-1})
u_i'	Fluctuating velocity components (m s^{-1})
V	Magnitude velocity (m s^{-1})
x_i	Cartesian coordinate (m)
X	Cartesian coordinate (m)
Y	Cartesian coordinate (m)
Z	Cartesian coordinate (m)
ε	Dissipation rate of the turbulent kinetic energy (W kg^{-1})
μ	Dynamic viscosity (Pa s)
μ_t	Turbulent viscosity (Pa s)
ρ	Density (kg m^{-3})
σ_k	Constant of the k–ε turbulence model (dimensionless)
σ_ε	Constant of the k–ε turbulence model (dimensionless)
δ_{ij}	Kronecker delta function (dimensionless)
τ_{ij}	Viscous shear stress tensor (Pa)

ZEB concept raises a new issue: how far should we go with energy efficiency measures and when should we start to apply renewable energy technologies? This analysis adopts the LCC methodology and uses a multi-family Net ZEB to find the answer to this question. Sorsak et al. [8] presented an approach in the determination of the most economically efficient building from the viewpoint of the costs of envelope's composition, the present value of heating costs and the costs incurred in fitting out the boiler room. Pikas et al. [9] determined the cost-optimal energy efficiency level for two lately built apartment buildings in a cold climate of Estonia, and achieved low energy and nZEB (nearly zero energy building) requirement levels. The influence of high-efficiency external walls, roofs, windows, ventilation units and solar collectors on energy use and construction costs were studied by using multi-stage methodology for reducing the number of combinations. Yang et al. [10] studied the natural ventilation of buildings can be closely related to building design. The object of this investigation is to conduct computational fluid dynamic (CFD) simulations and field measurements for studying the natural ventilation effectiveness of office space in a common public building with a built-in central ventilation shaft (CVS). Premrov et al. [11] demonstrated possibleavoidance of the latter energy. The research is based on a case study of a one-storeytimber-frame house, taking into account the climate data for three different European cities, those of Ljubljana, Munich (Muenchen) and Helsinki, whose average annual temperature and solar potential differ significantly. Irulegi et al. [12] studied the building design strategies based on the full integration of active-passive solar technologies and passive design criteria in order to achieve an energy self-sufficient proposal, providing high quality of life to its occupants. He and Hoyano [13] developed a passive cooling wall (PCW) constructed of moist void bricks that are capable of absorbing water and which allow wind penetration, thus reducing their surface temperatures by means of water evaporation. Passive cooling effects, such as solar shading, radiation cooling and ventilation cooling can be enhanced by incorporating PCWs into the design of outdoor or semi-enclosed spaces in parks, pedestrian areas and residential courtyards. Du et al. [14] presented the building microclimate in free-running buildings and the relationship with summer thermal comfort. Field measurements were conducted to investigate the microclimate in a Chinese traditional vernacular house. Macias et al. [15] developed and implemented for a new project of social housing. The passive cooling system incorporates a solar chimney in combination with high thermal mass in the building construction. The natural ventilation is enhanced with the help of the solar chimney and night fresh air cools the building structure. The design of this concept was calculated by balancing energy using basic thermal equations for a summer reference day and evaluated using two simulation tools, TRNSYS and TAS. Luo et al. [16] studied models of cuboids obstacles to characterize the three-dimensional responses of airflow behind obstacles with different shape ratios to variations in the incident flow in a wind-tunnel simulation. Wind velocity was measured using particle image velocimetry to study the design impact of this building on the aerodynamic characteristics. Tamayol et al. [17] used FTC and PTM to study the effects of the inlet position and the baffle configuration on the hydraulic performance of the primary settling tanks. Shortcomings of the FTC approach were stated. The optimal positioning of the baffles was also determined though a series of computer simulations. Sumon et al. [18] studied the performance of mixed convection in a rectangular enclosure. Four different placement configurations of the inlet and outlet openings were considered. A constant flux heat source strip is flush-mounted on the vertical surface, modeling an integrated circuit chips affixed to a printed circuit board. Rahmati and Ashrafizaadeh [19] compared the performance of proposed model, several benchmark problems, such as a cubic lid-driven cavity flow, flow over a backward-facing step, and a double shear flow. Bunsri et al. [20] suggested that the velocity of air-releasing during a wet process was higher than the velocity of air-entering during a dry process. The infiltration is the most important land applications. Boixo et al. [21] considered residential buildings with flat roofs using electrical heating. At the current energy prices, consumers can save 59 million euros annually in electricity costs and the emission of 136,000 metric tons of CO_2 can be directly avoided every year from the production of that electricity. If radiative forcings are considered, Andalucía can potentially offset between 9.44 and 12 Mt of CO_2. Ibrahim et al. [22] proposed to capture this wasted energy available during non-cloudy winter days and transfer it to the cooler north facade through water pipes embedded in an exterior aerogel-based insulating coating. The coating's projection technique through spraying or plastering allows the easy implementation of this system. The proposed system was presented with all the mathematical equations and numerical model. This model is then validated against experimental data found in the literature. To test its performance on a full-scale house, the MATLAB numerical model is coupled to the whole building energy simulation program EnergyPlus through co-simulation. Nam and Chae [23] developed the energy-foundation system by several researches which use building foundation as a heat exchanger. In order to establish the optimum design tool of an energy-foundation system integrated with the horizontal heat