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Energy savings by smart utilization of mechanical and natural ventilation for hybrid residential building model in passive climate

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ABSTRACT

This paper focuses on the efficiency of controlling building internal temperature and relative humidity by ventilation and infiltration flow rate. Building model is inevitable to study the feasibility of building ventilation, and how it affects the indoor air quality. A hybrid model is built using physical and empirical functions of subsystems model, where the empirical function being the residential load factor (RLF) used to calculate the cooling/heating load depending on the indoor/outdoor temperature. Furthermore, by using the RLF method, the parameters of the model can be calculated room by room, which is appropriate for variable air volume (VAV). The subsystem modeling approach chosen divides the building into four components, which are closely related to the indoor thermal comfort. Indoor thermal comfort represented by predicted mean vote (PMV) can be represented by temperature, indoor air velocity and relative humidity which are controlled by the HVAC system. Response sensitivity analysis is carried out on the main parameters of the model by applying real climate conditions data for a passive climate. Simulations with varied flow rate mechanical ventilation are conducted within 24 h. Results indicate that there is a great opportunity to take advantage of mechanical ventilation to help achieve thermal comfort while reducing the dependency on powered cooling.

1. Introduction

Many conceptual models have emerged since the realization on the importance of building performance modeling as a design tool [1–3]. The pioneering simulation work of Stephenson and Mitalas [4] on the *response factor* method significantly advanced the modeling of transient heat transfer through the opaque fabric and the heat transfer between internal surfaces and the room air. The heat balance approaches were introduced in the 1970s [5] to enable a more rigorous treatment of building loads. Baird et al. [6] indicated that most early models tend to fall into three main categories; engineering models, architectural models and energy models. Most engineering models are concerned with the energy consuming devices of buildings. They deal with a simple single building which may consist of energy consuming functions. Dubin and Long [7] defined those functions as heating, cooling, lighting, power of equipment and domestic hot water.

The building model simulation system has been in a constant state of evolution and renewal since its first prototype was developed over two decades ago [8]. Numerical discretization and simultaneous solution techniques were developed as a higher-resolution alternative to the response factor methods [8]. Essentially, this approach extends the concept of the heat balance methodology to all relevant building and plant components. More complex and rigorous methods for modeling HVAC systems were introduced in the 1980s. Transient models and more fundamental approaches were developed [9] as alternatives to the traditional approach which performed mass and energy balances on pre-configured templates of common HVAC systems. The delivery of training and the production of learning materials [10] are also receiving increasing attention. Additionally, many validation exercises have been conducted [11] and test procedures developed [12] to assess, improve, and demonstrate the integrity of simulation tools.

In addition to these fundamental methodological developments, more rigorous, accurate, and highly resolved methods are continuously developed for many of the significant heat transfer paths. The empirical thermal building simulation techniques were developed as a higher-resolution alternative to the response heat balance methods [13]. The empirical methods like RLF method was derived from residential

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Nomenclature

Symbols

A surface area (m^2)
C heat capacitance (J/°C)
$\frac{dE_s}{dt}$ rater of change in storage energy of the system (J/s)
$\dot{E}_{in}$ energy entering the system (J/s)
$\dot{E}_{out}$ energy leaving the system (J/s)
L length (m)
M mass (kg)
Cp specific heat (J/kg °C)
$\dot{m}$ mass flow rate (kg s)
M_{Cp} heat capacitance (J/°C)
T temperature (°C)
ω humidity ratio (kg_w/kg_{da})
h latent heat/heat transfer coefficient (J/kg, W/m^2 K)
$\dot{Q}$ cooling load (W)
CF surface cooling factor (W/m^2)
U construction U-factor W/(m^2 K)
v volume (m^3)
Δt cooling design temperature difference (K)
OF_t, OF_b, OF_r opaque-surface cooling factors
DR cooling daily range (K)
CF_{fen} surface cooling factor (W/m^2)
u_{NFRC} Fenestration U-factor (W/(m^2 K))
PXI peak exterior irradiance (W/m^2)
$SHGC$ solar heat gain coefficient
IAC interior shading attenuation coefficient
FF_s fenestration solar load factor
E_t, E_d, ED peak total, diffuse, and direct irradiance (W/m^2)
T_X transmission of exterior attachment
ig internal gains
l latent
fur fumiture
cl closed
N_{oc} number of occupants
N_{br} number of bedrooms
s sensible/supply
α_{roof} roof solar absorptance
τ Time constant (s)
I infiltration coefficient
$\Delta\omega$ indoor–outdoor humidity ration difference (kg_w/kg_{da})

Subscripts

F_{shd} fraction of fenestration shaded by overhangs or fins
L site latitude (°N)
ψ exposure (surface azimuth),° from south
SLF shade line factor from
D_{oh} depth of overhang (m)
X_{oh} vertical distance from top of fenestration to overhang (m)
F_{cl} shade fraction closed (0–1)
$\dot{v}$ volumetric flow rate (L/s)
IDF infiltration driving force (L/(s cm^2))
R thermal resistance (°C/w)
r room
o outside
i inside
a air
L leakage
wl wall
g glass
opq opaque
inf infiltration
fen fenestration
t at time t