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Prediction of hybrid ventilation performance using two simulation tools

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Abstract

This paper describes the results of a collaboration between ENTPE-LASH and LEPTAB within the framework of the IEA Annex 35 "Hybrid Ventilation in New and Retrofitted Buildings". The aim of the work is to carry out a cross-simulation study and to identify optimal control strategies for ventilation systems in order to provide a comfortable thermal indoor environment and a good indoor air quality with energy efficiency. Two models were developed by ENTPE-LASH and LEPTAB in order to carry out hybrid system simulations taking into account air flows, heat transfers and CO_2 concentrations, and numerical results are compared in this study. The models were first adjusted to an experimental cell, HYBCELL, created in the same project. The simulations were carried out using a fictive classroom. The test room was assumed to be in Copenhagen and to be equipped with a natural ventilation system (two inlet grilles and an exhaust chimney) or with mechanical ventilation systems (fans with or without heat recovery). This work also reveals what are the differences in results between the two tools and outlines some conclusions on relative performance of the specific control strategies chosen in this study.

Keywords: Hybrid ventilation; Control strategies; Comfort; Energy efficiency

1. Introduction

Nowadays, there is a growing interest in taking into account the ventilation at the early design stage of a building. Designers are interested in ventilation features as well as in indoor air quality, thermal comfort and energy consumption (Heiselberg, 2000). One way to reach these targets is to combine both natural and mechanical ventilation advantages into a hybrid system. In addition, reliable design tools are needed to generate guidelines on control strategies. Examples of existing hybrid ventilation and control strategy systems in office and educational buildings (Aggerholm, 2002) show that control strategies have to be carefully designed to take into account the building design, the ventilation system, the occupant behaviors and their indoor climate expectations.

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Nomenclature

t	time (s)
Δt	step time (s)
V	zone volume (m^3)
β	slop (°)
S_i	area of surface i (m^2)
T^t_{int}	indoor air temperature at time t (°C)
T^t_{ext}	outdoor air temperature at time t (°C) or (K)
$T^t_{z,i}$	indoor air temperature at time t for zone i (°C)
$T^t_{s,i}$	surface i surface temperature at time t (°C) or (K)
T^t_i	node i temperature at time t (°C)
T_v	sky vault temperature (K)
T^t_{rm}	mean radiative temperature at time t (°C)
$T^t_{air\_vent}$	ventilation temperature at time t (°C)
h_{int}	internal convection coefficient ($W\,m^{-2}\,K^{-1}$)
h_{ext}	external convection coefficient ($W\,m^{-2}\,K^{-1}$)
ρ_{as}	air sec density ($kg\,m^{-3}$)
ρ_{es}	pollutant density ($kg\,m^{-3}$)
$c_{p_{as}}$	specific heat of air sec at constant pressure ($J\,kg^{-1}\,K^{-1}$)
$c_{p_{es}}$	specific heat of pollutant at constant pressure ($J\,kg^{-1}\,K^{-1}$)
c_i	specific heat of material in layer i ($J\,kg^{-1}\,K^{-1}$)
λ_i	thermal conductivity of material in layer i ($W\,m^{-1}\,K^{-1}$)
α_i	absorbance of material in layer i (–)
ε_i	emissivity (–)
cc	nebulosity indicia (–)
σ_0	Stefan–Boltzman constant ($W\,m^{-2}\,K^{-4}$)
$F_{i,j}$	view factor from i to j (–)
F_{vault}	view factor between façade and the sky vault (–)
F_{Env}	view factor between façade and the environment (–)
Δx_i	sub-layers thickness (m)
W	opening width (m)
z	height (m)
Z_b	bottom of the opening (defined with reference to the floor) (m)
Z_s	top of the opening (defined with reference to the floor) (m)
Z_{NL}	neutral level (m)
$P_{o,i}$	reference pressure on the ground for the zone i (Pa)
$P_{z,i}$	pressure at height z for the zone i (Pa)
$\Delta P_{z,i}$	pressure difference across an exterior opening at a height z (Pa)
C_p	pressure coefficient (–)
C_d	discharge coefficient ($m^3\,s^{-1}\,Pa^{-2}$)
v	wind speed at the height of the building ($m^2\,s^{-1}$)
qm_{asji}	pure air mass flow rate from the zone j to the zone i ($kg_{as}\,s^{-1}$)
qm_{esji}	CO_2 mass flow rate from the zone j to the zone i ($kg_{es}\,s^{-1}$)
S_{es}	pollutant source ($kg_{es}\,s^{-1}$)
φ^i_{Conv}	convective heat for surface i ($W\,m^{-2}$)
φ^i_{SW}	short-wave radiative heat for surface i ($W\,m^{-2}$)
φ^i_{LW}	long-wave radiative heat for surface i ($W\,m^{-2}$)
Q_{ventil}	ventilation flow ($kg\,s^{-1}$)
Q_{Below}	volumetric flow below Z_{NL} ($m^3\,s^{-1}$)
Q_{Above}	volumetric above Z_{NL} ($m^3\,s^{-1}$)
Q_{ik}	volumetric flow from zone i to zone k ($m^3\,s^{-1}$)
$\Phi_{heating}$	heating power (W)
Φ_{gains}	gains power (W)
Φ_{rad}	radiative gain power (W)

This paper describes the work done by both ENTPE/LASH and LEPTAB laboratories within the framework of IEA Annex 35. The main work objective is to identify optimal ventilation systems within a simple school building in Denmark. Two mechanical ventilation systems were compared with a hybrid ventilation system during three seasons.

Analytical solutions are available to study natural driving forces (Li and Delsante, 2001) as well as numerical tools to perform a ventilation performance analysis (Frascatoro and Perino, 2002). Even if a hybrid-ventilated school has already been simulated with one of these tools (Jeong and Haghighat, 2002), some concerns remain about

- the difficulties encountered to simulate the problem,
- the robustness of the tools,
- the possibility to generate general guidelines on control strategies to be developed.