2013 International Conference for Enhanced Building Operations (ICEBO)

Assessment and prediction of the thermal performance of a centralized latent heat thermal energy storage utilizing artificial neural network

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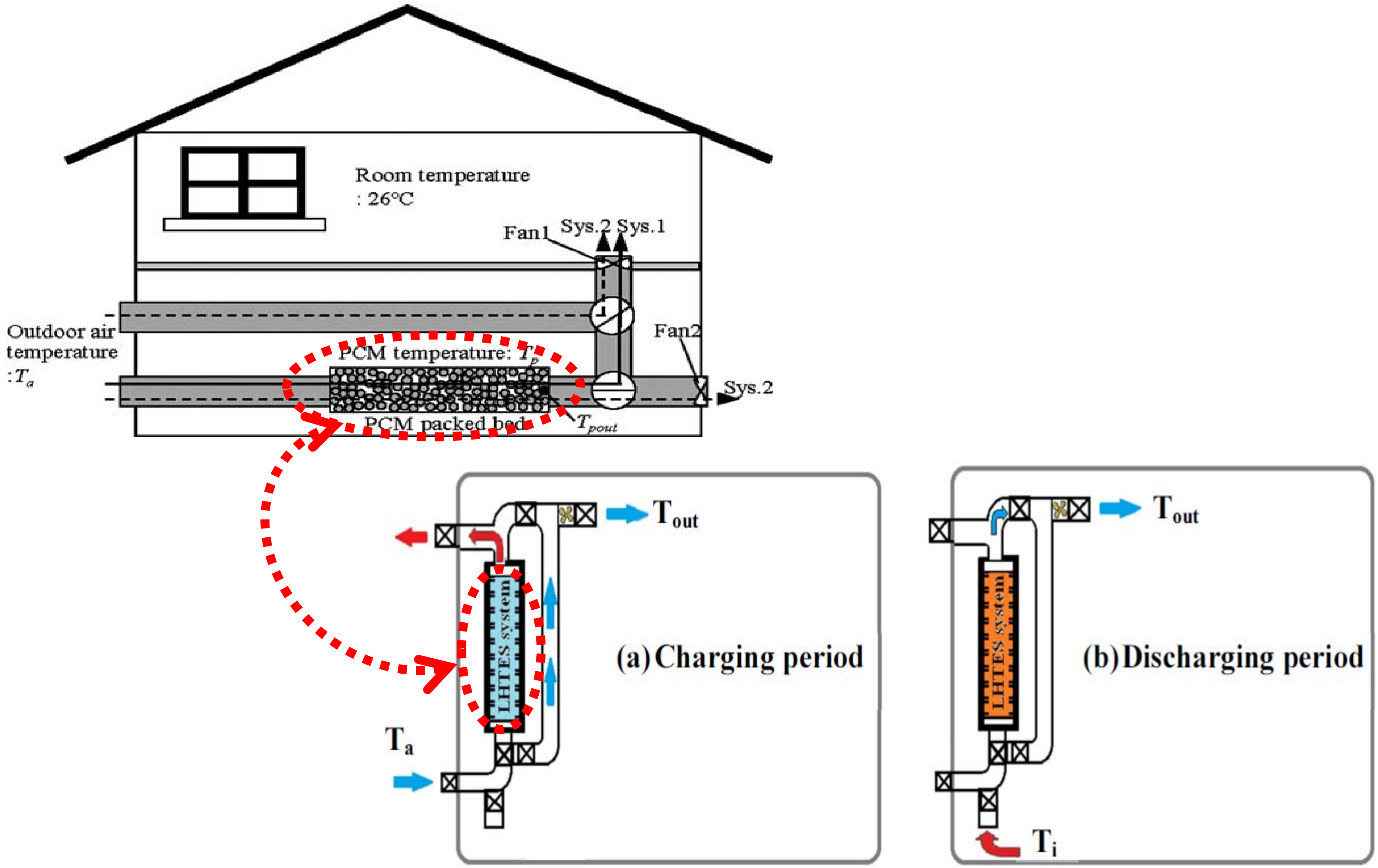
Outline

- Introduction
- LHTES Applications for buildings of future
- Objectives
- Methodology
- Physical model
- Results

Motivation: Why the centralized LHTES system?



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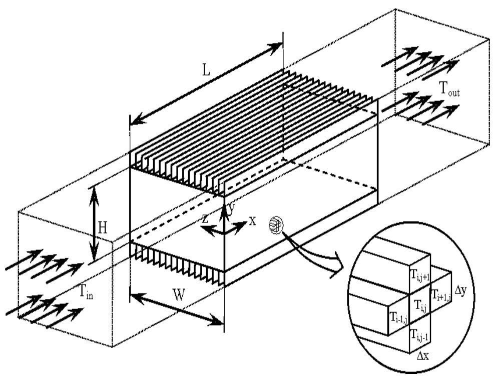
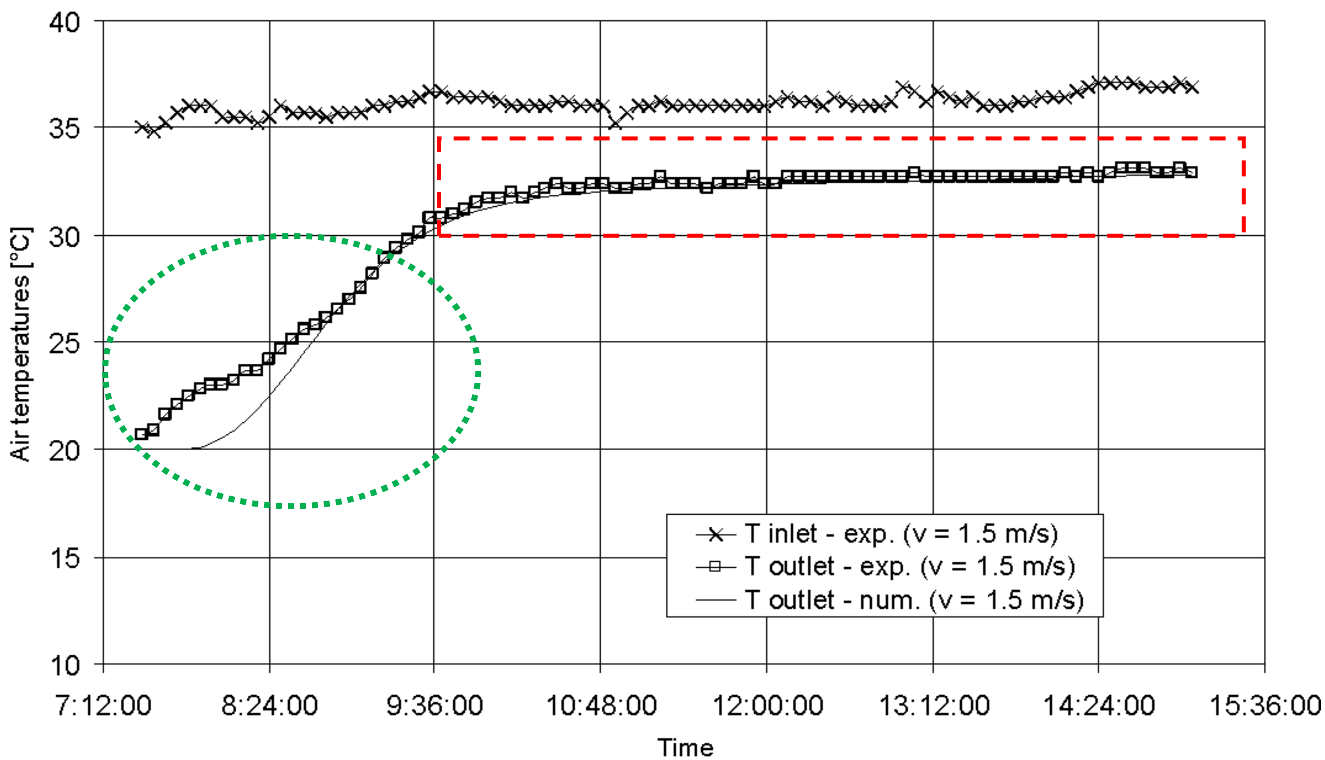
LHTES Applications for buildings of future





Stritih, U., and Butala, V. (2011). "Energy savings in building with a PCM free cooling system." *Strojniski Vestnik*, 57(2), 125-34.

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Limitations of existing work

1- The heat transfer problem is simply formulated into two-dimensional transient diffusion equation in most PCM problem.

2- The effect of thermal stratification and buoyancy-driven convection phenomena needs to be further investigated in LHTES.

3- Thermal behavior of phase change is not sufficiently investigated due to the removal of velocity convective term.

Objectives

- To develop a 3-D numerical model of LHTES and to study its thermal behavior under various conditions.

- To validate the integrated model with the experimental data.

- To carry out the parametric study to investigate the effect of the geometrical parameters on the HTF outlet air-temperature.

- To investigate the effect of integrated system on demand.

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Methodology & Governing equations

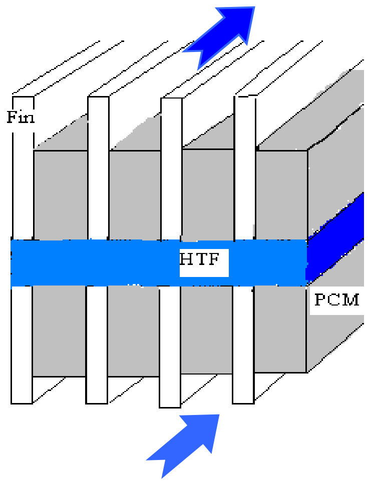
- The enthalpy-porosity technique for modeling convection-diffusion phase change is employed. The flow in solid–liquid region is modeled by the Darcy's law

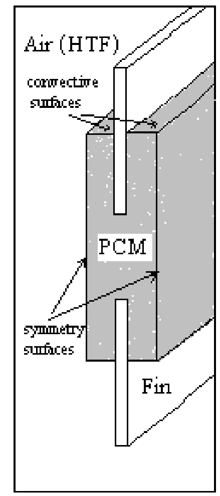
- The solver algorithm of coupling pressure-velocity is employed for solving momentum and continuity equations.

- VOF algorithm is used to update the volume fraction at each unit cell step by step in the entire computational domain.

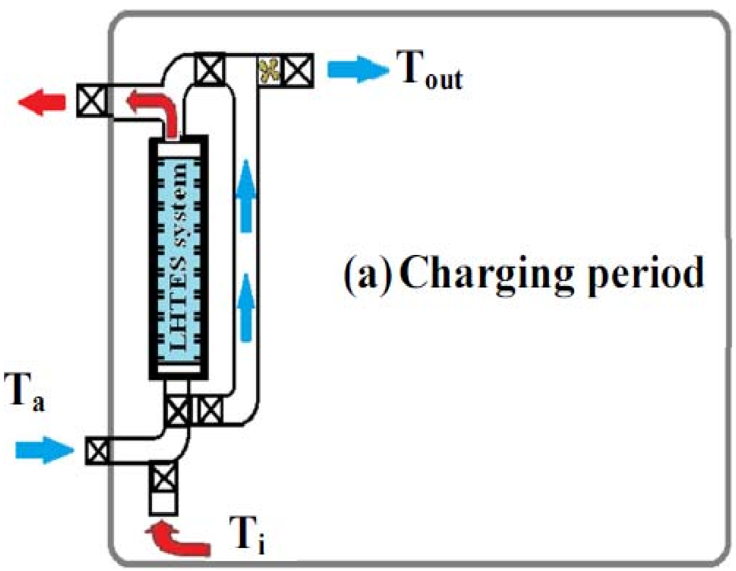
Physical model

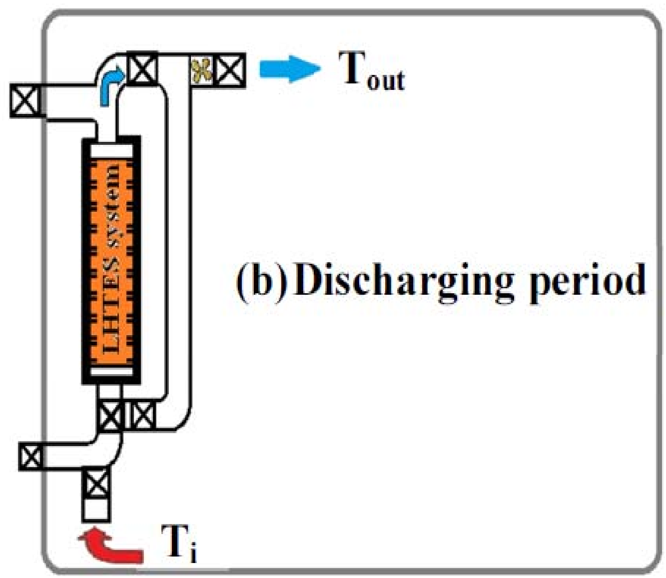
Storage unit.





Computational domain





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Governing equations

Continuity $$\frac{\partial \alpha_n}{\partial t} + u_i \frac{\partial \alpha_n}{\partial x_i} = 0$$

Momentum $$\frac{\partial}{\partial t}(\rho\, u_i) + \frac{\partial}{\partial x_j}(\rho\, u_j u_i) = \mu \frac{\partial^2 u_i}{\partial x_j \partial x_j} - \frac{\partial p}{\partial x_i} + \rho g_i + S_i$$

Energy $$\frac{\partial}{\partial t}(\rho\, h) + \frac{\partial}{\partial x_i}(\rho\, u_i\, h) = \frac{\partial}{\partial x_i}\left(k \frac{\partial T}{\partial x_i}\right) + S_h$$

$$S_i = -\frac{C(1-\gamma)^2}{\gamma^3 + \varepsilon} u_i$$

$$\rho_{(PCM)} = \frac{\rho_l}{\beta(T - T_l) + 1}$$

$$\gamma = \frac{T - T_s}{T_l - T_s}$$

$$\mu = 0.001 \times exp\left(A + \frac{B}{T}\right)$$

α_n= the volume fraction of nth fluid in the computational cells.

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Governing equations

$$S_h = \frac{\partial(\rho \Delta H)}{\partial t} + div(\rho \underline{u} \Delta H)$$

$$H = h + \Delta H$$

$$\mathit{\Delta} H = F(T)$$

$$F(T) = \begin{cases} L, & T \geq T_{liquid} \\ L(1 - f_s), & T_{liquid} \geq T \geq T_{solid} \\ 0, & T < T_{solid} \end{cases}$$

$$\underline{u} = \begin{cases} u_i, & for\ liquid\ region \\ (1 - f_s)u_{i,} & for\ mushy\ region \\ 0, & for\ soild\ region \end{cases}$$

$$\underline{u} = -\left(\frac{K}{\mu}\right) gardP$$

$$gradP = -\frac{C(1-\lambda)^2}{\lambda^3 u} \qquad A = -\frac{C(1-\lambda)^2}{\lambda^3 + \omega}$$

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Governing equations

Boundary conditions:

Initial condition:

$$t = 0, \quad T = T_i = 298\text{ K}$$
$$u = v = 0, \quad w = 1.5 m/s$$

Symmetry boundary conditions at side:

$$\left.\frac{dT}{dx}\right|_{x=0} = \left.\frac{dT}{dx}\right|_{x=L} = 0, \qquad \left.\frac{dT}{dy}\right|_{y=-H/2} = \left.\frac{dT}{dy}\right|_{y=H/2} = \alpha\left(T_{out,i} - T_{in,i}\right)$$

Indoor environment:

$$\rho_a V_r c_a \frac{dT_a}{dt} = h_{in}(T_s - T_a)A_{wa} + q_{rad,in}A_{wa} + Q_{I/V} - Q_{HVAC} + Q_W$$

$$Q_{I/V} = \rho_a V_r c_a \times ACH \times \frac{(T_{amb} - T_a)}{3600}$$

$$Q_W = U_W A_W (T_{amb} - T_a)$$

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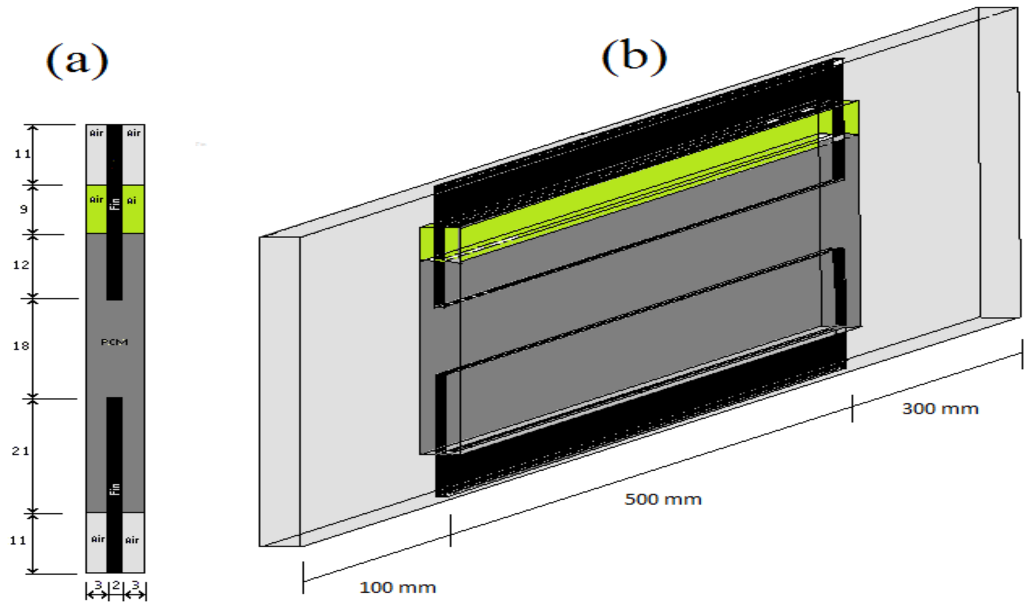
CFD simulation for 3-D PCM model



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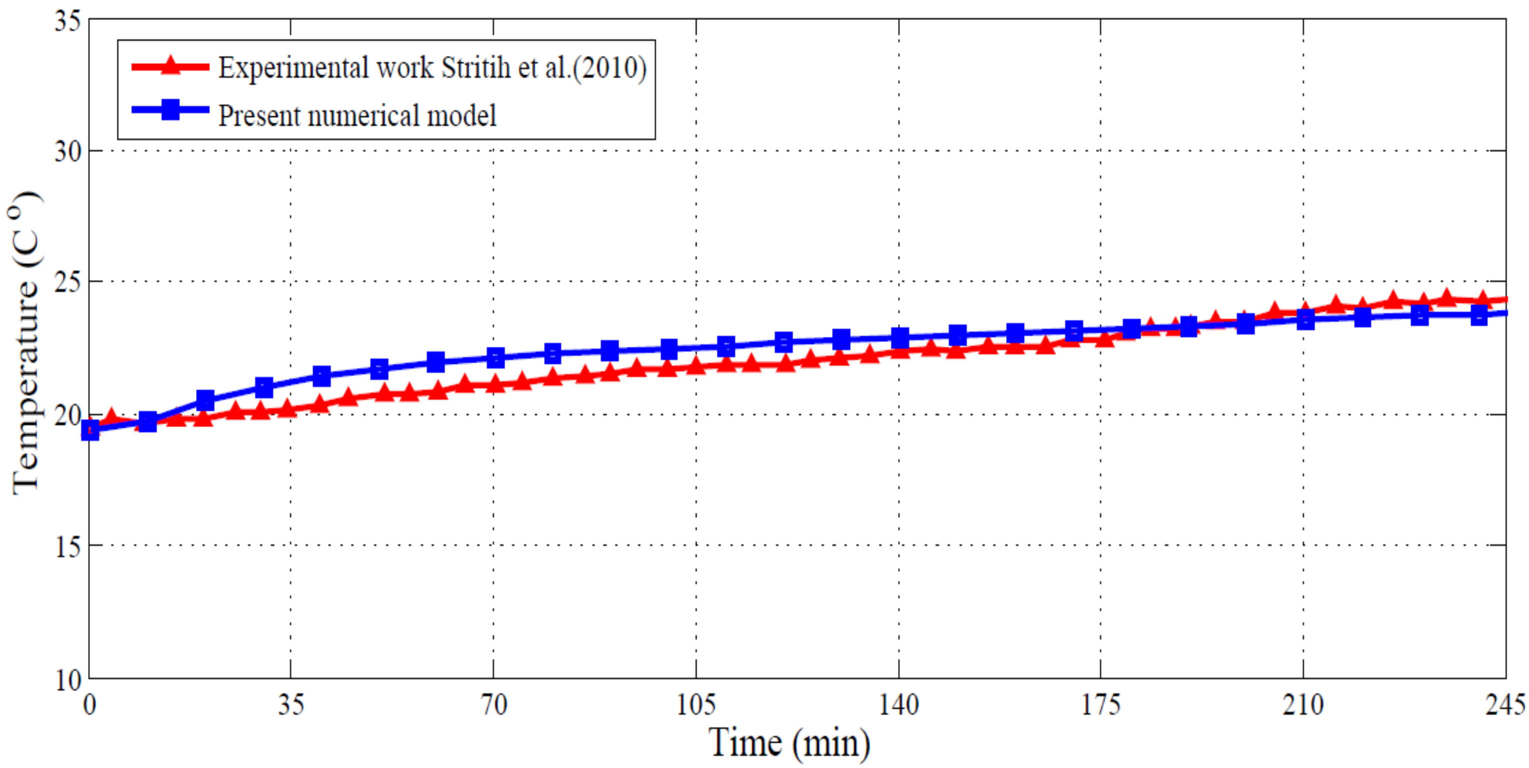
Validation of 3-D model for with experimental data



Comparison of outlet temperature of storage unit during different time of melting between experimental work and developed numerical model

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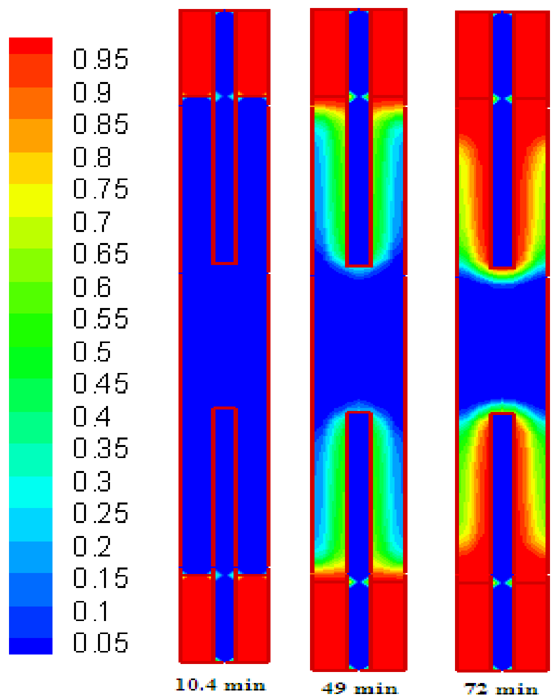
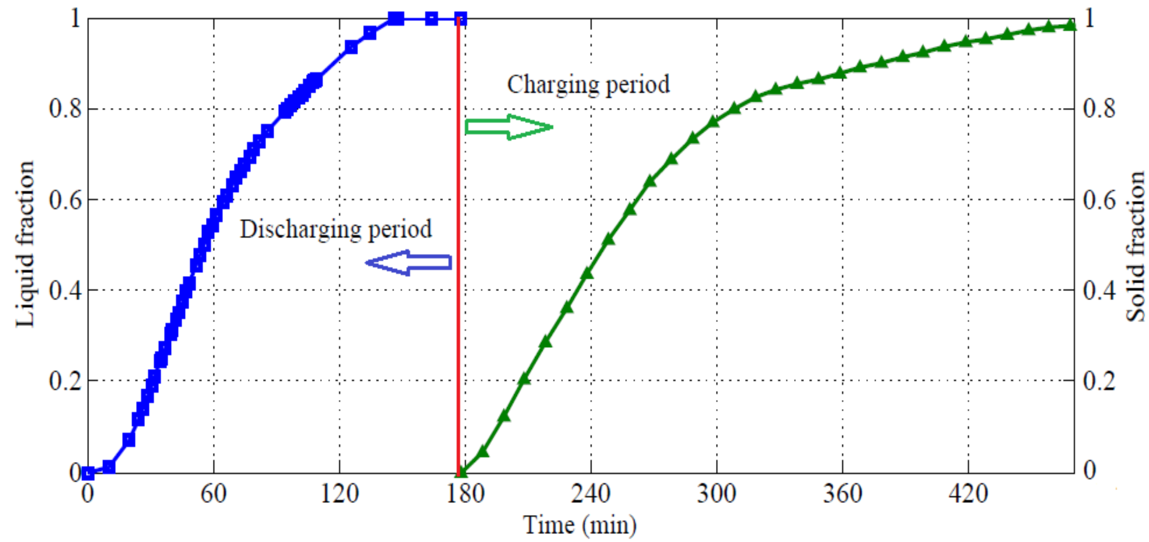
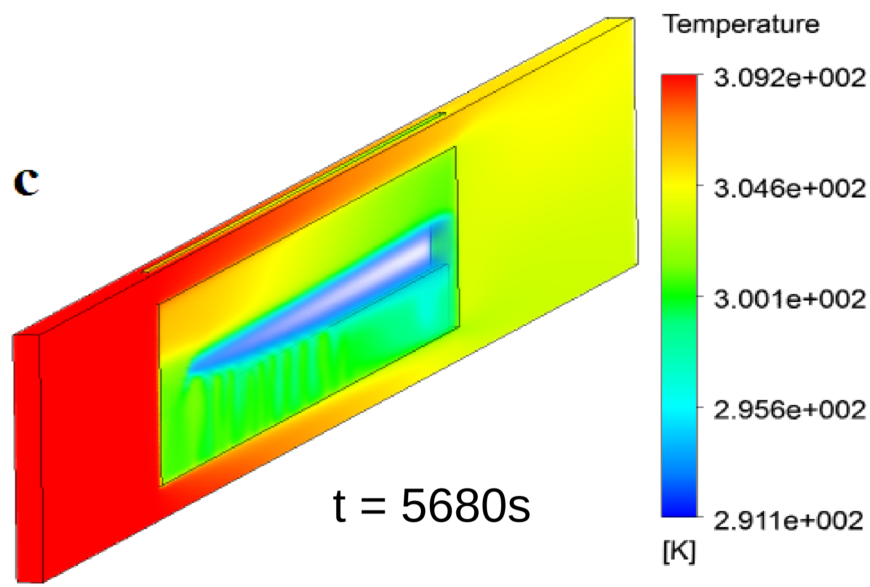
Hear transfer of 3-D PCM model







The liquid fraction and phase distribution of PCM at different time during melting process of energy release at the inlet air temperature of 36^{o}C and the velocity of 1.5m/s

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Thermal performance calculations for cooling demand

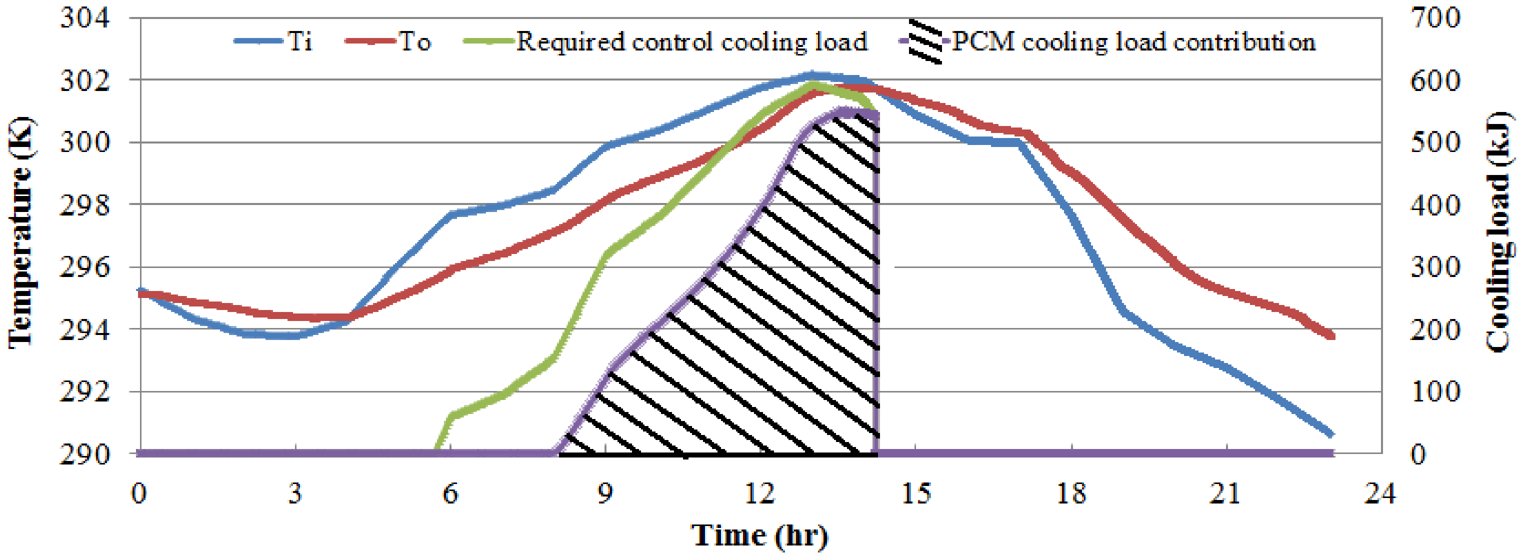
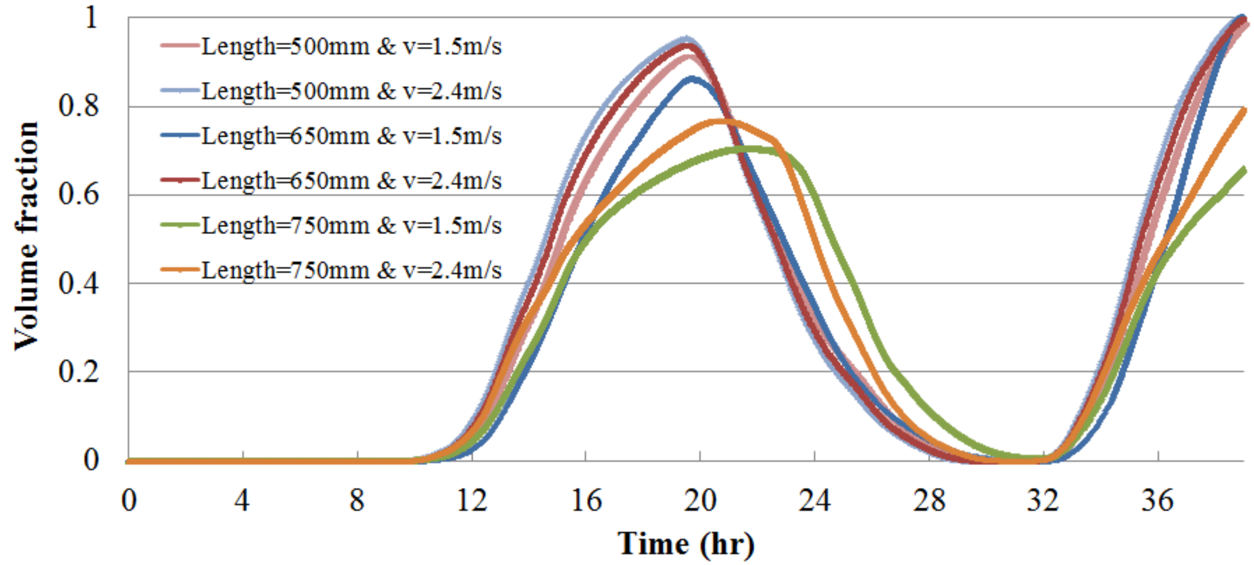
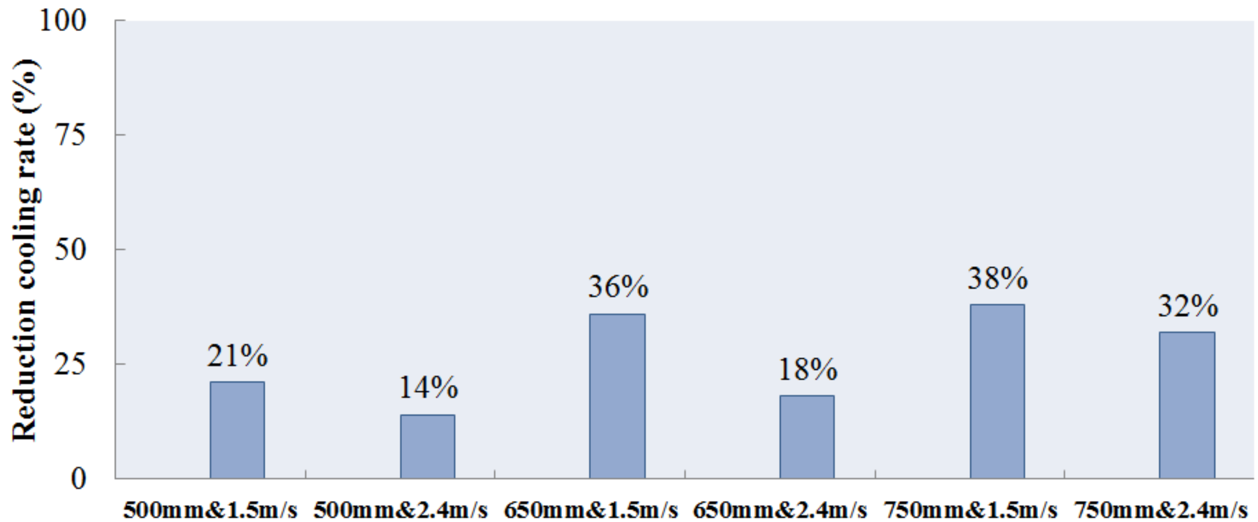


Fig Shape of variations of the measured ambient air and calculated outlet air temperatures associated with PCM energy release

Effect of the geometrical parameters on the thermal performance

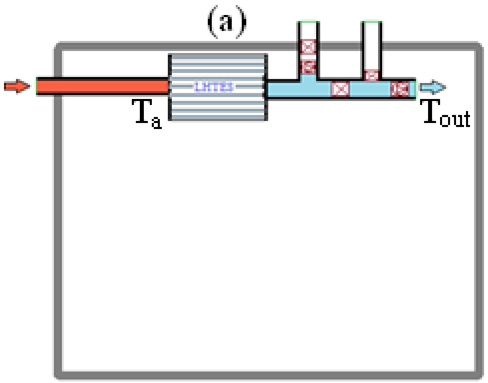


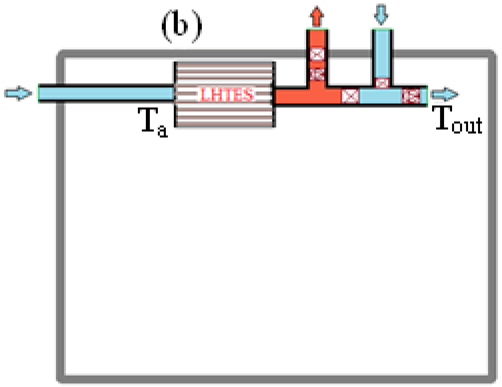


Performance evaluation of an integrated unit with energy building model

Low-energy single-family building; Ljubljana, Slovenia

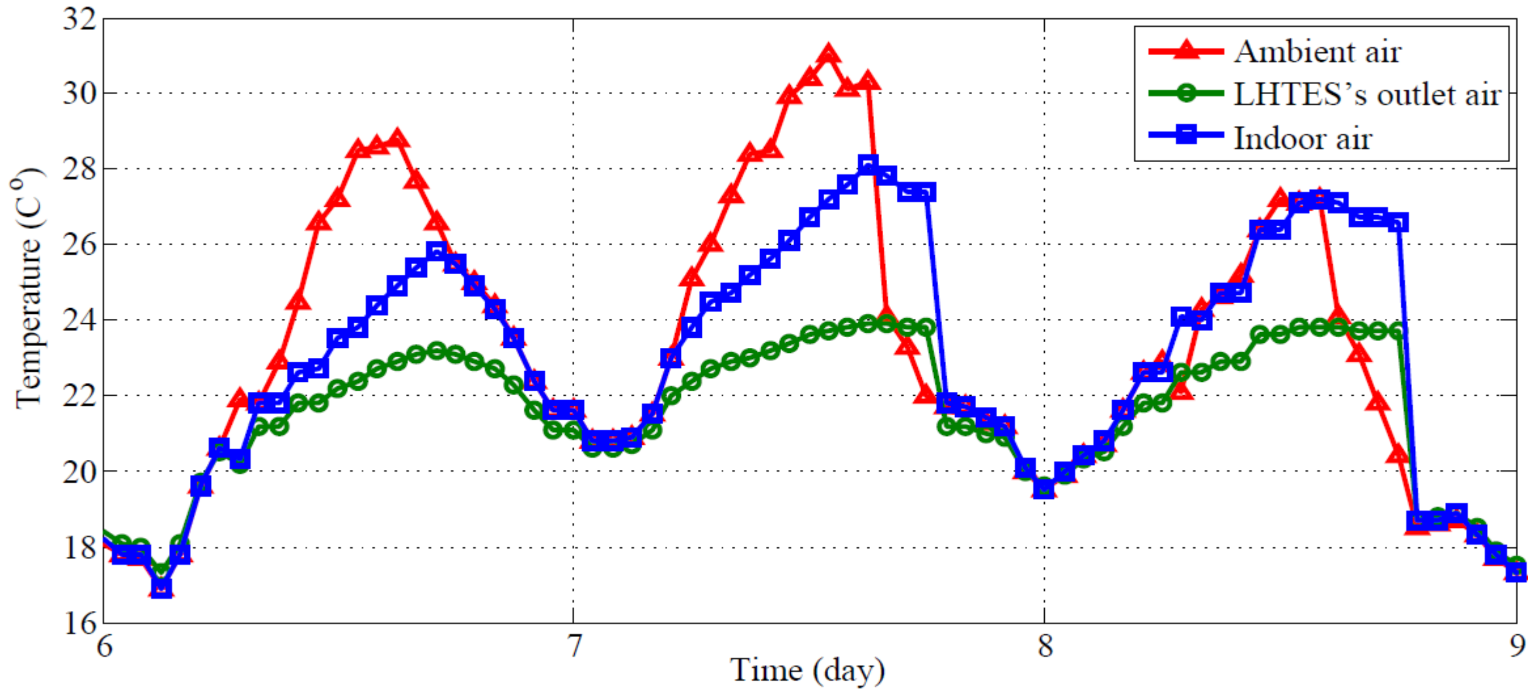
Floor area =65m^{2}.
Building volume = 179 m^{3}.





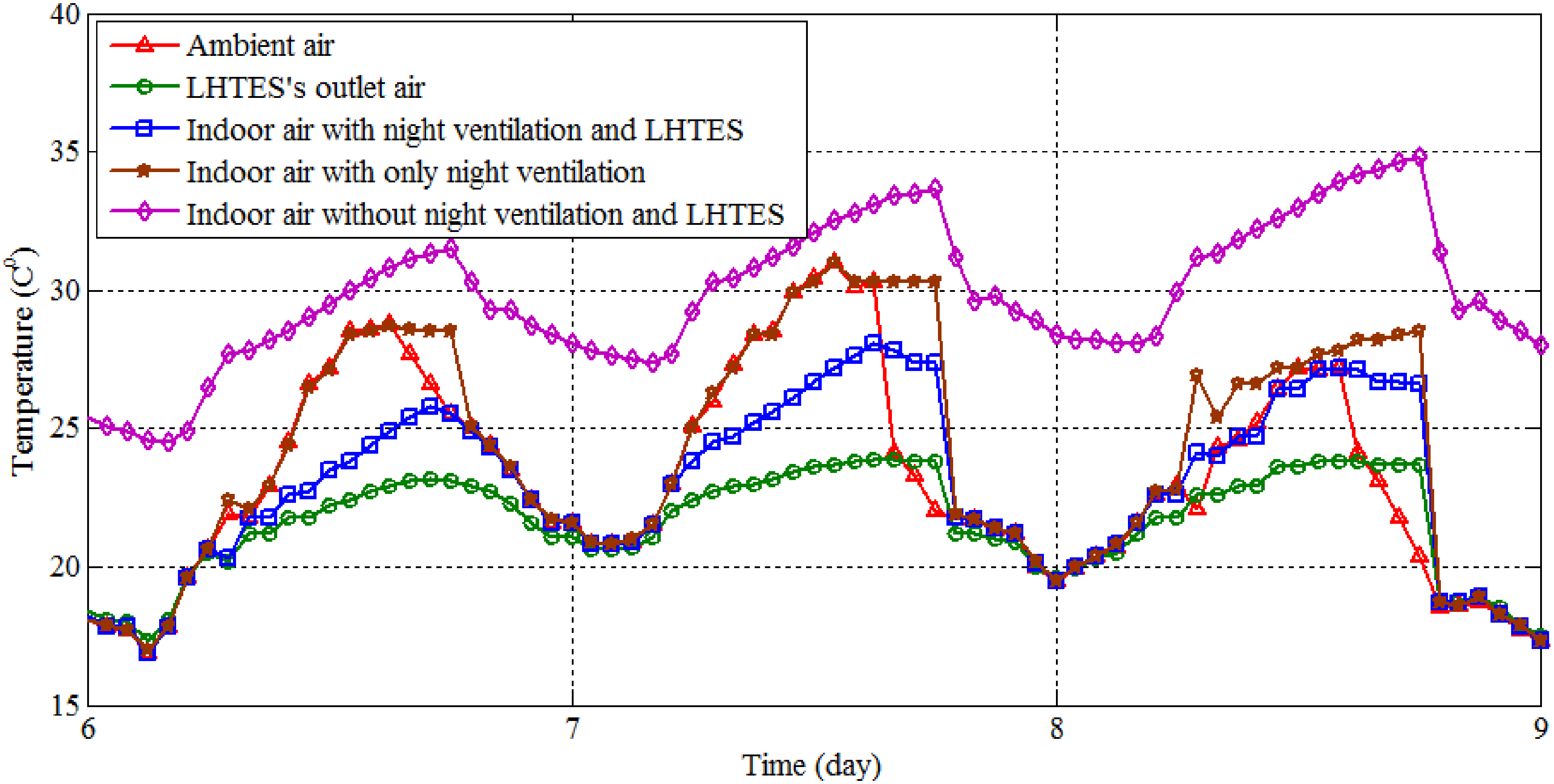
Arkar, C., and Medved, S. (2007). "Free cooling of a building using PCM heat storage integrated into the ventilation system." *Solar Energy*, 81(9), 1078-87.

Performance evaluation of an integrated unit with energy building model



The Variation of Indoor Air-Temperature of The Building Model Integrating Into The LHTES System For (6-9) Days of July For Passive Space.

Performance evaluation of an integrated unit with energy building model



Indoor Air Temperature Histories With and Without LHTES System Combined With Night Ventilation For (6−9) Days of July

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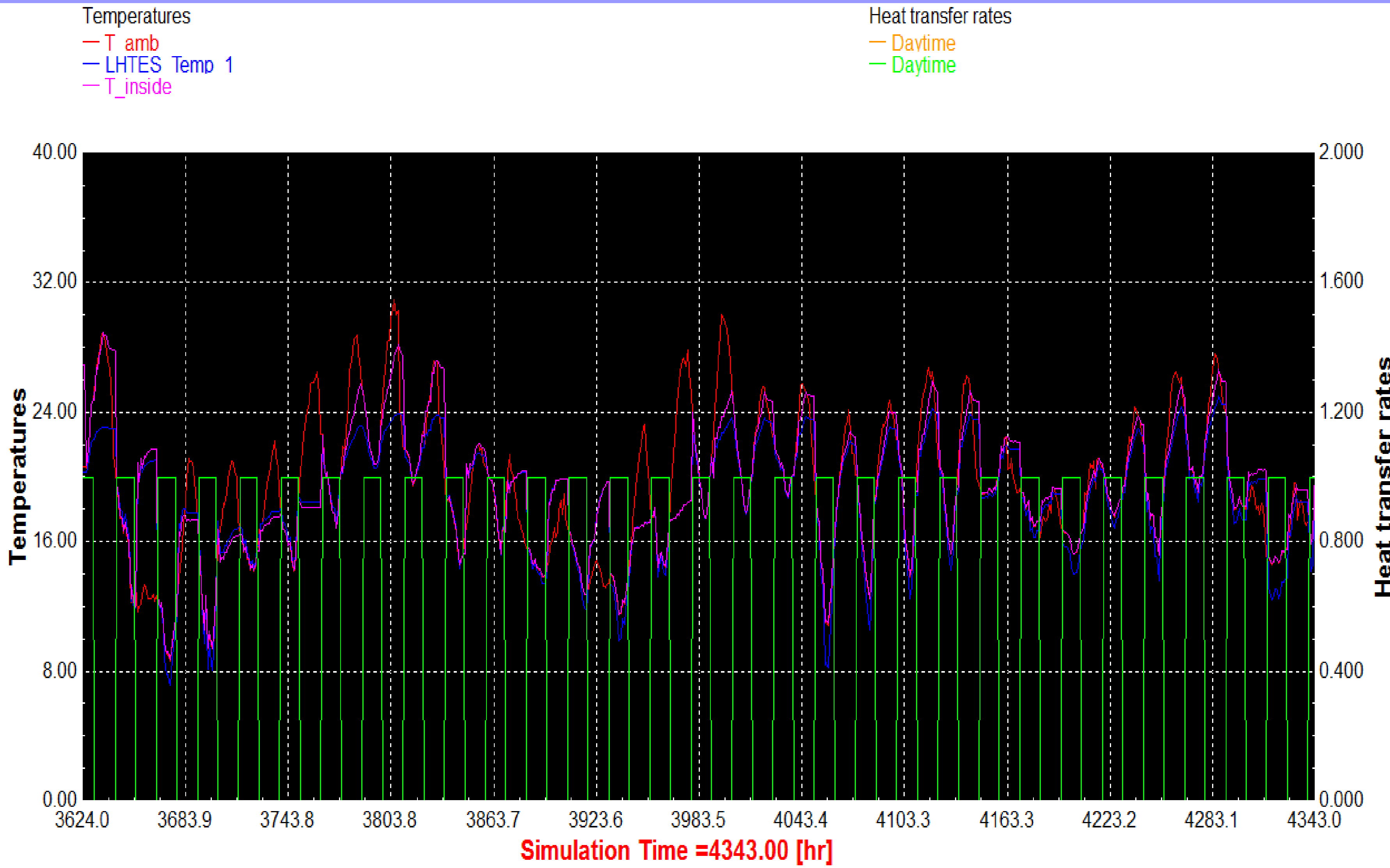
Performance evaluation of an integrated unit with energy building model



Thanks for your attention

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