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

Azeldin El-sawi

Building, Civil and Environmental Engineering Department
Concordia University

a_elsawi@encs.concordia.ca

Supervisors
Prof. Haghighat & Prof. Akbari.

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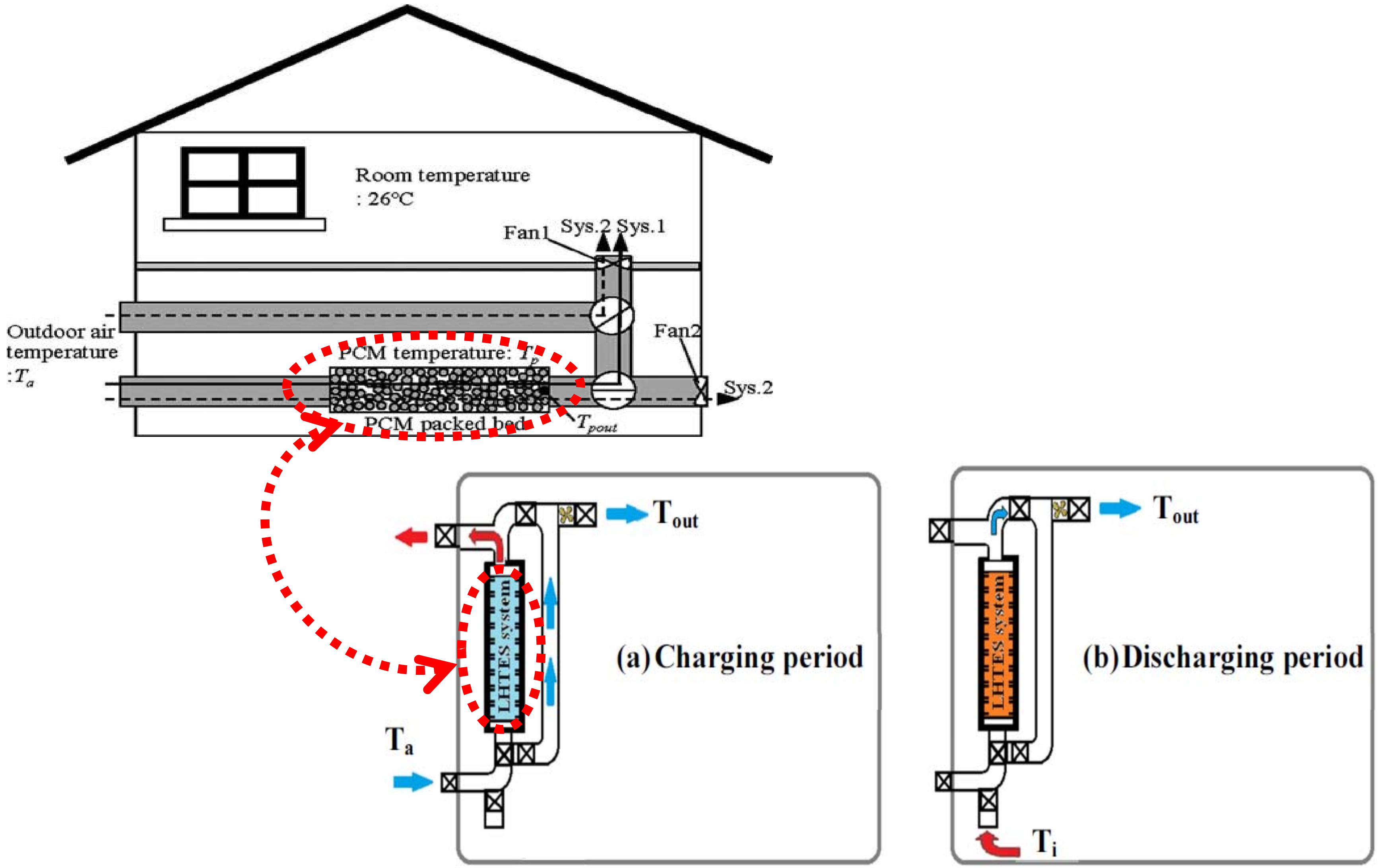
Outline

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

Motivation: Why the centralized LHTES system?



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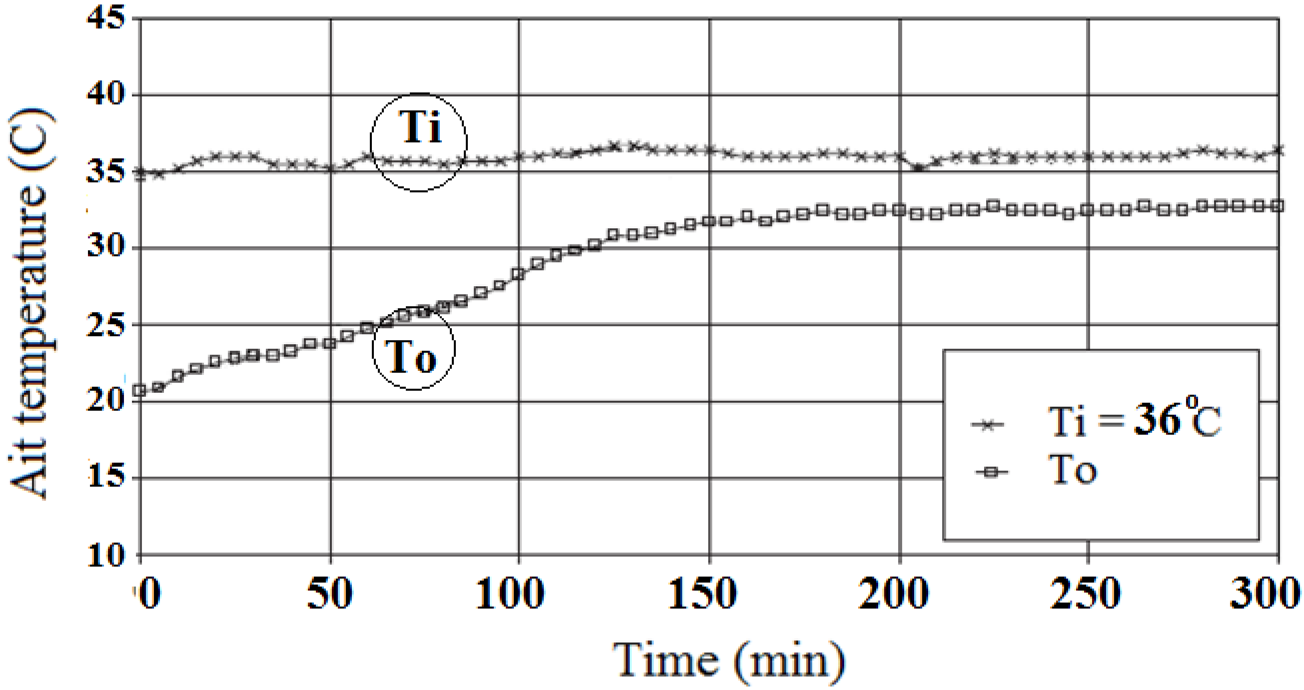
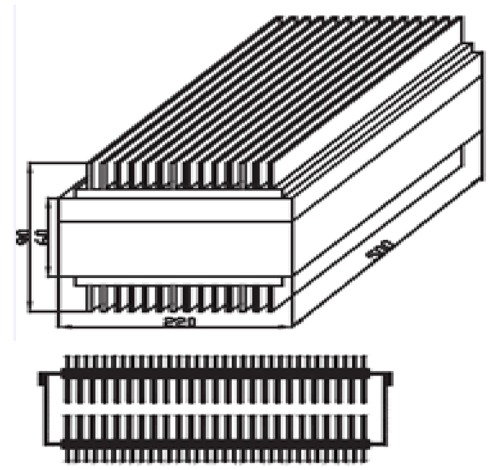
Experimental investigation of energy saving in buildings with PCM cold storage





Advantages:

- Experimentally proven that the stored cooling energy for about 3hr for air velocity of 1.5m/s.

Disadvantages:

- Numerical model was not consistent with experimental data during transient period of phase change.

Stritih U, Butala V. Experimental investigation of energy saving in buildings with PCM cold storage. International Journal of Refrigeration. 2010;33:1676-83.

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.

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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.

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.

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Governing equations

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

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

$$S_i = -\frac{C(1-\gamma)^2}{\gamma^3 + \varepsilon} u_i \qquad \rho_{(PCM)} = \frac{\rho_l}{\beta(T - T_l) + 1}$$

$$\gamma = \frac{T - T_s}{T_l - T_s} \qquad \mu = 0.001 \times exp\left(A + \frac{B}{T}\right)$$

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

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Governing equations

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

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

$$H = h + \Delta H$$

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

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

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

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

Governing equations

Boundary and initial conditions:

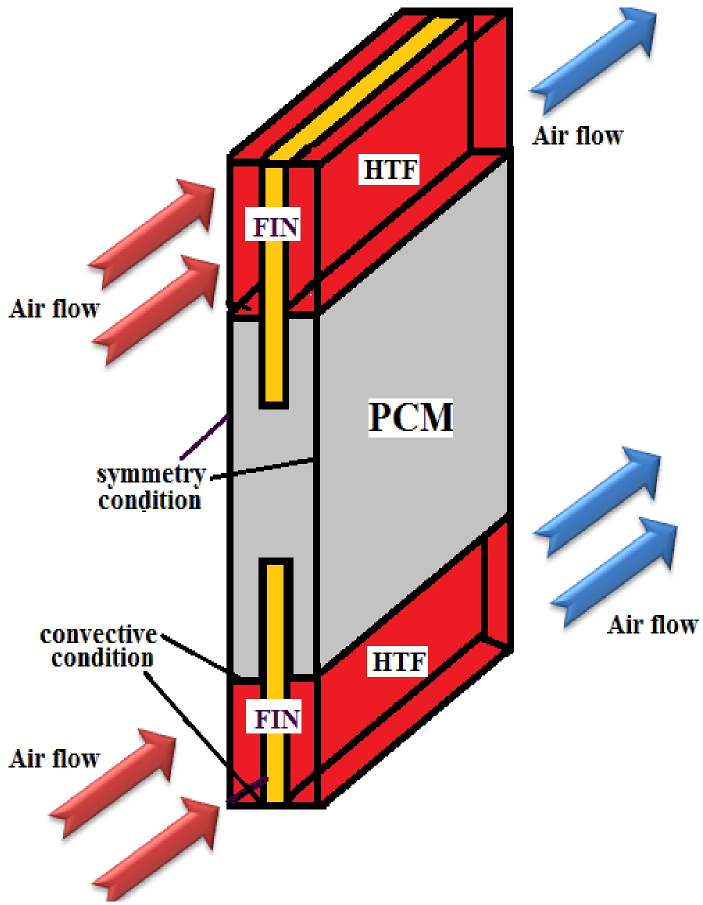
Symmetry boundary conditions at side:

$$\left.\frac{dT}{dx}\right|_{x=0} = \left.\frac{dT}{dx}\right|_{x=L} = 0,$$

$$\left.\frac{dT}{dy}\right|_{y=-H/2} = \left.\frac{dT}{dy}\right|_{y=H/2} = h\left(T_{out,i} - T_{in,i}\right)$$

Initial condition:

$$t = 0, \qquad T = T_i = 288\text{K}$$
$$u = v = 0, \qquad w = 1.5\text{m/s}$$



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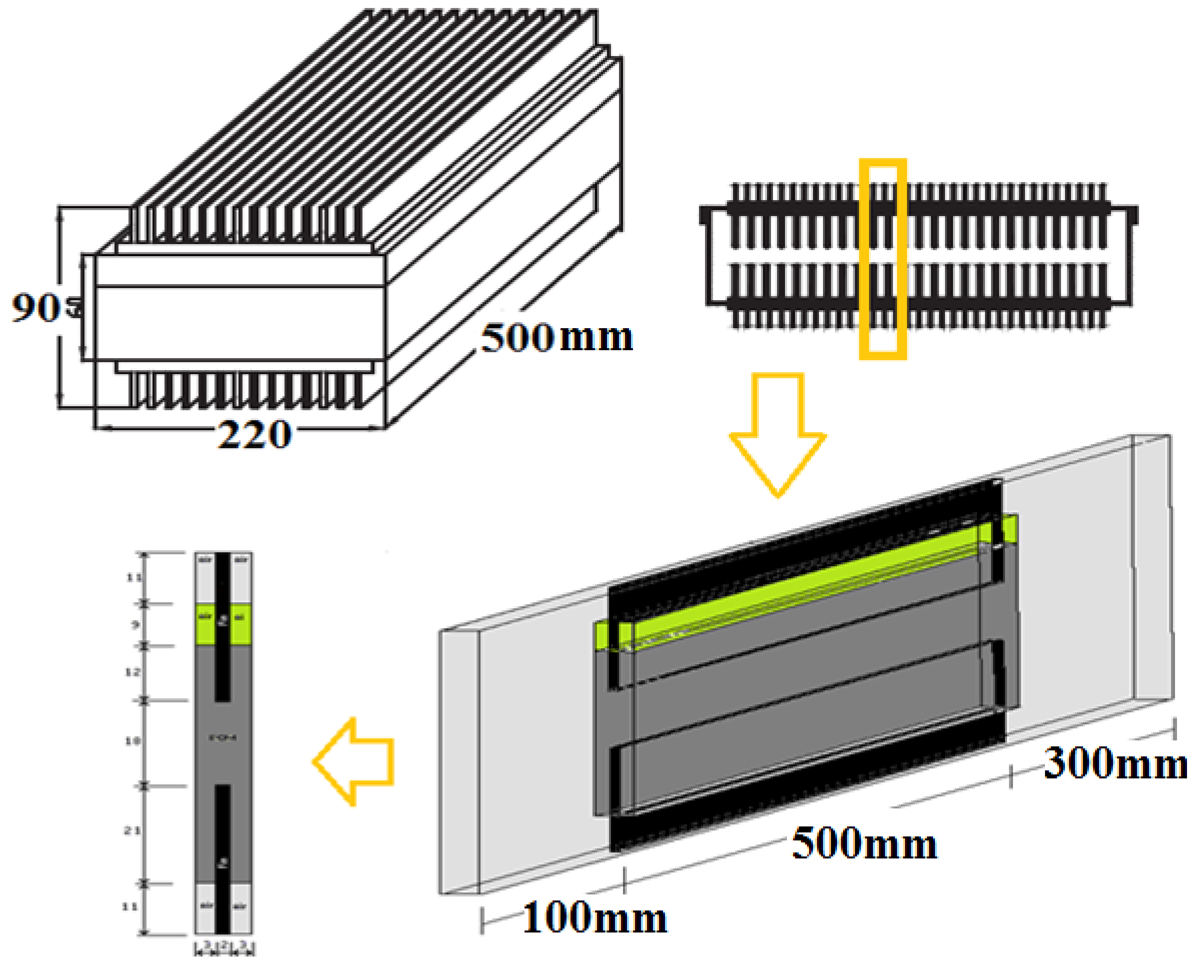
3-D LHTES-proposed model



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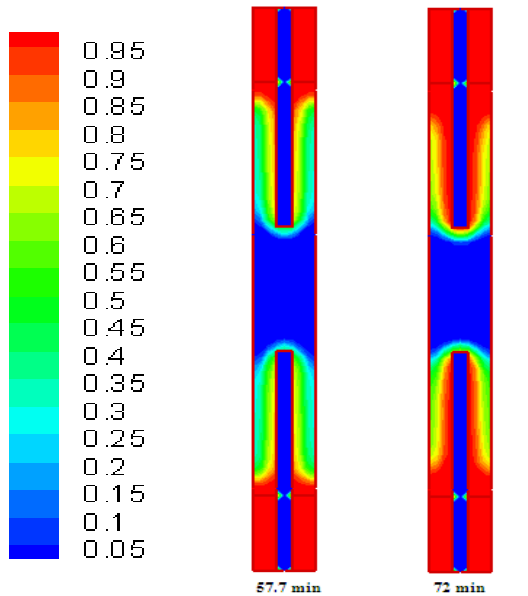
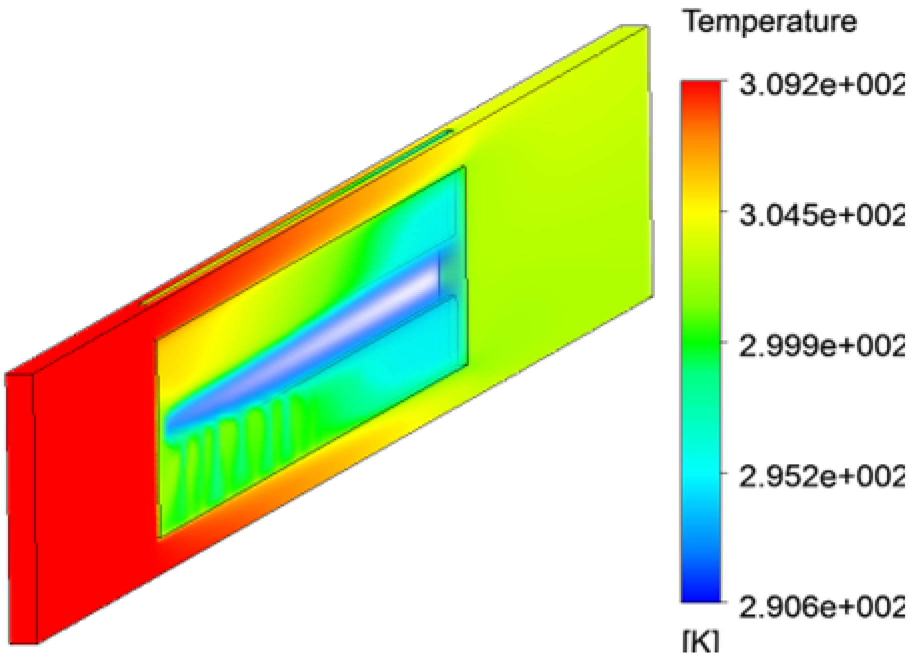
3-D LHTES-developed model characterisation



The liquid fraction and phase distribution of PCM



PCM temperature contours for the evolution of melting process at case 1 at t = 1.5hr

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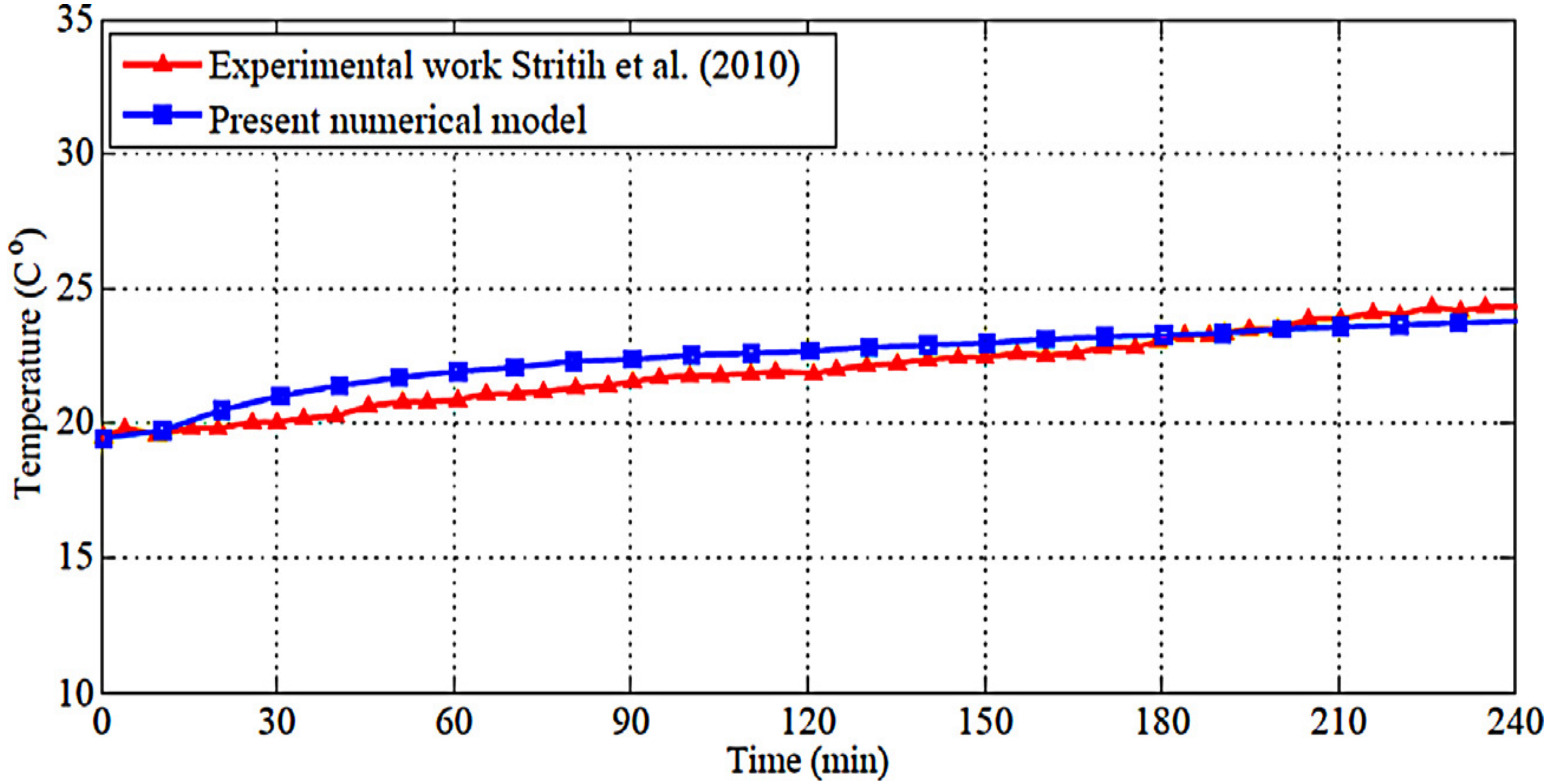
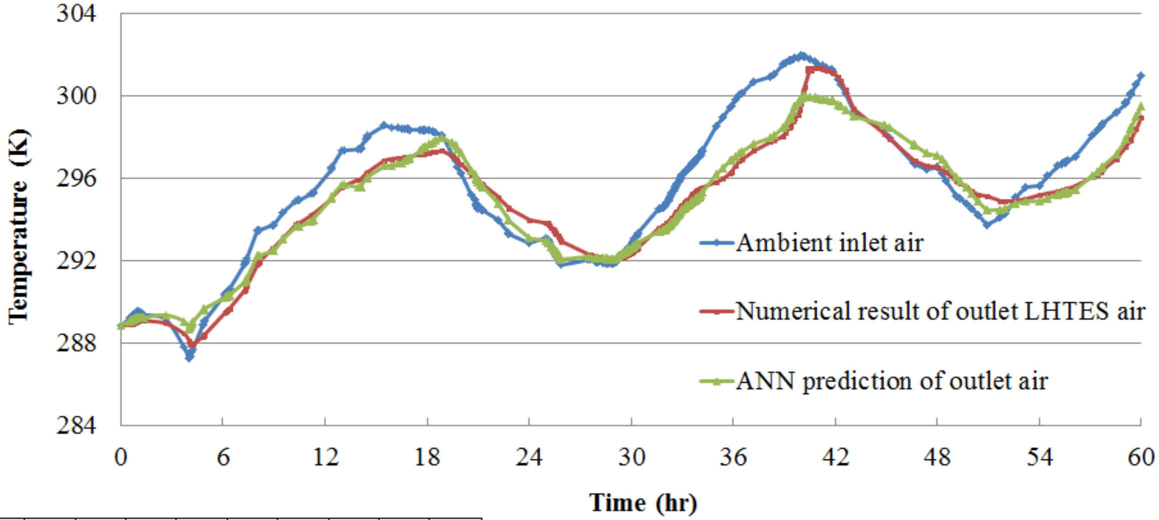
3-D LHTES-developed model validation

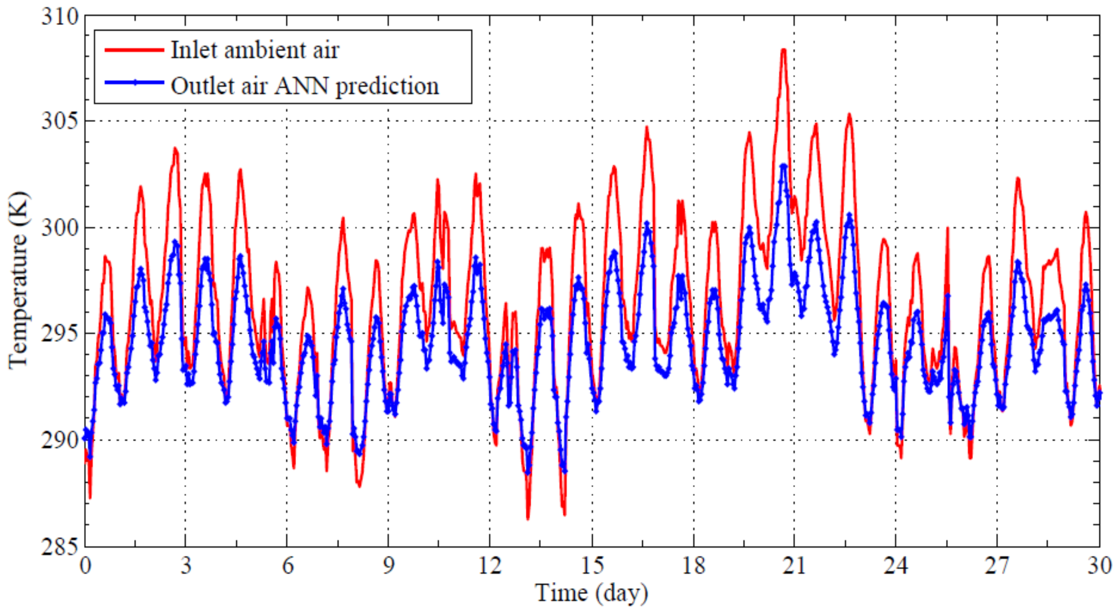


Temperature of the inlet air T_i = 26°C

Performance of LHTES
Assessment long-term performance of LHTES utilizing ANN

Comparison of the numerical calculation and ANN prediction





ANN's prediction for single outlet air-temperature

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Integrating the centralized LHTES system into a building model

- TRNSYS Building thermal response for single–zone model of 11.44m×5.69m×2.76m
- LHTES thermal response function
- Ventilation system modes
- Scheduled night ventilation
- Characterization and optimal design of LHTES system

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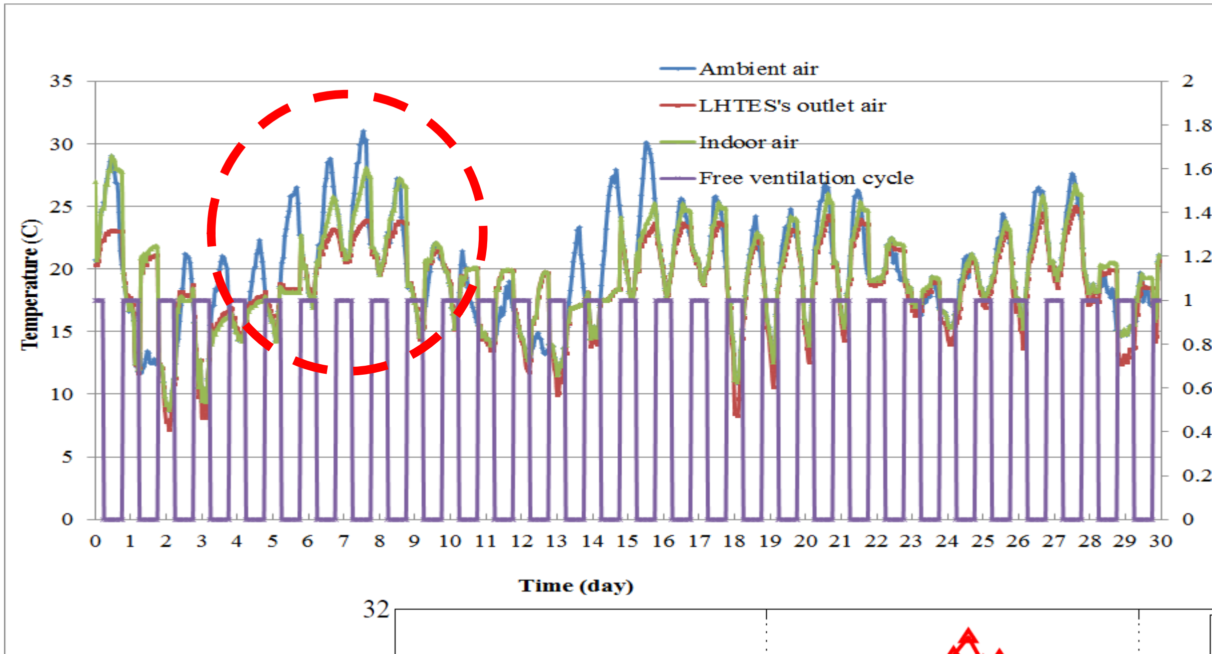
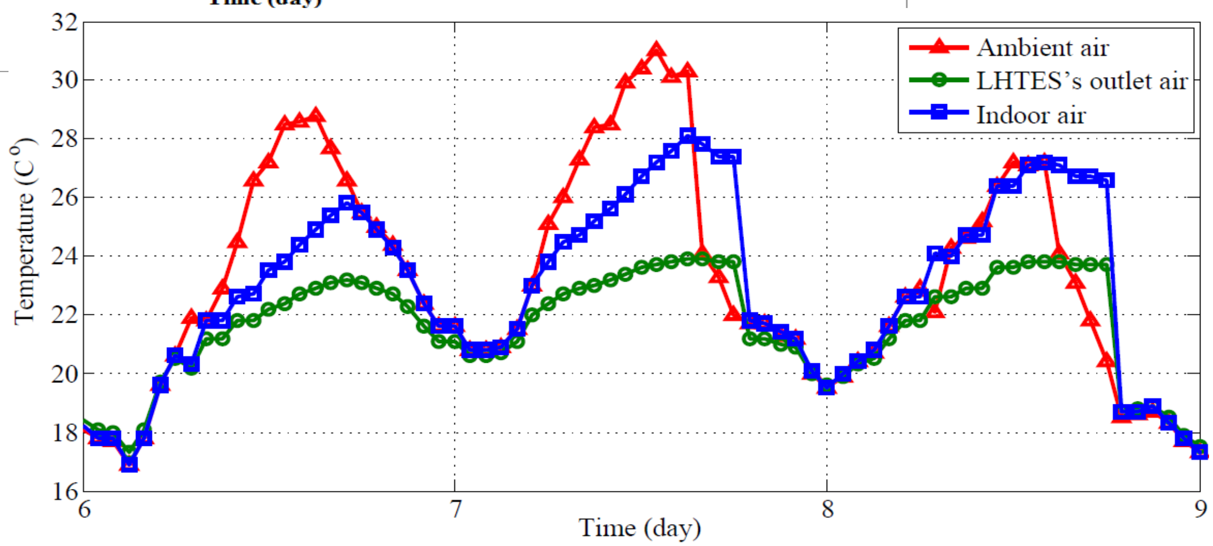
Integrating the centralized LHTES system into a building model





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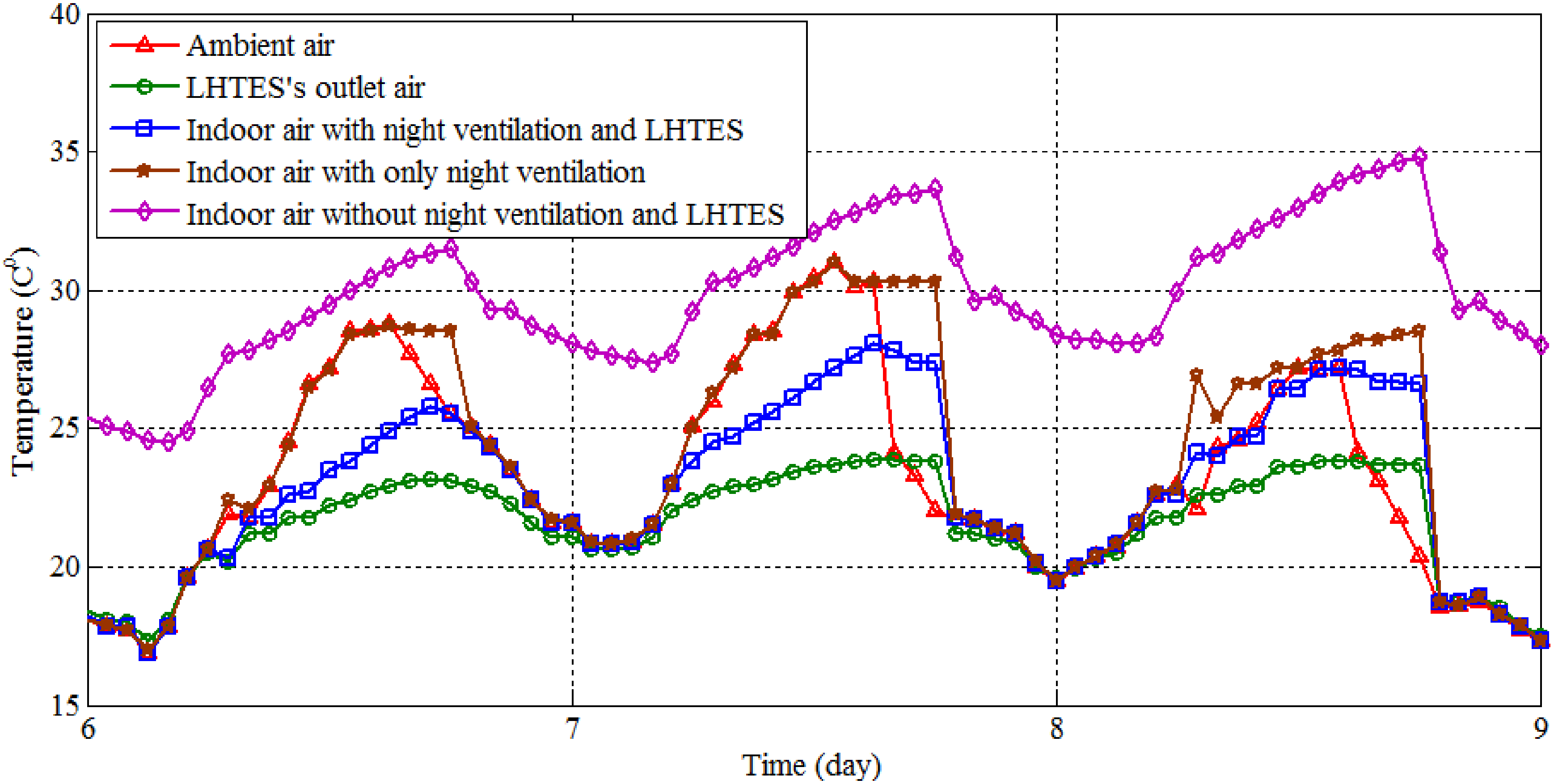
Performance evaluation of an integrated unit with energy building model



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

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Thanks for your attention

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