NUMERICAL MODELLING OF A REAL-SCALE AIR/PCM HEAT EXCHANGER BEHAVIOUR FOR FREE-COOLING IN BUILDINGS

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Abstract:

As a part of a positive-energy house project, a real-scale LHTES device has been designed and made for free-cooling of buildings (Fig. 1) [1]. This system uses the thermal gap between night and day to refresh indoor air. The air passes along a box-section tube bundle filled with paraffin wax which has a latent heat capacity of 245 kJ/kg (Rubitherm RT28 HC) and a melting point around 28°C: the melting temperature depends on the enthalpy (Fig. 2). In the scope of developing a designing tool, a simplified numerical model has been developed to simulate the system thermal behaviour during PCM melting. This 1-D model considers the close-contact melting of the PCM due to the PCM density variation and a corresponding fluid phase buoyancy term; conduction and natural convection occur in liquid phase. An enthalpy formulation is used for PCM governing equation. Results from a previous experimental approach [2] are used to verify the theoretical approach suitability.

Experiment procedure:

Air is collected from the heating room kept at constant temperature. It is pushed back by a fan in the heat exchanger. Then, the air is blown in the room where the heat exchanger is put in (Fig. 3).Five thermocouples continually measure air temperature. Air velocity and air pressure are measured along pipes radius at the inlet and the outlet of the system.

Modelling equations:

The Fig. 4 shows the 1-D model scheme and the governing equations. We used an enthalpy formulation [3],[4] for thermal equation of PCM. To estimate heat exchange coefficient, we considered the close-contact melting of PCM [5], [6] and usual equations [7] for air flow

Results:

The Fig. 5 is a comparison between preliminary experimental results and numerical results. It shows the relevancy of the numerical approach. Indeed, the shape of temperature curves sticks to the reality with 8% maximum error on the temperature values.

According to numerical model, The PCM is totally melted in 237 minutes whereas the PCM melted in 300 minutes during the experiment. Hence, the melting time error is 21%. A study of parameters influence shows that a reducing of 10% on air velocity in the model compared to the experiment decreases the maximal error on temperature to 3.2% and the melting time error to 1%. Following this assessment, in order to improve our modelling approach, we conclude that air velocity and heat exchange coefficient of air have to be respectively precisely measured and determined; moreover, a theoretical PCM enthalpy-temperature function is considered in this work and envisaging an experimental characterization of this paraffin characteristics would be suitable.

Conclusion:

Comparison of experimental and simulation results lead to point out the ability of the modelling approach to predict the thermal behaviour of an air/PCM heat exchanger. Further measurements, especially PCM temperature, PCM container temperatures and PCM enthalpy-temperature function measurements by Differential Scanning Calorimetry, will lead to refine this modelling approach; experiments are in progress.

In the future, this modelling approach will be integrated, as a computing module, in a designing tool which includes energetic simulation of buildings.

References:

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Figures:

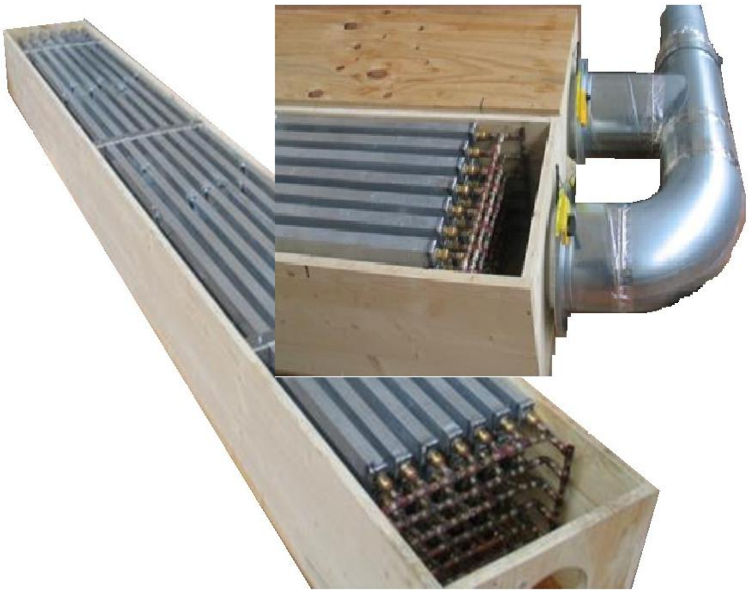


Fig. 1: Tube bundle heat exchanger

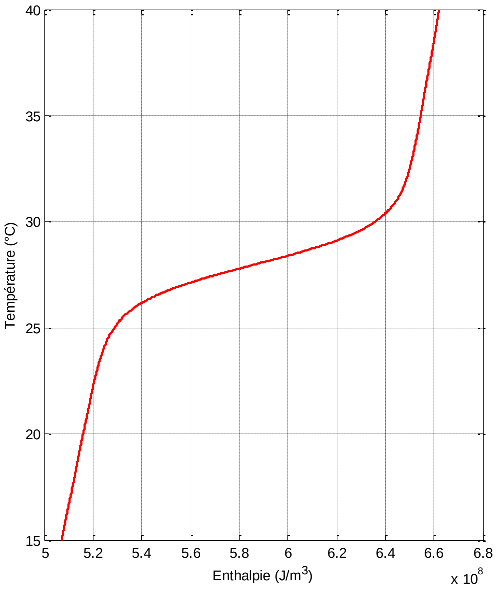


Fig. 2: PCM enthalpy-temperature function

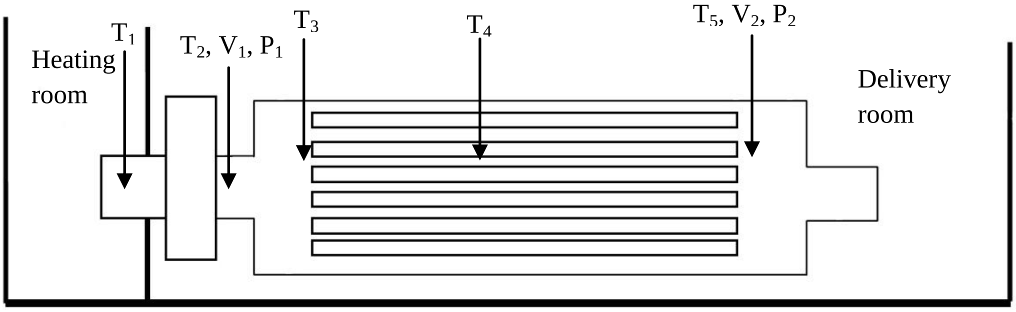
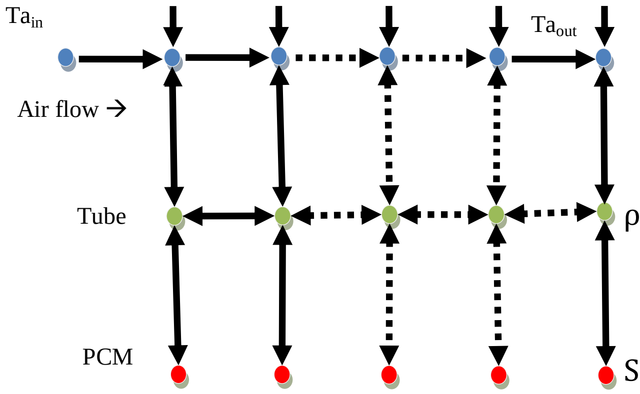


Fig. 3: Experimental device



$$\left[q_a Cp_a \frac{\partial T_a}{\partial x} + \rho_a Cp_a S_a \frac{\partial T_a}{\partial t}\right] dx = h_{air,tube}\, A_{tube\ ext}\, (T_t - T_a) + h_{env,tube}\, A_{env}\, (T_{env} - T_a)$$

$$\rho_t Cp_t S_t \frac{\partial T_t}{\partial t} dx = \lambda_t \frac{\partial^2 T_p}{\partial x^2} + h_{air,tube} A_{tube\ ext} (T_a - T_t) + h_{pcm,tube} A_{tube\ int} (T_{pcm} - T_t)$$

$$S_{pcm} \frac{\partial H_{pcm}}{\partial t} dx = h_{pcm,tube} A_{tube\ int} (T_t - T_{pcm})$$

Fig. 4: Model scheme with equations

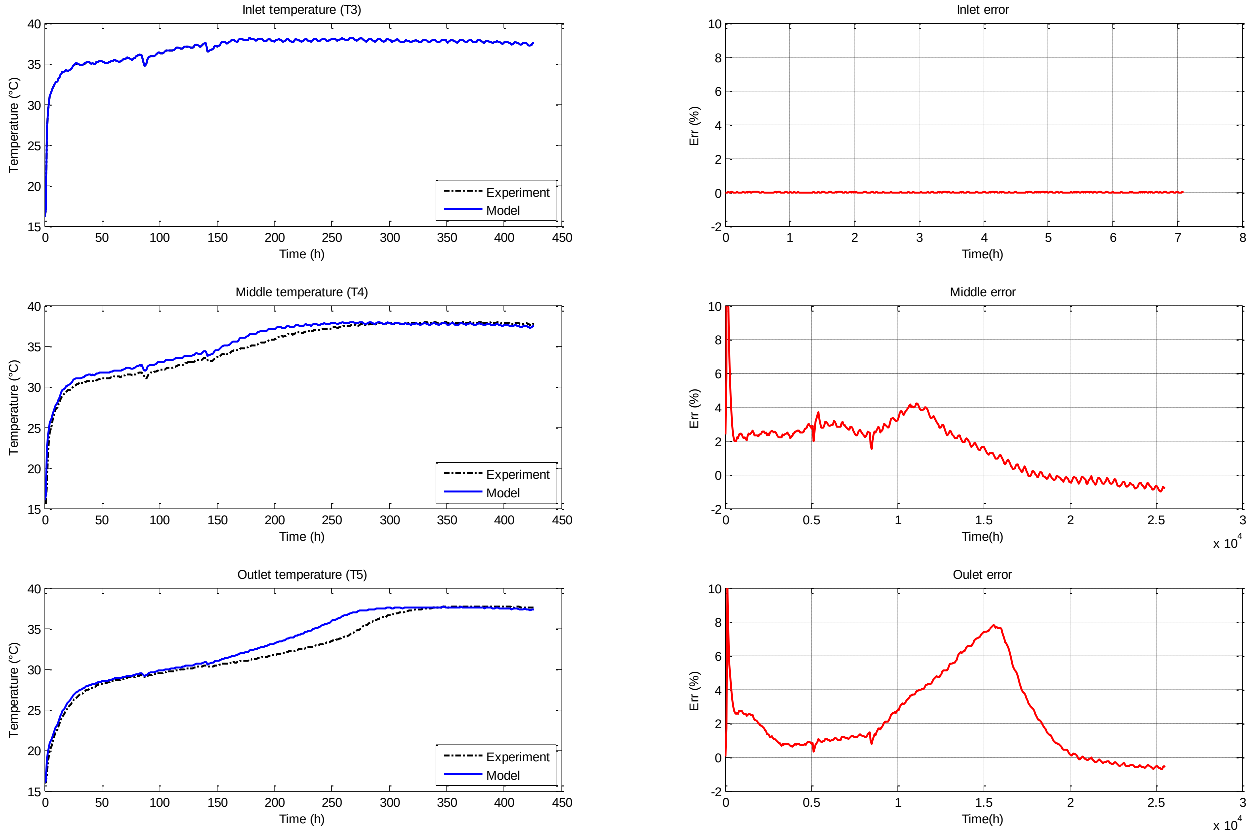


Fig. 5: Comparison of experimental and numerical results: Q_{air}=672m^3/h