THESIS: Physics-based dynamic model for reversible liquid-to-liquid heat pump systems. Development, validation and simulation with different systems, time scales, operation conditions and working mode switch.

Abstract

The energetic problem is an issue that concerns the entire world. For instance, heating and cooling in buildings accounts for around the 80% of total final energy use in buildings, of which the 75% is still generated from fossil fuels and only 19% from renewable energy. In this context, Heat Pump systems (HP) are one of the most promising technologies to reduce fossil energy consumption for heating and cooling in buildings. Additionally, newer and more efficient heat pump technology would improve the energy sustainability of the building in which it is used.

In order to develop new HPs, there are two important aspects. The improvement of the components and the improvement of the joint system. The components would improve by optimizing geometrical parameters and materials, among others. Regarding the joint system, the main goal is to improve the control loop of the system. Nowadays, the best way to address these aspects is by the dynamic modeling of the components and systems that could simulate accurately their behavior. During this thesis a model for reversible liquid-to-liquid HP has been developed.

Firstly, a review is presented on the state-of-the-art of residential HPs and the advances on their modeling. A general energy background is presented. In it, the main global energy problems, heating and cooling handicaps in buildings and the latest energy policies are presented. Then, a brief description of HP operation principles, types of HPs and their role in the energy transition is depicted. Additionally, different tests with HPs conducted by the community are described. Finally, the advances in mathematical modeling of vapor compression cycles are reviewed explaining the different approaches to model them, the advantages and disadvantages of those approaches and the already existing models.

Then, the physics-based dynamic model to simulate the behavior of reversible liquid-to-liquid HPs is presented. The model of each component of the HP is developed separately and then they are joined together. The model is implemented in Matlab/Simulink environment.

A refrigerant-to-liquid plate heat exchanger (PHEX) model was developed using the Finite Control Volume method. The behavior of PHEXs either if they are working as condensers or as evaporators can be simulated. Moreover, they allow the user to choose the configuration of the PHEX between parallel-flow and counter-flow. The equations and their implementation have been presented.

After that, the model is validated in micro-scale situations, understanding that the micro-scale is the time scale at which fast transient-states are produced. Examples include operation condition changes, working mode switches or system start-ups.

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Different tests under different transient situations were developed. Measurements have been used to validate the model under heating, cooling and start-up situations. Simulation results present good agreement with test data.

Once the model was validated under different micro-scale transient situations, working mode switch was simulated. The reversible behaviour of the system was simulated by starting in cooling mode, switching to heating mode and going back to cooling mode. Since experimental data of working mode switches was not available, it was not possible to compare the simulation results with test data. However, the obtained results could have a good alignment to the actual behavior of the system during a working mode switch.

Finally, the model was used to simulate the behavior of other HP under macro-scale situations, understanding that the macro-scale is the time scale at which the dynamics of the system are studied during long time periods. With it, the utility of the model to obtain the performance of the system is studied. With respect to micro-scale simulations, the discretization of the model into finite volumes was reduced to the half.

The HP used (different from that used in micro-scale tests), test rig and tests procedure is explained. Then, the model is validated under the cooling working mode. A good agreement is observed between test data and simulation results in water temperatures but the compressor power consumption is underestimated. After that, a system energy performance study was conducted in order to clarify the divergences between test data and simulation results. It was concluded that by improving the compressor model more accurate results could be obtained.

To summarize, the validity of the model can be asserted to simulate liquid-to-liquid HPs with accurate results. It can be used to carry out micro- and macro-scales simulations under different working modes and configurations of PHEXs. Additionally, working mode switch simulations can be carried out.

Keywords: Reversible liquid-to-liquid heat pump, Finite control volume approach, Switching mode, Dynamic modeling, Experimental validation.