Development of an inter-seasonal thermal storage system

Tshewang Lhendup

Abstract

The use of a ground-coupled heat pump (GCHP) has the potential to significantly reduce the amount of energy required for heating and cooling buildings. In order to reduce the impact of unbalanced heating and cooling load on the system performance and the ground temperature, an inter-seasonal thermal storage system integrated with unglazed solar collectors is proposed. This study examines the viability of using an inter-seasonal thermal storage integrated with a GCHP and unglazed solar collectors (ISTS-GCHP-SC) for the heating and cooling of residential buildings in Australia. Technicality and practicality of the proposed system has been assessed by experiment and simulations. The financial viability has been assessed by using life cycle cost (LCC) analysis.

An experimental rig for ISTS-GCHP-SC system (heating capacity of 4.8 kWh and cooling capacity of 6.1 kWr) was set up at the University of Melbourne, Burnley campus. The system capacity, which depends on the peak building heating and cooling loads, was determined by simulating the building. The building model was verified by comparing simulated temperatures of the building zones with the measured temperatures. The borehole length of the ISTS depends on the effective ground thermal conductivity which is not directly measurable. Therefore, it was derived from the secondary measurements of heat transfer rate and temperature by performing an in-situ thermal response test. The set-up was tested with charging and discharging experiments conducted over a period of one and half years. The proposed system was found to be workable in Melbourne climatic conditions and there are no major issues with the installation and operation of the proposed system. The unglazed solar collector was able to charge with both heat and coolth. The average cooling rate of the unglazed solar collector was found to be 120 W m\(^{-2}\). However, a single borehole configuration of the ISTS, is not able to retain the heat and coolth until the next season. As the system was to be used for predicting the performance of the system in different climatic zones, the experimental results were used to validate the TRNSYS components.
A TRNSYS model was developed to simulate the performance of the proposed system for different types of loads based on various climatic conditions. The load types investigated were cooling-only (Darwin), cooling-dominated (Alice Springs), heating-dominated (Melbourne) and heating-only (Hobart). The TRNSYS components (Types 257, 559, 919, 39 and 31) and the system simulation model were validated using the experimental data. Results show that the TRNSYS components are able to predict the performance of the corresponding system components. The system model was also found to be able to predict the performance of the system set-up. The financial viability of the proposed system was assessed through LCC analysis of the optimised system.

The TRNSYS simulation model coupled with GenOpt was used to minimise the LCC for single and multi-building applications. The optimisation process was repeated for four cities representing four climatic zones using the same building as a load. Results showed that the optimisation process was able to find the optimal set of borehole length and solar collector area for each city except Darwin due to its high cloud cover of more than 46%. The LCC and the performance of the ISTS-GCHP-SC system were compared with the optimised conventional GCHP (without solar collectors) system. For a single residential building application, the results show that by using unglazed solar collectors to recharge heat and coolth, the borehole length can be reduced between 2.4% and 26.5% depending on the location. However, it was found that cost saved from the reduction of borehole length was offset by the operating cost of pumps and the solar collector cost. Therefore, except in the case of Hobart which has heating-only load, the ISTS-GCHP-SC system was found to be more expensive than the conventional GCHP system. This was also proven by the system coefficient of performance of the ISTS-GCHP-SC being lower than that of the conventional GCHP system except in the case of Hobart. The unit cost of heating a single residential building using the ISTS-GCHP-SC system was found to be higher than the air-source heat pump (ASHP) system and liquefied petroleum gas (LPG) heating system in Alice Springs and an ASHP and ducted natural gas heating system in Melbourne. In Hobart, it was found that heating with the ISTS-GCHP-SC system is cheaper than the ASHP and ducted natural gas heating system. However, the unit cost of cooling using the ISTS-GCHP-SC system is higher than an ASHP in both Alice Springs and Melbourne. The analysis was repeated for a multi-building application.
The ISTS-GCHP-SC system was optimised for a multi-building application comprising of 30 residential buildings. Three water-to-water heat pumps were used with a separate heating and cooling coil units for each building. The system was found to be able to supply the heating and cooling load to 30 buildings with a constant system coefficient of performance (COP) over a period of 20 years. The LCC per building is 40-50% lower than for a system used for a single building application. The unit cost of heating multi-building using the ISTS-GCHP-SC system is lower than the ASHP and LPG heating system in Alice Springs and ASHP and ducted natural gas heating system in Melbourne and Hobart. However, the unit cost of cooling is higher than that of an ASHP. As the cost of the ISTS-GCHP-SC system was based on a one-off cost in Melbourne, a sensitivity analysis was performed.

A sensitivity analysis was conducted to investigate the impact of varying the cost of the components and the grout thermal conductivity on the LCC and the unit cost of heating and cooling for a single building application. The results showed that the LCC is most sensitive to the heat pump and borehole drilling cost and is least sensitive to the solar collector area except in the case of Alice Springs. The LCC was also found to be highly sensitive to the grout thermal conductivity. For a multi-building application, the LCC was found to be more sensitive to the borehole length and the discount rate. Therefore, in order to reduce the cost of ISTS-GCHP-SC system, the focus should be on the minimisation of cost of drilling vertical boreholes and heat pumps.

The greenhouse gas (GHG) emission savings depends on the type of fuel used for heating and climatic zones where it is used. The results were found to be similar for both single and multi-building heating applications. In Alice Springs, it was found that using ISTS-GCHP-SC system could result in lower GHG emissions compared to the ASHP and LPG heating systems. However, in Melbourne a ducted natural gas heating system results in the lowest GHG emissions and in Hobart, it is the ISTS-GCHP-SC system that results in the lowest GHG emissions. For a single building cooling application, the ISTS-GCHP-SC system results in lower GHG emissions in both Alice Springs and Melbourne but for a multi-building, it is the ASHP that results in lower GHG emissions.