Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 75 (2015) 1470 – 1476

Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

The design and development of an innovative simulator for an open loop system for extracting energy from flooded coal mines

Amin Al-Habaibeh*, Ben Meyerowitz, Duolan and Anup Athresh

Product Design, School of Architecture, Design and the Built Environment
Nottingham Trent University, Butrton Street, Nottingham, NG1 4BU, UK

Abstract

Water source heat pumps, in comparison to air-to-air heat pumps, have significant advantage for heating or cooling applications due to the relatively regulated temperature of most water resources. In the UK, similar to many other countries, disused coal mines have untapped potential for low cost green energy due to the flooding of coal mines with water at reasonable warm temperature due to the availability of geothermal energy at different depths. This allows to use water source heat pumps in locations away from rivers and seas for heating and cooling applications. Extracting energy from flooded coal mines using water heat pumps with open loop systems is still relatively a new concept, but can provide much heating capacity due to eliminating the time needed for heat transfer between the external environment and the heating loop in case of closed loop systems. The use of real systems to conduct research could be an expensive task or impractical to users of the application such as the residents of the served building. On the other hand, computer simulation includes significant assumptions that might not be accurate in many real situations. In this paper, the authors have developed a small scale simulator to help in understanding such energy systems and to conduct research in this field for the benefit of researchers, educators and students within the applied and renewable energy field. The paper describes the detailed design, the complete prototype and initial assessment of the system using infrared thermography and temperature monitoring. The results show that the system has been found successful in conveying the concept of extracting energy from coal mines and to characterize the general performance.

* Corresponding author. Professor Amin Al-Habaibeh,
Tel.: +44(0) 115 848 2564;
E-mail address: Amin.Al-Habaibeh@ntu.ac.uk.

1876-6102
doi:10.1016/j.egypro.2015.07.266

Keywords: coal mines, heat pumps, open loop, district heating, green energy,

1. Introduction

Despite the fact that UK is not actively volcanic, there is still a significant resource of geothermal energy available at different depths that could provide a clean and sustainable alternative to conventional domestic heating methods [1]. Ground energy source heating systems are considered to be one of the most energy efficient, environmentally sustainable and cost effective heating and cooling systems using the thermal store of the earth [2]. Ground source heating systems use a water source heat pump to extract heat from the ground and use it for heating or extract heat from buildings and dump it to the ground. Heat pumps are a simple concept that is used in almost every home as a 'refrigerator' or 'freezer' to extract heat from food and dump it externally. Air-conditioning systems are also a type of heat pumps that extract heat from buildings and dump it to the external environment. However, heat pumps for heating systems have been used more commonly in air-to-air heat pump systems to extract heat from the environment. Their drawback is, for heating purposes as an example, that the colder the weather and less efficient the processes becomes and hence the Coefficient of Performance (COP) becomes much less than expected. The 'efficiency' of a heat pump is measured by the Coefficient Of Performance (COP), which is the ratio between energy produced and the energy consumed by the system. A water source heat pump has relatively more stable COP because the temperature of the water source is not very sensitive to the change in outdoor air temperatures since the ground from which the heat is extracted has a more stable temperature. Figure 1 presents three configurations of water source heat pumps.

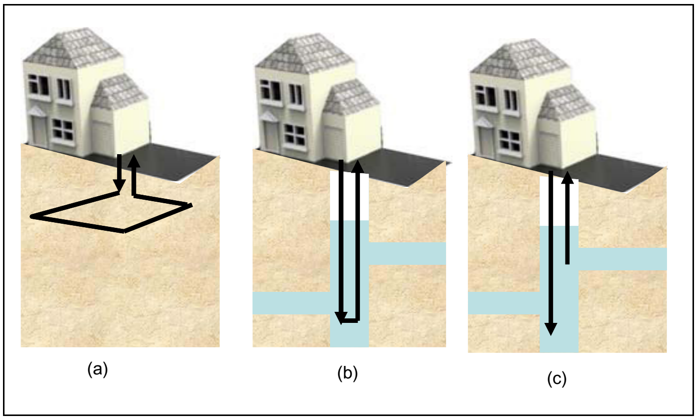


Figure 1: Three configurations for water source heat pumps, closed loop system ground source heat pump (a), closed loop energy from flooded coal mine (b) and open loop energy from flooded coal mine (c).

Configuration (a) presents the most common geothermal heating by using an underground closed loop where water is circulated to utilise the relatively stable temperature. Configuration (b) uses a closed loop system but uses the coal mine water as the media for heat exchange. This system is similar to configuration (a) but it enjoys much more efficient heat exchanging process since the closed loop is surrounded by water. Configuration (c) can be one of the most efficient configuration due to the fact the water itself from the coal mine is circulated in the system, hence a much larger capacity for heating can be utilised. This area of research in using water source heat pumps and disused coal mines has been attracting significant attention internationally; see for example [3-8]. This paper describes a novel system to simulate open loop coal mine heating system, configuration (c) of Figure 1, and its advantages and the results obtained from the initial testing.

2. The Design Idea

The first author through his research could not find a ‘user friendly’ energy from coal mine system at reasonable cost. Moreover, small scale water source heat pumps are relatively expensive and are not easily available. The initial idea of the novel approach is shown in Figure 2. The main idea is to use a simple portable fridge/freezer as a heat pump. Water will be circulated in the cold chamber, where food and drinks are stored in normal applications, to extract the heat. The extracted heat will be discarded by the condenser which will be utilized to heat a secondary circuit through a pipe coil with fins to transfer the heat to a small radiator inside a model of a house to simulate real life scenarios. Two pumps will be used, a large one to pump the water from the coal mine and the other one is used to pump the water in the closed circuit to exchange the heat between the heat pump and the house. An insulated chamber is used for the heat pump to enhance the heat transfer process between the condenser and the closed loop heating circuit.

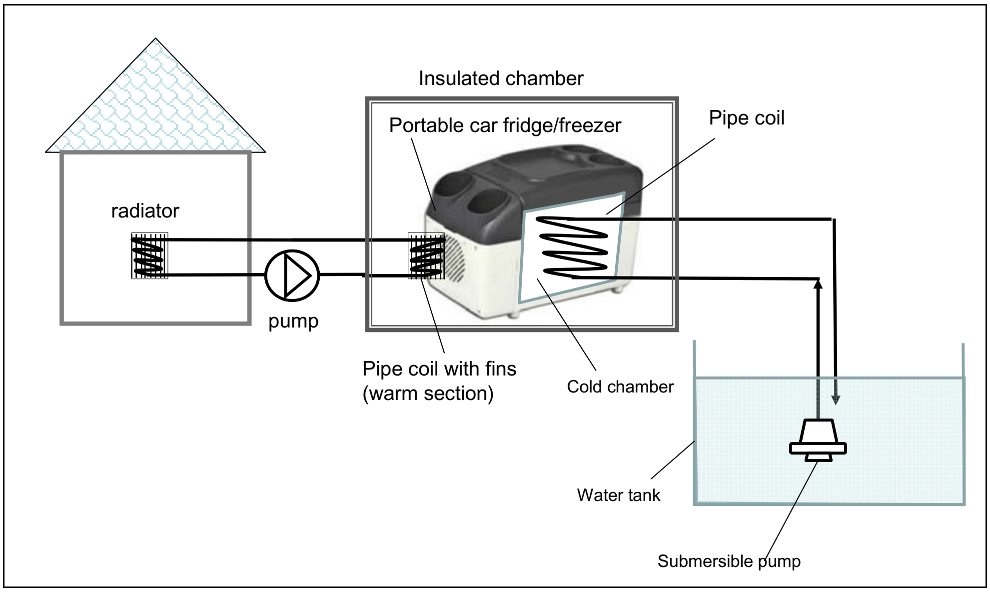


Figure 2: The novel concept of utilising mainly a portable fridge/freezer with a water tank to simulate the open loop coal mine heating system.

The design problem has been integrated as a product design brief which has been developed further by the MSc students at Nottingham Trent University in the product design team. To solve this problem, a practical but esthetically appealing system has been designed as shown by the CAD models in Figure 3. The design idea, as shown in Figure 2, is to develop a small scale system to simulate the configuration in Figure 1-c and Figure 2. With the lack of a reasonable low cost and small scale water source heat pump systems, the authors have used a small scale 12 volts car portable fridge/freezer and a fish tank as the two main components to simulate the system.

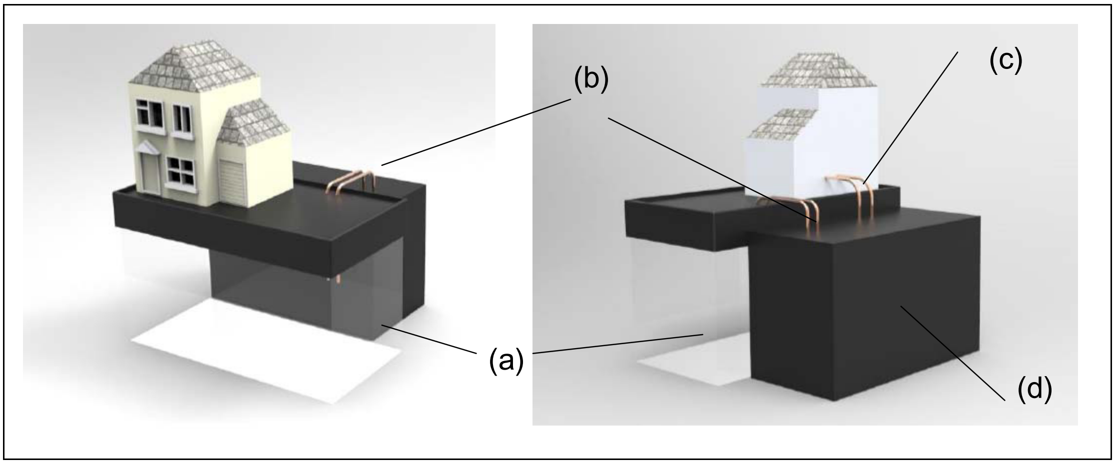


Figure 3: A 3D CAD model of the design systems; the water tank that simulates coal mine water (a), pipe from and to the coal mine (b), pipes from the heat pump to the house and vice versa (c) and the heat pump chamber (d).

Due to the relatively large scale of the portable fridge/freezer, the heat pump is integrated behind the water tank, see Figure 3. Figure 4 presents the actual system that has been developed and built which is almost identical to the initial design plan.

Figure 4: The complete novel design and built system based on the initial CAD model.

As presented in Figure 5, the heat pump is located behind the water tank with pipes attached to the cold chamber and the condenser.

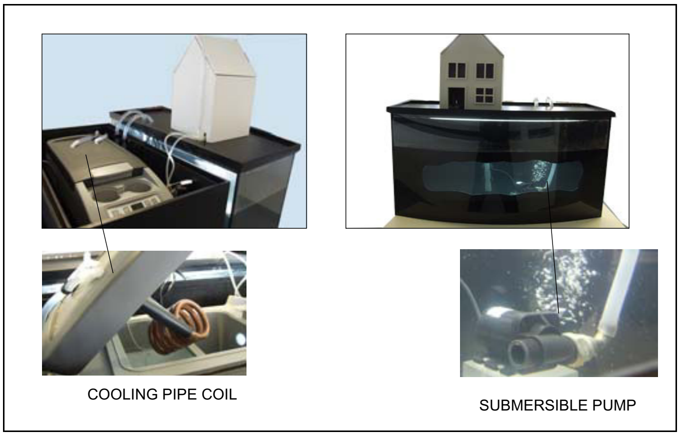


Figure 5: The novel system with the cooling pipe coil within the heat pump and submersible pump in the water tank.

3. Results and discussion

Figure 6 presents the results of the system using infrared thermography. It has been found clearly that the simulator is working as expected where the radiator in the house model has reached a temperature above 40 degree C while the water from the coal mine is at much lower temperature.

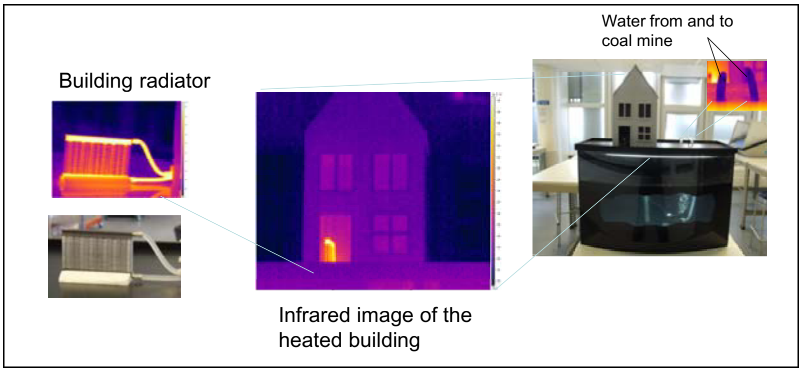


Figure 6: Results of the test using infrared thermography.

Figure 7 presented a temperature monitoring of the radiator, the water in the tank and the room temperature. Notice how the room temperature and the water tank temperature has been stable while the radiator temperature has reached a temperature of about 41 degree C. This heat has been extracted from the water tank through the heat pump. This model has provided a low cost opportunity for research as well as teaching applied energy concepts including energy from coal mines and heat pumps. People can 'feel' and 'see' the complete process which provides comprehensive understanding of the concept.

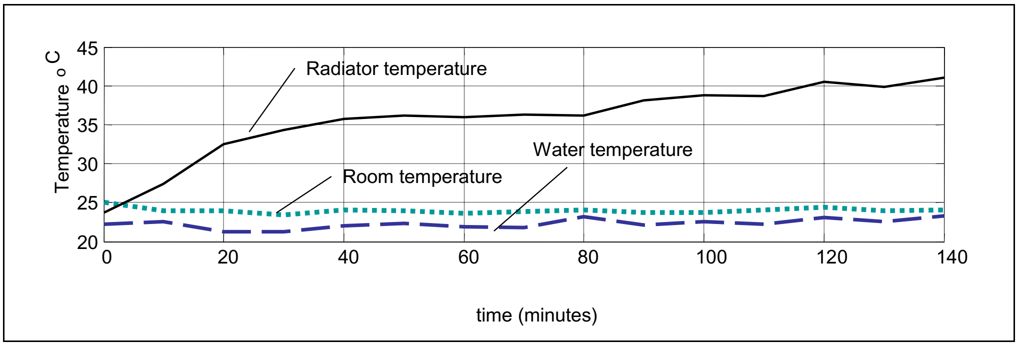


Figure 7: Comparison between room temperature, water temperature and radiator temperature.

4. Conclusions

This paper has presented a very successful and user friendly energy from coal mine physical simulator. The system can help in understanding the relationship between different variables at a very low cost and reduce development time. The simulator can be used for educational and teaching purposes. This work has been done as an integrated teaching and research project. Although the simulator has been found successful, further work is still needed. Calculation and improving COP is still on going work. To study and improve the COP, controlling the speed of the two pumps (i.e water flow rate) as well as improving the design of the heat exchangers are still needed to improve the performance and enhance energy efficiency. Future work will include also a fully automated and control system for full analysis, including the design of PWM and the effect of water height on the COP.

Acknowledgements

The authors would like to thank Innovate UK, Knowledge Transfer Partnership number 9032, for partially funding this work and Alkane Energy Plc for their collaboration. Also special thanks are due to the technical team at Nottingham Trent University, particularly Mr. Mark Beeston, for their support.

References

[1] Busby, J. (2013). Deep geothermal energy in operation. Available: http://www.bgs.ac.uk/research/energy/geothermal/home.html. Last accessed 23/04/2014.

[2] Rollin, K. (2010). Ground Source Heat Pumps - A Low-Carbon Energy Technology. Energy Resources. 12 (1), 10-19.

[3] Campbell, D. (2012). BGS expertise on the heat energy beneath Glasgow. Available:http://www.bgs.ac.uk/research/energy/geothermal/expertiseHeatEnergyGlasgow.html, accessed 30/10/2014.

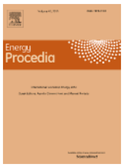
[4] Verhoeven, R. Willems, E. (2013). Minewater 2.0 Project in Heerlen the Netherlands: Transformation of a Geothermal Mine Water Pilot Project into a Full Scale Hybrid Sustainable Energy Infrastructure for Heating and Cooling. Energy Procedia. 46 (1), 58-67.

[5] Hall, A. Ashley-Scott, J. (2011). Geothermal energy recovery from underground mines. Renewable and Sustainable Energy Reviews. 15 (2), 916–924.

[6] Karytsas, S. Theodoropoulou, H. (2012). Public awareness and willingness to adopt ground source heat pumps for domestic heating and cooling, Renewable and Sustainable Energy Reviews. 34 (1), 49–57.

[7] Luo, P. Chen, N. (2011). Abandoned coal mine tunnels: Future heating/power supply centers. Mining Science and Technology. 21 (5), 637–640.

[8] Watzlaf, G. Ackman, T. (2006). Underground Mine Water for Heating and Cooling using Geothermal Heat. Mine Water and the Environment. 25 (1), 1–14.



Biography

Professor Amin Al-Habaibeh is a professor of Intelligent Engineering Systems within the Product Design team at Nottingham Trent University. He is currently leading the Innovative and Sustainable Built Environment Technologies research group (iSBET). Amin's interest also includes condition monitoring, intelligent systems, sustainable technologies, product design and advanced manufacturing technologies.