JOURNAL OF ENERGY SYSTEMS

2022, *6*(2)

2602-2052

DOI: 10.30521/jes.1058233

Research Article

Investigation of the performance of ground-coupled heat exchanger technology for tempering air

Mahendra Gooroochurn
University of Mauritius, Mechanical and Production Engineering Department, 80837 Reduit, Mauritius,
m.gooroochurn@uom.ac.mu
Maheshsingh Mungur
University of Mauritius, Mechanical and Production Engineering Department, 80837 Reduit, Mauritius,
atish.mungur24@gmail.com
Heman Shamachurn
University of Mauritius, Electrical and Electronic Engineering Department, 80837 Reduit, Mauritius,
h.shamachurn@uom.ac.mu
Yashwansingh Surnam
University of Mauritius, Mechanical and Production Engineering Department, 80837 Reduit, Mauritius,
y.surnam@uom.ac.mu
Fardeen Mandarkhan
University of Mauritius, Mechanical and Production Engineering Department, 80837 Reduit, Mauritius,
fardeen_mandarkhan@hotmail.com
Devin Bhoodoo
University of Mauritius, Mechanical and Production Engineering Department, 80837 Reduit, Mauritius,
dvin.bh@gmail.com

Submitted: *17.01.2021*
Accepted: *22.04.2022*
Published: *30.06.2022*

Abstract: A horizontal ground heat exchanger has been applied as a simpler sustainability measure in buildings compared to its vertical counterpart, making it more suitable for residential application. A lack of contextual scientific findings within the specific construction culture has precluded its widespread application in the developing world. In this study, an experimental and simulation investigation was carried out on the thermal performance of an air-based horizontal ground-coupled heat exchanger buried 3 m below the ground. The study was performed in the tropical climate of Mauritius with a focus on space cooling. The ground temperature and air temperature inside the pipeline at several locations of the installation was measured. A CFD simulation model was developed and calibrated against the experimental data, which allowed further analyses on the influence of system parameters on performance. The study allowed to confirm the performance of the technology for application as a sustainability measure in the local construction industry and to identify practical challenge that need to be addressed. A drop in temperature of up to 5°C was achieved at 2.3 m/s and 8°C at 4 m/s. The latter result holds promise to achieve thermal comfort by achieving indoor air temperature of 27 °C or lower when ambient air is at 33-34°C during typical summer periods.

Keywords: *CFD simulation, Ground-coupled heat exchanger, Thermal analysis, Tropical climate*

Cite this paper as:	Gooroochurn, M., Mungur, M., Shamachurn H., Surnam, B. Y. R., Mandarkhan, F., & Bhoodoo, D., Investigation of the performance of ground-coupled heat exchanger technology for tempering air. *Journal of Energy Systems* 2022; 6(2): 309-321, DOI: 10.30521/jes.1058233

1. INTRODUCTION

With the latest IPCC report confirming the dramatic consequences of climate change on human habitats, the built environment can become one of the most powerful levers in developing climate action solutions. It is fundamental to find solutions that are well adapted to the local context, and ground-coupled systems have been well recognized as an effective sustainable measure for building projects to reduce their carbon footprint in achieving adequate indoor environmental quality, either by providing cooling or heating. One of most effective approach to increase the energy performance of a building is to make use of passive methods for meeting thermal comfort or space requirements as much as possible and turning to active energy systems only when the naturally-powered, passive systems cannot meet demand. Proven passive engineering systems are daylight and natural ventilation systems, which are necessarily coupled to artificial lighting and mechanical ventilation systems respectively wherever a given level of lighting/air quality level need to be enforced.

In the context of commercial buildings, it is well-known that air-conditioning energy can take as much as 60% of the total energy consumption, especially in warmer coastal areas in Mauritius. The government has initiated several project ventures to regulate the energy performance of our buildings and air-conditioning energy is a promising area to target to reduce the carbon footprint of our building stock considerably. One proven method to reduce air-conditioning energy in buildings is the use of geothermal energy, specifically, use of the thermal mass of the earth to sink and source energy as needed. In the context of Mauritius, being largely in need of cooling rather than heating, the use of the earth mass for sinking heat is of greater interest.

Due to a lack of scientific findings to demonstrate the performance of such systems in developing countries, it has not been found its way into projects, where an increased use of air-conditioning systems has been witnessed, which in itself further contribute to climate change by carbon emissions as well as refrigerant leakage. Yet, there are ample findings and good practices reported in literature that can support the use of ground-coupled technologies to increase the COP of HVAC systems or used in conjunction with natural ventilation systems. Two main alternatives for implementing ground-coupled systems are the vertical and horizontal ground-coupled systems, which are primarily pipes buried to suitable depths and thermally connected to the earth to enable heat transfer. This paper presents the findings with a horizontal ground-coupled, air-based heat exchanger system, targeted primarily for the residential sector where low-cost solutions are required.

Horizontal systems are easier and cheaper to implement being at a shallower depth, although due to the temperature fluctuation of the soil at the depth of installation, a lower heat sinking or sourcing capability can be achieved than its vertical counterpart. Properly designed earth cooling tubes are known to offer a sustainable alternative to reduce or eliminate the need for conventional compressor-based air conditioning systems. The fundamental principle of this technology relies on the moderate temperatures in the ground to boost efficiency and reduce the operational costs of cooling systems.

The increasing demand for energy and the depleting fossil fuels have fuelled explorations in new frontiers of renewable energy technology. Geothermal heating and cooling are new advancement in HVAC industry, where the earth's thermal capacity and temperature constancy are utilized, with reported electricity saving up more than 50% in HVAC energy use and reduced CO_2 emissions. It has been observed that the temperature of ground at a depth of about 2 m remains almost constant throughout the year and is approximately equal to the annual average temperature of a particular locality. In summer season, this constant temperature of the earth's undisturbed temperature remains lower than the ambient temperature. Thus, the cooling requirement of a building can be partly or fully met by using a ground-coupled heat exchanger (GCHE) system if its outlet temperature is low enough.

The early growth in GSHP deployment in United States, Scandinavia, and Switzerland (followed soon after by Germany and Austria) and increasing interest for worldwide installation has led to constant improvement in associated technologies. The extensive application of ground source heat pumps has provided valuable data to validate and devise best practices for future system design. In 2000, the number of installations recorded in the different countries are listed as in Ref. [1]:

- 400,000 installations in the United States
- 55,000 installations in Sweden
- 30,000 in Canada
- 24,000 in Switzerland
- 19,000 in Austria and 18,000 in Germany.

No GSHP systems was reported in China at this time and there were relatively small number of installations in the other 19 countries providing reports. The rate of increase of new GSHP installations was estimated to be around 10% in the United States. The data from the World Geothermal Congress [2] and EurObserv'ER (https://www.eurobserv-er.org/) compared the trend from the year 2000 to 2015, showing a continued growth in the number of GSHP, with a reported 1.4 million installations in the United States alone. With no installations in 2000, and being ranked at just less than 1 million in 2015, China came second. The main appeal of GSHP over conventional heating and cooling heat pumps is that both heating and cooling needs can be met with a single heat pump, as opposed to two separate systems as well as the improved energy performance. The number of GSHP around the world in 2015 is depicted in Figure 1.

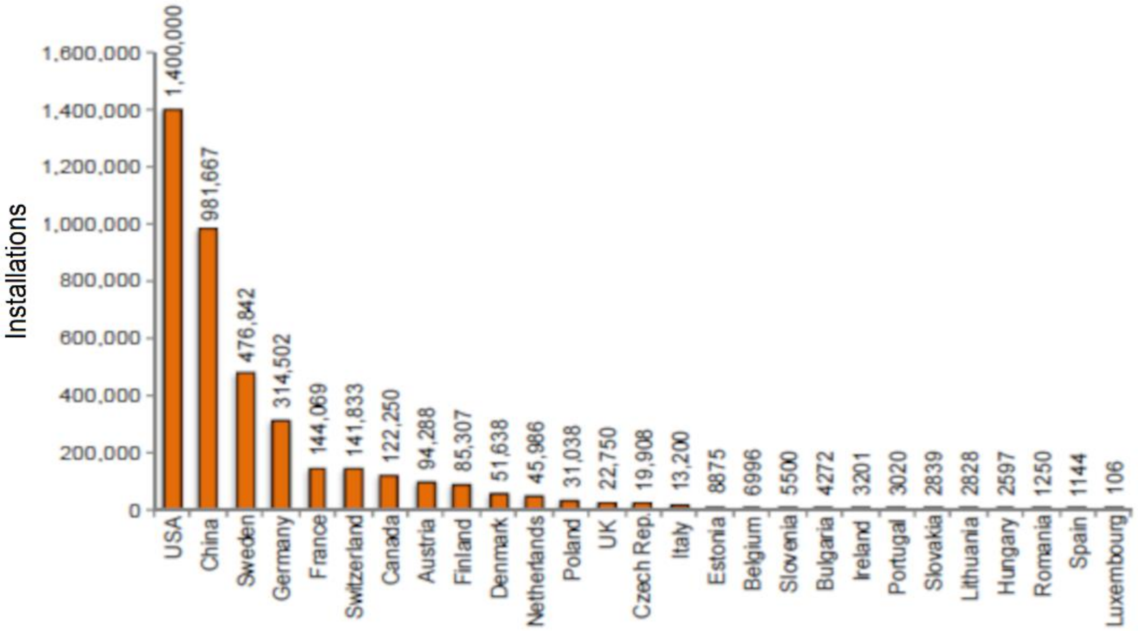

Figure 1. EurObserv'ER (Ref. [2]).

The types of ground-coupled heat exchangers reported in literature can be categorised broadly as horizontal and vertical, with the latter offering better thermal discharge potential due to less fluctuation in earth temperature with depth. Several configurations have been devised for installation of the ground loop heat exchangers. For example, researchers at Oak Ridge National Laboratory came up with a solution to avoid digging trenches by using the excavation works and service trenches of the building for the system [3]. In this scenario, the foundation walls need to be insulated in case there is a basement. The thermal model for the ground-coupled heat exchanger has been shown to depend on the level of the water table, where a high-water table leads to ground water movement. Xu and Spilter [4] also showed that surface ice and snow can yield significant deviation from established models, e.g., the Kusuda and Achenbach's model.

Urban settlements have also been reported to yield to long-term build-up of heat, which needs to be accounted for. In-situ performance of vertical ground-coupled heat exchangers are well reported in literature, but the performance of horizontal ground-coupled heat exchangers are more scarce, and a variety of other data sources is used for design purpose [5]. The saturated condition of soil in vertical GHE means that the thermal conductivity does not vary considerably over the length of the loop, whereas the same cannot be said for horizontal GHE. Shallow conditions used for horizontal GHE have been attributed for the low thermal conductivity in dry summer periods [6,7]. King et al [7] has recorded considerable variation of thermal conductivity across particular sites, and such variation is expected.

Gan [8] observed that the type, texture, moisture and temperature of a soil and the depth of the buried pipes are key design considerations that influence the performance of a ground heat exchanger. The COP of the system has been employed as a key indicator to assess and compare system performance. Wu et al [9] investigated a horizontal slinky-type system for a duration of two months, and reported that the COP on average was 2.5. The study recommended a longer heat exchanger length and a larger space for the installation. Tiwari [10] investigated an air heat exchanger in Chennai, India and obtained a temperature of 29.3°C during summer conditions at an ambient temperature of 34°C, clearly showing the potential of the system to promote thermal comfort or achieve air tempering for further cooling by Air Handling Units at less energy requirements. Singh et al [11] reported a COP between 1.8 and 2.9 for a system tested in India for winter and summer conditions respectively. Mongkon et al [12] tested a GCHE of 38.5 m length iron pipe, having a diameter of 80 mm, buried at 1m depth in Thailand and recorded COPs 3.56, 2.04 and 0.77 during summer, winter and monsoon days respectively, hence also confirming a higher COP for cooling during summer conditions.

Bansal et al [13] investigated the influence of pipe material on system performance in Ajmer, India, and observed little difference in outlet air temperature when using steel and PVC pipes, hence concluding that the thermal phenomena in place in such systems bear little dependence on the material of the pipe. Therefore, pressure-rated PVC pipes have been favoured for cost and durability reasons. Furthermore, in their study, Bansal et al [13] found that greater heat exchange occurred between the air inside the pipe and the surrounding earth, leading to a larger temperature drop at 2 m/s compared to that obtained at 5 m/s. However, Congedo et al [14] carried a CFD investigation of the three system configurations, involving straight, helical and slinky pipes, showing an increased heat exchange at higher velocities. This clearly shows that the velocity of the fluid medium is important in ground-coupled heat exchanger systems, and layout of the pipe plays a central role. The phenomena of change in direction of air flow at bends and turbulent flow caused at increased velocities are equally important considerations in addition to the increased exposure of the air to the earth environment at lower velocities. Moreover, Gooroochurn et al [15] carried out a simulation study for Mauritius through a parametric analysis of various factors to assess the most significant ones and concluded that pipe length played a critical role as well as the separation of the pipes. For the pipe configuration under consideration, a total length of 50-60 m was found to be optimal and a spacing of 2m to avoid cross-heat exchange between the buried pipes while maximising space.

2. MATERIALS AND METHODS

The experiments with the horizontal ground-coupled heat exchanger were conducted over the summer period (October to March) as the prime focus of the study was to investigate the cooling effect of the system. The experimental set up was located at Réduit, Mauritius (latitude 20.23°S and longitude 57.49°E, with an elevation of 307 m above sea level). The experimental set-up above ground level is shown in Figure 2 with the inlet and outlet labelled. 110 mm diameter PVC pipe was used for the installation below and above ground due to the commonality of this pipe used in plumbing installations for the residential sector. PN16 pressure-rated pipe was used for the segment buried under the ground and PN10 pressure-rated pipes were used for the part above ground. A schematic of the full experimental set-up, including the segment of the pipe buried under the ground at 3 m depth, is illustrated in Figure 3 where the length and width of the trench was 10m by 8m, typical of the footprint for a house in Mauritius. The idea behind choosing this trench size was firstly to target a potential synergy with the trenching works normally carried out for the foundation of houses, where the pipes can be buried at that stage. This will lead to little or no additional cost, and secondly due to previous simulation studies [15] showing that 50-60 m length of buried PVC pipe can achieve an optimal temperature drop. The labels P1 to P4 show the positions at which temperature sensors (TMCx-HD from Onset) were connected to measure the air temperature inside the pipe and soil temperature.

Figure 2. Experimental set up.

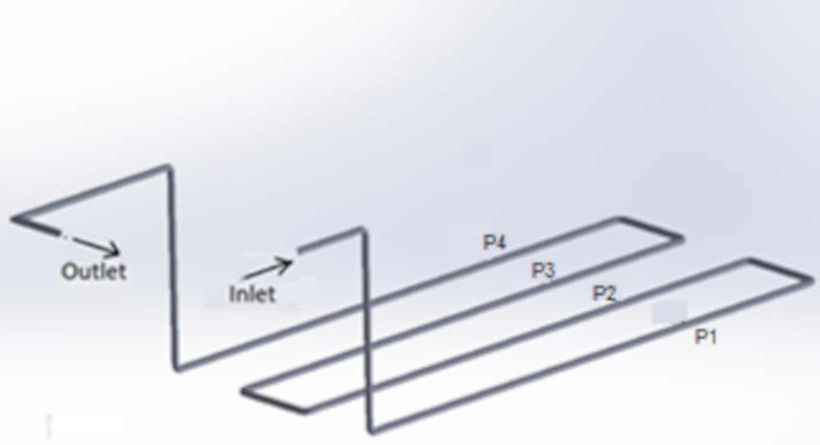

Figure 3. Design of the experimental set up.

A weather station (Davis Vantage Pro Plus 2) was also installed at the site to record the ambient air temperatures and other data such as humidity, wind direction, wind speed, precipitation. Soil humidity sensors were also installed at 3m and ground level. Two data loggers (U12-008) illustrated in Figure 4 were used for the data collection of air and soil temperatures since each data logger has four input channels. A CFD model was developed to simulate the heat transfer phenomenon between the soil and the air through the pipeline wall to validate the experimental results and offer the basis to perform parametric analyses on important system factors such as layout, soil thermal conductivity and flow rate of air inside the pipe. Moreover, the availability of a validated CFD model will allow extending the investigation to other locations around Mauritius where thermal conductivity results are available. The CFD model is illustrated in Figure 7. The soil was assumed to be homogeneous and the flow in the tube incompressible. The properties of the pipe and the soil are displayed in Table 1.

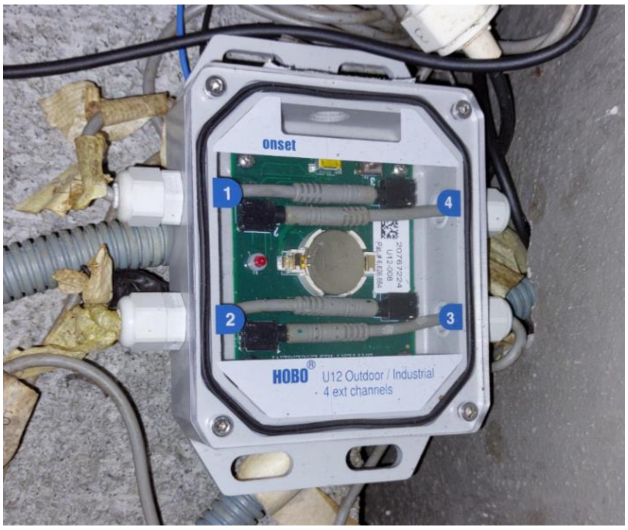

Figure 4. Data logger.

Figure 5. Degree Controls Air Velocity and Temperature Sensor.

Figure 6. Blowing of ambient air inside the pipes using a fan.

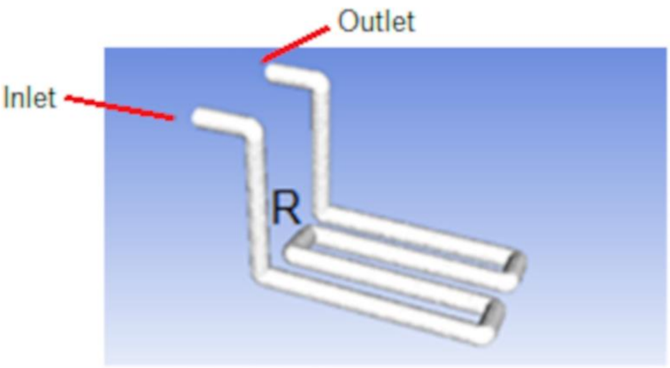

Figure 7. CFD Model of system.

Table 1. Materials used and their properties.

Material	Density (kg/m^3)	Specific heat capacity (J/kgK)	Thermal Conductivity (W/mK)
PVC	1380	900	0.161
Air	0.0242	1006.43	1.225

A mesh dependency analysis was performed on the CFD model to establish acceptable values for the mesh size for the earth and pipe to compromise on computational load of the simulation and accuracy of the results. These were set at 300 mm and 20 mm respectively upon measuring the variation of the temperature at a reference temperature measured at point *R* (see Figure 7). A time step of 1 s was configured for the simulation to ensure a satisfactory simulation time, while yielding accurate results. The thermal conductivity of the soil was measured using a TLS-100 meter for soil samples taken during excavation when completely dried in an oven.

It was assumed that the soil act only on the boundary of the pipe and the heat transfer between the soil and the pipe occurred only at the boundary of the model with a heat transfer coefficient obtained from the soil properties measured. The CFD solver was then used to numerically solve the mass (continuity) and momentum conservation equations along with other additional transport equations depending on the complexity of the flow (e.g. energy conservation, species mixing or reactions, turbulent flow). The turbulence and heat transfer governing equations are described below. Fluid flow in the pipe was modelled using the k-ε turbulence model. This k-ε model introduces two transport equations and two dependent variables:

- The turbulent kinetic energy (k),
- The dissipation rate of turbulence energy (ε).

The turbulent viscosity is modelled by Eq. 1:

$$\mu_T = \rho C_\mu \frac{k^2}{\varepsilon} \tag{1}$$

Where $C\mu$ is a model constant.

Eq. (2) shows the transport equation for k.

$$\rho \frac{\delta k}{\delta t} + \rho \boldsymbol{u}. \nabla k = \nabla . \left(\left(\mu + \frac{\mu_T}{\sigma_k} \right) \nabla k \right) + P_k - \rho \varepsilon \tag{2}$$

Where the production term is defined as per Eq. 3.

$$P_k = \mu_T \left(\nabla \boldsymbol{u}. (\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T) - \frac{2}{3} (\nabla . \boldsymbol{u})^2 \right) - \frac{2}{3} \rho k \nabla . \boldsymbol{u} \tag{3}$$

Eq. 4 shows the transport equation for ε.

$$\rho \frac{\delta \varepsilon}{\delta t} + \rho \boldsymbol{u}. \nabla \varepsilon = \nabla . \left(\left(\mu + \frac{\mu_T}{\sigma_\varepsilon} \right) \nabla \varepsilon \right) + C_{\varepsilon 1} \frac{\varepsilon}{k} P_k - C_{\varepsilon 2} \rho \frac{\varepsilon^2}{k} \tag{4}$$

3. RESULTS

The simulation for the turbulence modelling of the CFD was attempted. A *k-ε* model was used to simulate the heat transfer of the flow for the system. The model was configured with an inlet velocity of 2 m/s and inlet temperature of 303K (29 °C) with a soil temperature of 295 K (21 °C) based on experimental measurements collected (described later). A maximum velocity of 3 m/s was observed inside the pipework. At the outlet, an average temperature of 295 K (22°C) was achieved at steady state condition while in the interior part of the pipe the air temperature was 296 K (23 °C). At steady state condition at the outlet, a velocity of 2 m/s was observed. The flow of air inside the pipe was ascertained to be turbulent. A heat transfer coefficient was considered for the soil transfer to the fluid component. The convection heat transfer coefficient was determined using Eq. 5.

$$\alpha_c = \frac{Nu \, \lambda_w}{D_h} \tag{5}$$

The heat transfer coefficient of the soil is a function of the thermal conductivity and the Nusselt number. The thermal conductivity of the soil for Réduit is 0.196 W/mK and the hydraulic diameter is 110 mm. For a velocity inlet of 2.5 m/s, the flow is considered to be fully turbulent with a Reynolds number of 1.86×10^4. The Nusselt number needs to be found empirically dependent on the flow parameter of the Prandlt number and Reynolds number based on the paper of Congedo et al [14]. The equation for the Nusselt number is hence given by Eq. 6.

$$Nu = 0.023 \, Re^{0.8} \, Pr^{0.3} \tag{6}$$

An experiment was conducted to validate the model with the experimental values recorded. Based on the work by Golik et al [16], the Nusselt number was taken as 25 inside the earth-air heat exchanger the temperature of the bottom soil varies steadily about 293.5 K (20°C). The velocity inlet of the flow is considered to be 2.3 m/s based on the mean air velocity measured experimentally (describe later). The heat transfer coefficient is calculated using Eq. 5. Figure 8 shows the outlet temperature values (green circles) obtained experimentally with respect to the inlet temperature (blue circles at specific points of comparison on a blue profile) compared to the outlet temperature values obtained from simulation (shown as red circles) with time intervals of 10 minutes. It can be seen that the outlet air temperature values obtained experimentally (green circles) and from simulation (red circles) can be considered to be comparable, hence validating the CFD model created.

Using the 145 W rated extraction fan, the air velocities measured at the outlet are illustrated in Figure 9. These values of air velocity were recorded at 10 s intervals over a period of 45 minutes. The resulting air temperatures at the four locations (P1, P2, P3 and P4) inside the pipe are depicted in Figure 10 along with the ambient air temperature fed to the system. It can be seen that a mean velocity of 2.3 m/s was recorded at the pipe inlet. This mean velocity resulted in pipe temperatures ranging from 297 K (24 °C) to 301.5 K (28.5 °C). Comparing these results obtained experimentally with the simulation results, it can be found that the temperature values are in the same range for both, hence the simulation results are found again to correspond. From Figure 10, it can also be seen that the ambient temperature recorded using the weather station had an average value of about 29.5 °C. This was the temperature of air that was circulated inside the pipe. At the average speed of 2.3 m/s, it was observed that a cooling effect of over 5°C was achieved, which clearly showed the performance of the system in an environment representative of the type of soil, summer air temperature and humidity levels prevailing in Mauritius.

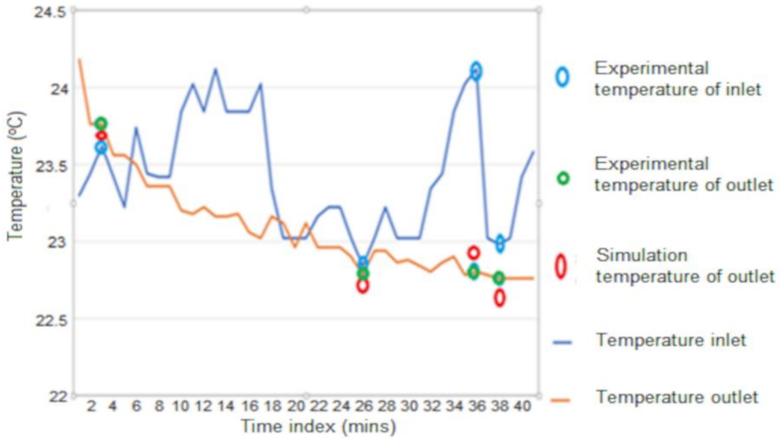

Figure 8. Comparison of experimental results with simulation results.

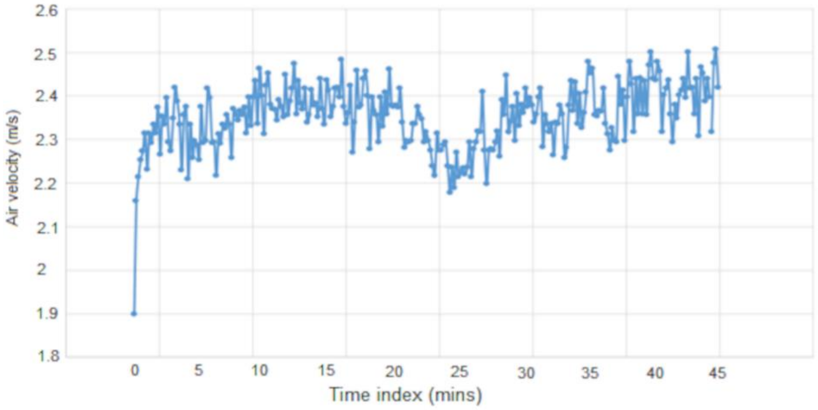

Figure 9. Velocity of air at the inlet with 145 W fan.

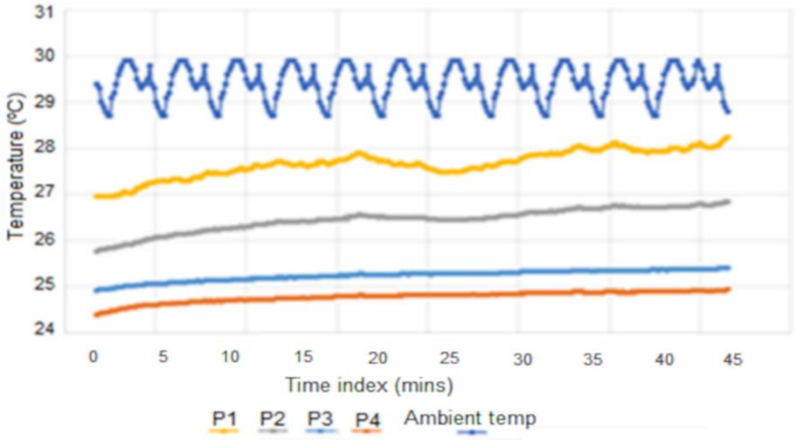

Figure 10. Air temperatures inside pipe at four locations.

As noted by Gooroochurn et al [17] in their simulation study, a temperature drop of up to 8°C can be achieved at higher air velocity over a pipe length between 50 and 60 m using the proposed layout with more than eight 90° bends buried under the ground at which greater heat exchange was observed in the simulated temperature profile. Therefore, a larger fan (Lineo 315 VO) rated at 330W was used to circulate air through the system, and the profile of air velocity and temperature recorded is shown in Figure 11 for a test period of around 4 hours on a warm sunny day.

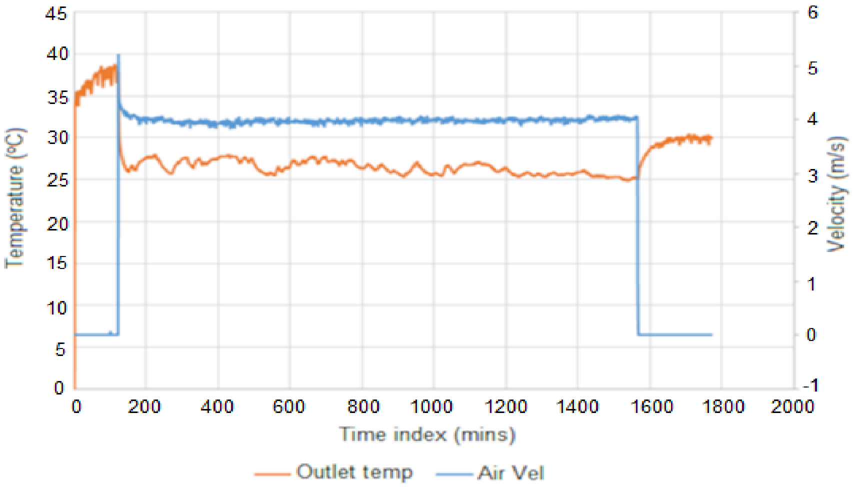

Figure 11. Profile of air velocity and temperature measured with larger fan.

The velocity is found to achieve a maximum value of 5.1 m/s but overall fluctuates around 4 m/s. The cooling effect of the ground coupling is clearly seen on the graph, with a drop in air temperature at the outlet with the flow through the pipework. Before circulating air, an average temperature of 36.7 °C was recorded, and during the air flow, an average temperature of 26.4 °C was obtained, showing that as much as 10 °C drop in temperature can be obtained for velocities in the range of 4-5 m/s known to cause turbulence in the flow of the pipes.

4. DISCUSSION

Following the preliminary results reported on a 6 m straight PVC pipe [17], the aim of this paper was to present the development of a larger scale experimental model and an associated CFD model to allow generation of scientific findings on the performance of horizontal ground-coupled heat exchangers in Mauritius and to allow optimization of system parameters. The system was implemented for a length of around 50 m of buried pipe at a depth of 3 m, which the previous study found to be a satisfactory compromise between performance and cost, and targeting the residential sector, a suitable size for considering to bury the PVC pipes at trenching stage for foundation works. The study was carried out through two investigations, one being simulation modelling and the other being experimental, with the validation of the former using techniques reported in literature. Past research findings have shown that the velocity of air inside the pipe is a critical parameter to determine the level of heat exchange where low velocities allow the air to be present inside the pipe longer, although at a reduced flow rate, whereas higher flow rates allow the air to undergo a turbulent flow. These two effects can have different results depending on which one predominates as observed in findings reported by Refs. [13] and [15]. For the proposed pipe layout, the combined effect of the presence of several bends (which have been found to promote heat exchange) and the effect of a turbulent flow, has been found to be dominant, with greater temperature drops obtained at higher velocities. Specifically, the drop in temperature observed at 2.3 m/s was 5°C and at 4 m/s was 8 °C. The results show the potential to use low energy circulation fans to achieve significant drop in air temperature, and with 8-10 °C drop, this technology hold great promise for tempering air to promote thermal comfort and energy efficiency in buildings under summer conditions.

The experimentation and simulation studies with the air-based ground-coupled systems has provided a good insight into the efficacy of previously untested ground-coupled heat exchanger technology for improving the energy performance of the built environment from an air-conditioning and ventilation perspective, where a clear increase in the carbon footprint has been observed in recent years due to warmer summers resulting from climate change. Due to the lack of guidance and scientific results to demonstrate the performance of ground-coupled heat exchanger systems, there has been a tendency to stick to conventional HVAC systems, but there is clearly a good potential to investigate the integration of ground-coupled technologies as a key approach in the local building services engineering industry.

Considering an airflow of 4 m/s with a 110 mm PVC pipe, this corresponds to a flow rate of around 40 L/s, which can meet the 10 L/s/person rate for a four-person household recommended in building services standards such as CIBSE Guide A. From an energy perspective, achieving 10 °C drop in temperature for this flow rate corresponds to a thermal power transfer of around 470 W representing a COP of at least 1.43 (calculated at the maximum fan power of 330W). Provided the trenching works are integrated with foundation works of building, and hence discounting the cost for trenching, the additional cost for pipe work, fittings, labour and the fan comes to around $1,500. This cost is equivalent to the price of two split air-conditioning units rated at 12,000 Btu/h (3.5 kW) which translates to around 1.2 kW for a COP of 3, representing more than three times the power rating for the ground-coupled heat exchanger system. Clearly, the economics for the proposed air-based ground-coupled heat exchanger system is favourable and clearly supports sustainable development, specifically SDG11 Sustainable Cities and Communities, SDG13 Climate Action and potentially SDG3 Good Health and Well-Being due to the fresh air renewal achieved.

Furthermore, the ground-coupled heat exchanger system has the merit of bringing fresh, oxygen-rich, outside air into the building to maintain a healthy level of carbon dioxide concentration as opposed to the operation of a split-type air-conditioning system with typically 100% recirculation rate and any outside air admitted treated as infiltration. An added advantageous use of the ground-coupled system is in night flushing to provide a pathway for outside air to be admitted to the interiors since the simple use of windows has been found to be inadequate due to lack of pressure gradient across the interior spaces, and the coincidence of the proliferation of mosquitoes with summer in Mauritius further discourages the opening of windows. The high potential for night flushing stems from a drop of up to 10 °C during peak summer time between daytime and night-time temperatures (see Figure 12), hence the pipework of the ground-coupled system can be used to provide the desired connection between the interior and exterior environments when the ambient conditions are right.

The horizontal ground-coupled system is implementable within the technical skills of the local construction industry, although measures to maintain a good air quality by ensuring a clean environment inside the buried pipe becomes quintessential with the air-based system, as well as finding means to deal with any condensation that may occur inside the pipe given the high relative humidity levels in Mauritius (typically in the range of 70-90%). The experimental set-up included a siphon at the lowest point in the buried pipe network to drain any condensate. Air filtering measures can also be considered to prevent propagation of any particulate matter or microorganisms from the underground pipe environment to the building spaces. Means to investigate the pipe conditions and decontaminate on a frequent basis are other areas for future research.

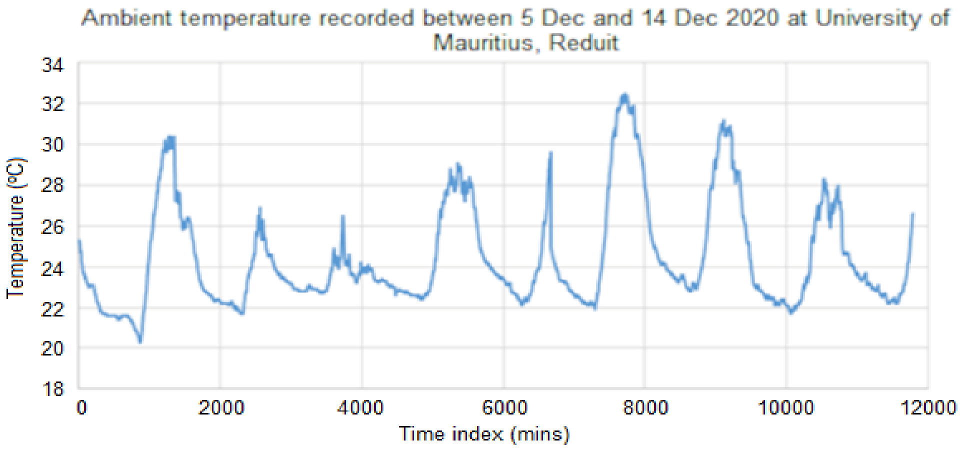

Figure 12. Diurnal variation in ambient temperature during summertime.

The simulation models developed from the study has allowed generating results that were comparable to experimental data. The importance of an integrated software environment for system design, modelling and optimisation is well recognised in this field, although the software packages available on the market are predominantly geared for water-based system modelling as opposed to air-based systems. The way forward to implement ground-coupled technology in Mauritius should be the construction of demonstration prototypes around Mauritius to raise awareness on the technology and showcase its benefits, and offering tax incentive schemes from government to encourage investment in such systems. Indeed, ground-coupled heat systems can become a key technology to drastically improve the energy performance of buildings and serve as a highly efficient climate action strategy to provide thermally comfortable interior spaces.

5. CONCLUSION

The research findings reported in this paper clearly support the application of ground-coupled systems as a viable technology for a tropical country like Mauritius where the need for active cooling systems has been on the constant rise. Incentives should be considered by government and funding agencies to support its integration in the built environment. Practical implementation with on-site testing and performance monitoring will be key to further generating scientific findings for this technology across various locations in Mauritius, with a concomitant research effort to investigate types of soil from a thermal perspective, including thermal conductivity measurement and influence of moisture content on system performance as well as long-term system performance with respect to soil temperature fluctuations. Although the project has demonstrated the performance of the ground-coupled systems from a thermodynamics perspective, there are practical aspects such as air quality, condensation and workmanship from the industry that need to be looked at to achieve efficient and operational systems. The experimental set-ups installed for the project was for testing the system performance in isolation, and the next step should be to connect them to a building space or building project to demonstrate their operation in an actual scenario. Like most sustainable measures, demonstration prototypes should be considered by authorities and the private sector to generate further performance data and build confidence over time to inspire developers to adopt the technology in their projects.

Acknowledgment

The authors wish to express their humble gratitude to the Higher Education Commission, Mauritius for funding the research work.

REFERENCES

[1] Lund, J., Freeston, D. World-wide direct uses of geothermal energy 2000. *Geothermics* 2001; *30* (1): 29-68.

[2] Lund, J. GEOTHERMAL HEAT PUMPS - TRENDS AND COMPARISONS - Geo-Heat Center.

[3] Im, P, Hughes, P, Liu, X, Ridge, O. Demonstration and performance monitoring of foundation heat exchangers (FHX) in ultra-high energy efficient research Homes Field test of the foundation heat exchanger concept. In: 17th ACEEE Summer Study on Energy Efficiency in Buildings; 12-17 August 2012: Pacific Grove, CA, pp. 114-126

[4] Xu, H, Spitler, JD. The relative importance of moisture transfer, soil freezing and snow cover on ground temperature predictions. *Renewable Energy* 2014; 72: 1-11.

[5] Busby, J. Determination of thermal properties for horizontal ground collector loops. In: Proceedings of World Geothermal Congress 2015; 19-25 April 2015: Melbourne, Australia, pp. 19-25.

[6] Naylor, S, Ellett, KM, Gustin, AR. Spatiotemporal variability of ground thermal properties in glacial sediments and implications for horizontal ground heat exchanger design. *Renewable Energy* 2015; *81*: 21-30.

[7] King, W, Banks, D, Findlay, J. Field determination of shallow soil thermal conductivity using a short-duration needle probe test. *Quarterly Journal of Engineering Geology and Hydrogeology* 2012; *45* (4): 497-504.

[8] Gan, G. Dynamic thermal performance of horizontal ground source heat pumps – The impact of coupled heat and moisture transfer. *Energy* 2018; *152*: 877-887.

[9] Wu, Y, Gan, G, Verhoef, A, Vidale, P, Gonzalez, R. Experimental measurement and numerical simulation of horizontal-coupled slinky ground source heat exchangers. *Applied Thermal Engineering* 2010; *30*(16): 2574-2583.

[10] Tiwari, G. Design of an Earth Air Heat Exchanger (EAHE) for Climatic Condition of Chennai, India. *Open Environmental Sciences* 2014; *8*: 24-34.

[11] Singh, C, Kocher, G, Singh, P. A Computational Study on the Performance of Earth Air Heat Exchanger (EAHE) Using Different Duct Geometries and Material Combinations. *International Journal of Computer Sciences and Engineering* 2018; *6*(8): 514-519.

[12] Mongkon, S, Thepa, S, Namprakai, P, Pratinthong, N. Cooling performance and condensation evaluation of horizontal earth tube system for the tropical greenhouse. *Energy and Buildings* 2013; 66: 104-111.

[13] Bansal, V, Misra, R, Agrawal, G. Mathur, J. Performance analysis of earth–pipe–air heat exchanger for summer cooling. *Energy and Buildings* 2010; *42*(5): 645-648.

[14] Gooroochurn, M, Hossenbaccus MZ. Horizontal Ground-Coupled Heat Exchanger as a Passive Design Technique for Tropical Climates. *International Journal of Advances in Mechanical and Civil Engineering (IJAMCE)* 2018; *5*(4): 56-62.

[15] Congedo, PM, Colangelo, G, Starace, G. CFD simulations of horizontal ground heat exchangers: A comparison among different configurations. *Applied Thermal Engineering* 2012; *33*: 24-32.

[16] Golik, A, Zemenkov, VV, Gladenko, YD, Seroshtanov, I.V.Modeling the heat transfer processes in the pipe-soil system. *In IOP Conference Series: Materials Science and* Engineering 2019; *663*(1): 012012.

[17] Gooroochurn, M, Seegobin, B, Jankee, L. A preliminary in-situ measurement and simulation of the performance of ground-coupled heat exchanger system in the tropical context of Mauritius. In: 8th Eur. Conf. Ren. Energy Sys.; 24-25 August 2020: dhepublisher, pp.637-643.