Affordable Heating System Exploration for a Net Zero Energy Experimental Home in Melbourne, Australia

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Abstract: This research explores affordable heating for hydronic systems of a net zero energy experiment home built in Melbourne, Australia. For this research purpose, a 3m-wide 6m-long outbuilding is built next to a backyard garage. Inexpensive 12mm-dia poly tubes are spaced 100mm inside the 55mm-thick tiled concrete which rests on 100mmT (R2.5 $m^2{\cdot}K/W$) recycled cold-room panels laid on ground. This hydronic floor and ground is insulated from the outdoors by 400mm-deep 40mm-thick (R1 $m^2{\cdot}K/W$) polystyrene. Simulations show that heating this hydronic floor by a vertical ground heat exchanger with 17°C bottom temperature, together with a hydronic wall radiator heated by 30 evacuated tubes and a 2-cubic meter thermal storage, the indoors could reach the Nationwide House Energy Rating Scheme (NatHERS) respective night and day heating thermostats of 15°C and 20°C across winter. This assumes that the indoor had been at NatHERS temperatures for 5-6 years for the temperature at the bottom surface of the floor to stabilize. Since this warmup period has not been met, the results in this paper show the temperatures with water heated by a sawdust/wood burner. An experiment was also conducted with a compost pile. Two months after its initial 1-month exothermic phase, the temperature at the center was still 32°C. Thus, compost piles will be located outside external walls to help keep the perimeter of the floor warm. To obtain affordable hot water for the indoors to reach 20°C, a 6m-long 750mm-wide flat-belt collector was boxed up and covered with glass. In late autumn, it could only heat water by only 1-2°C and was thus not used in winter. However, by late spring, the empty poly belt had melted, indicating that, the temperature under the glass had reached above 50°C. Typical meteorological year data shows that the solar radiation has tripled that in autumn. Therefore, for future winter experiments, the weak solar radiation would be concentrated, by say, a north-facing parabolic trough with an aperture three times the area of a glazed metallic collector

Keywords: Renewable heat, Affordable hydronic radiator, Compost piles, Concentrated solar collector.

1. Introduction

Hydronic heating systems make homes in cool/cold climates comfortable quietly. This project explores affordable renewable sources to heat water for a hydronic floor. The experimental building in Melbourne Australia has an inexpensive 3m x 6m hydronic concrete floor which rests on recycled cold room panels laid on ground. As the temperature of the ground below the floor takes years to stabilize against the variations in the outdoor temperature, this paper reports the results to warm up the floor with a wood/sawdust burner.

It also reports test results for the exothermic decomposition of organic waste and the effect of glazing a flat belt solar collector that heats water for swimming pools. Test results are discussed and plans for future experimentation are presented.

This project is spurred by past 2-decade data from the US which shows that in winter, the energy use by the residential sector is nearly twice that by its commercial sector.

The vertical axes of Figure 1 show the Yearly Energy Consumption in the US for the last 2 decades. The scale in the top figure, by the commercial sector, is half of that in the bottom figure, which is that for the residential sector.

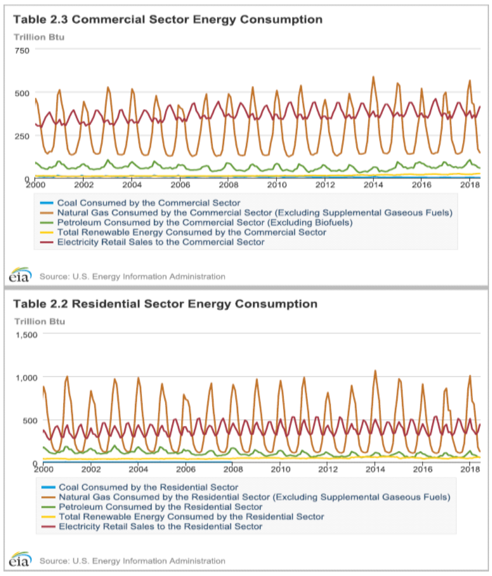

Figure 1. Energy consumption. 2-decade US data

2. Literature Review

2.1. Low Temperature Hydronic Radiators

Qian Wang et al (2015) [1] showed that low temperature hydronic can improve the thermal performance of five retrofits to an acceptable level. Dietrich Schmidt et al (2017) [2] pointed out that currently 12 research institutions from 8 countries are participating in the research to use low temperatures in district heating. Mats Dahlblom et al (2018) [3] evaluated a feedback control method for hydronic heating systems based on indoor temperature measurements. Matjaž Prek and Gorazd Krese (2018) [4] presented an experimental validation of an improved heat output regulation concept for multi-panel radiators and showed that the implementation of the modified water flow arrangement significantly improves the transient response of heating radiators in terms of reduced time.

Petr Ovchinnikov et al (2017) [5] made a study that aims at evaluating practical application of low temperature hydronic space heating systems in residential buildings in Russia. M. Jangsten et al (2017) [6] stated that to maintain the competitiveness and improve the environmental performance of district heating, in the future, it is essential to transition to lower operating temperatures and suggested supply and return temperatures of 50–55 °C and 20–30 °C for low temperature radiators.

2.2 Solar Thermal – Limitations

Cüneyt Kurtay et al (2009) [7] reported that solar thermal systems supply 15-20% of the heating requirements of a building. They concluded that “at Ankara conditions it is not possible to provide thermal comfort conditions with thick clothing ensemble using solar energy” Ankara is the capital of Turkey and highest and lowest temperatures are like those in Melbourne Australia.

Solar domestic hot water systems with natural circulation are most favorable in areas with a mean annual sum of global radiation on a horizontal surface above 1800 $kWh^{-2}\ yr^{-1}$ and with collector areas up to 10 m^2, G. Faninger (2012) [8]. Representative Meteorological Year statistics show a much lower 48.439kWh. $m^{-2}\ yr^{-1}$ or 484.39kWh yr^{-1} for 10m^2 for Melbourne, Australia. This creates doubt on the use of solar thermal systems.

2.3. Simulated Results – Vertical Ground Heat Exchanger, heating floor to 15°C?

The heating performance of low temperature hydronic radiators was simulated by the EnergyPlus™ building simulation software. Ooi et al (2015) [9] showed the simulated results; the circulation of water in the U-tube of a 50m-deep VGHE to a floor-HR could heat the bedroom of a

60m² house to the Nationwide House Energy Rating Scheme (NatHERS) night heating thermostat of 15°C and the circulation of water, heated by 30 evacuated tubes and stored in a 2m³ indoor tank at 50°C at the end of summer, could heat the living area to NatHERS day heating thermostat of 20°C throughout winter.

Masa and Ooi (2020) [10] reported on the Melbourne experimental building. The 3mx6m hydronic floor (floor-HR) is constructed from affordable 5.8m long 13mm diameter irrigation tubing spaced at 100mm apart and laid on top of 100mm thick metallic-clad polystyrene laid on ground. At the rear of this 3mx6m building is a 50m-deep vertical ground heat exchanger (VGHE). The temperatures measured at the bottom of the VGHE is 17°C and the water conditioned by its U-tube is 15.5±1°C.

Messaoud Badache1 et al [11] reported on Ground-Coupled Natural Circulating Devices (Thermosiphons). To check if it could be possible to use zero energy to circulate water from this experiment building's 50m-deep VGHE to the floor, monthly averaged outdoor and ground temperatures are shown in Table 1. For April to June, the (4m-deep) ground temperature is hotter than the average, and is also above Australian National House Energy Rating Schemes (NatHERS) night heating thermostat of 15°C.

Table 1. Monthly Averaged Outdoor and Deep Ground Temperatures, 4m-deep

°°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	38.1	37.1	32.1	29.0	21.0	16.2	16.7	19.1	22.3	27.5	31.5	37.3
Min	11.6	10.3	8.9	5.8	4.8	4.4	3.7	2.5	2.6	5.2	8.2	8.9
Ave.	20.3	21.2	17.9	15.6	12.3	10.6	10.4	10.7	12.2	14.8	15.8	18.2
Ground	15.4	16.5	17.3	17.5	17.0	16.0	14.7	13.5	12.7	12.6	13.1	14.1

Representative Meteorological Year statistics for Melbourne, EnergyPlus™ (2020) [12]

Ooi and Masa (2017) [13] projected the higher ground temperatures at deeper depths and showed by simulation that 400m-deep VGHE could supply water temperatures up to 23°C. This is deemed sufficient for the day heating thermostat of 20°C. However, it was subsequently found that the cost of drilling is too exorbitant.

3. Method

Figure 2 shows the 3m-wide experimental outbuilding beside the 4.88m-wide 6m-long garage in the backyard of the 150m² experimental house. This 18m² outbuilding has 200mm thick ceiling with an R-value of 5 m².K/W, 150mm thick metallic-clad polystyrene walls (R-value 3.75 m².K/W) and 100mm thick metallic-clad polystyrene floor (R-value 2.5 m².K/W). This 48m² building is energy rated at the mandatory 6-stars by the Australian Nationwide House Energy Rating Scheme (NatHERS).

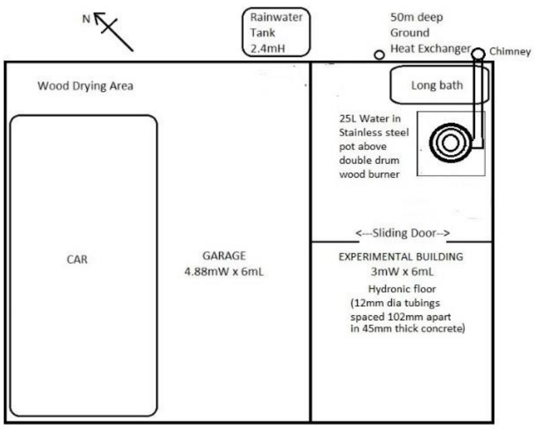

Figure 2 Experimental outbuilding

The hydronic floor (floor-HR) has 12mm diameter poly tubes embedded in 45mm thick concrete covered with 10mm thick ceramic tiles. This floor-HR is on top of 100mm thick recycled cold room panels, i.e., metallic clad polystyrene, that is laid on the ground.

Simulation results by Ooi et al (2015) [9] indicated that the direct circulation of water from the VGHE to the floor-HR could heat indoors to the night heating thermostat of 15°C. The assumption is that the temperature of the thermal mass in the ground under the floor has stabilized after a warmup of 5-6 years by keeping the indoors at the day and night heating thermostats of, respectively, 20°C and 15°C. Since the outbuilding has not satisfied this warmup period, the experiment was conducted with a wood/sawdust burner. At the same time, an affordable belt solar collector for swimming pool was tested with a glass cover. The external edge of the floor/ground is wrapped by 300mm deep R1 $m^2 \cdot K/W$ polystyrene to create an insulated thermal mass in the ground under the floor.

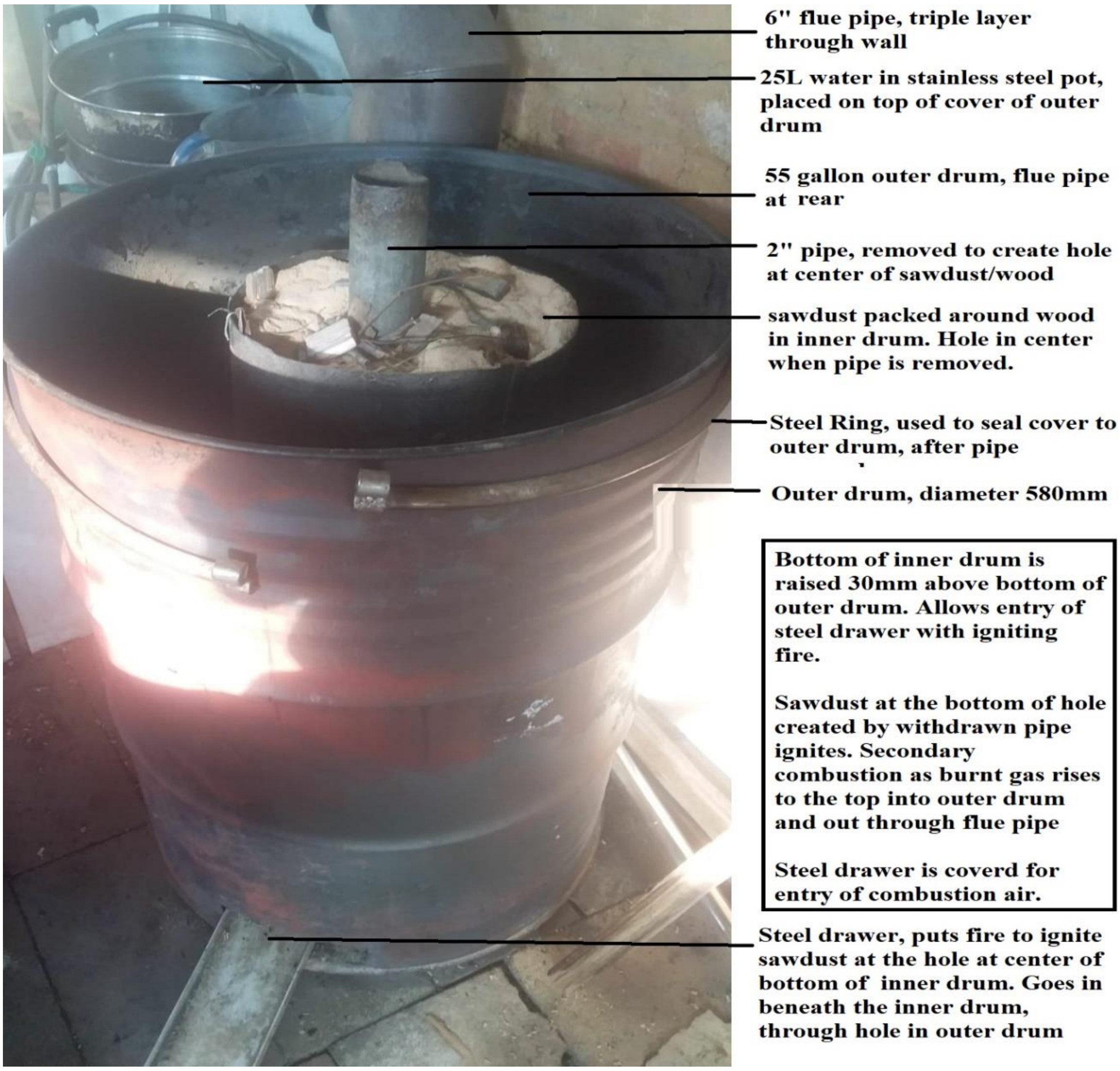

Figure 3. Sawdust/wood burner - hot water for floor-HR.

3.1. Sawdust/wood burner.

Figure 3 shows the sawdust/wood burning apparatus inside a 580mm diameter 44-gallon outer drum. The sawdust is packed, around a 50mm diameter pipe at its center, in the 480mm diameter inner drum. Beneath this inner drum is a 30mm-tall 150mm-wide, 350mm-long radial compartment that allows the entry of, a drawer with the igniting flame, and combustion air, into the central 50mm diameter hole, formed by the pipe after it is pulled out. Before ignition, the outer drum is sealed with a lid. On ignition, the flame rises through the central hole of the packed sawdust/wood. The burnt gases exit, via the gap between the inner and outer drums, through to a hole at back of the outer drum, to the chimney.

Figure 4 Wood Moisture Meter

The flue pipe exits the outer drum from behind. Its 45-degree penetration through the wall helps to draw the flue out to the vertical chimney, which is outside the building, to reduce the chances of particulates falling onto the roof. The roof is used to collect rainwater. Figure 4 shows the $20 wood moisture detector, to ensure the moisture in the wood is less than 20%, which is the standard used in UK. A carbon dioxide tester was also installed in the room. On top of the external drum is a 25-liter stainless-steel pot. The water in this pot heated by the fire in the inner drum. The fire can last for 8-10 hours. The hot water is circulated to the floor-HR.

3.2. Poly solar collector for swimming pool – cover with glass.

The 30 evacuated tubes used in simulations by Ooi et al (2015) [9] to heat the indoors to 20°C during the day is expensive and requires a 2 cubic meter indoor storage to buffer the winter coldness. An affordable 750mm-wide black polyethylene belt designed to heat swimming pool water is tested. There is no sign of deterioration after a few years' exposure, without water, to the sun. It is enclosed in a 6m-long 800mm-wide wooden box and placed over the 10-degree double-sloped garage roof. The bottom half of the belt rests on polycarbonate roofing sheets and the top half rests on 2" thick polystyrene. Glass sheets are placed on the wooden box to trap the longwave radiation.

3.3. Exothermic Decomposition of organic waste

Vegetable end cuttings and tea bags are piled together with alternate layers of grass cuttings (nitrogen) and paper or cardboard strips (carbon) at a corner of the backyard. Inside the pile are coils of perforated 4" diameter soft plastic pipe. Together with tilting, this enables aerobic decomposition so that methane gas is not produced. With air and water, the temperature of the compost pile can reach 45C as it undergoes the three phases of decomposition as shown in Figure 5.

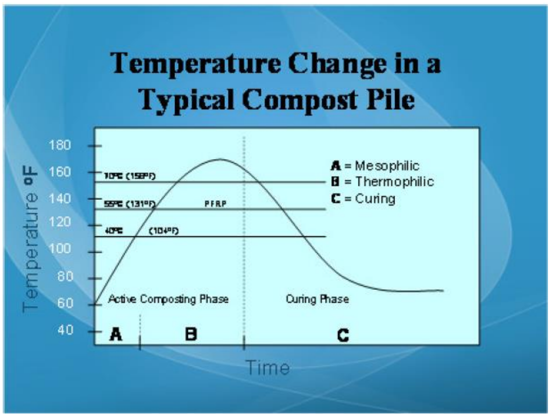

Figure 5. Three phases of aerobic decomposition

4. Results

4.1. Sawdust/wood burner – Results in the cold months, i.e. autumn, winter, spring.

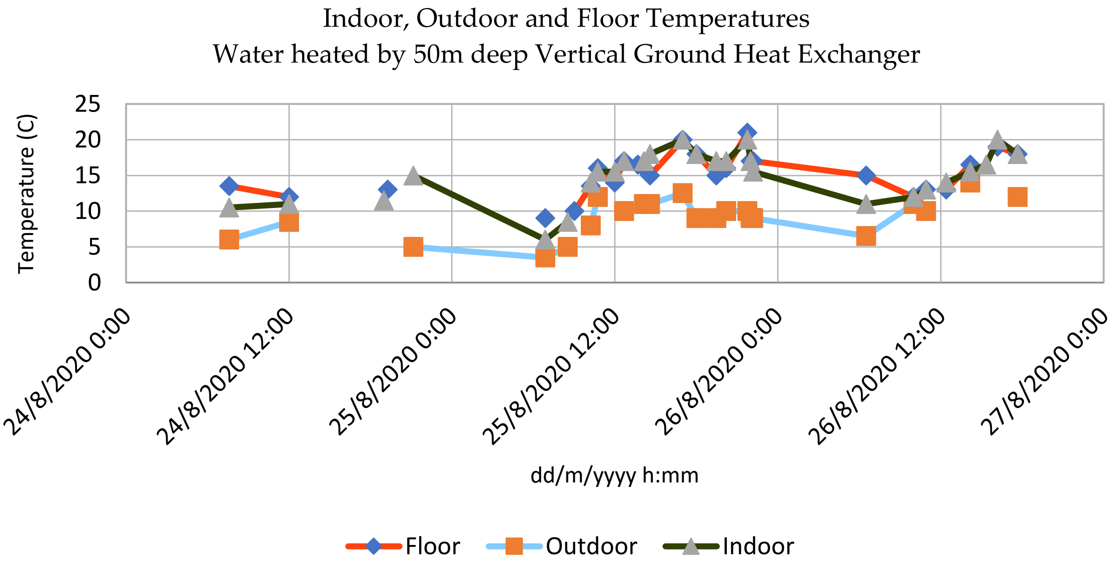

Figure 6. Temperatures during autumn

Figure 6 shows the temperatures during the autumn of 2020. The ground below the floor has heated up. The water is heated only by the 50m deep vertical ground heat exchanger and pumped directly to the floor-HR. The indoor temperature reaches the National House Energy Rating Scheme (NatHERS) daytime heating thermostat of 20°C only when the outdoor temperature is not less than 10°C.

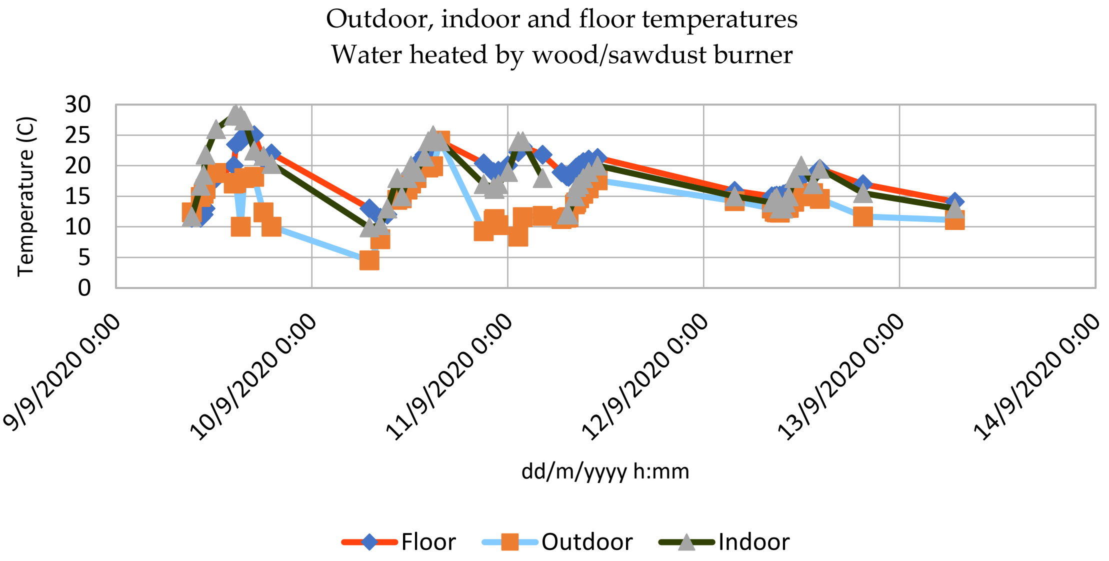

Figure 7 Temperatures during winter

Figure 7 shows the temperatures during winter 2020. The water is heated by the sawdust/wood burner and circulated to the floor-HR. The indoors could reach NatHERS day and night respective thermostats of 20°C and 15°C, even if the outdoor is cold.

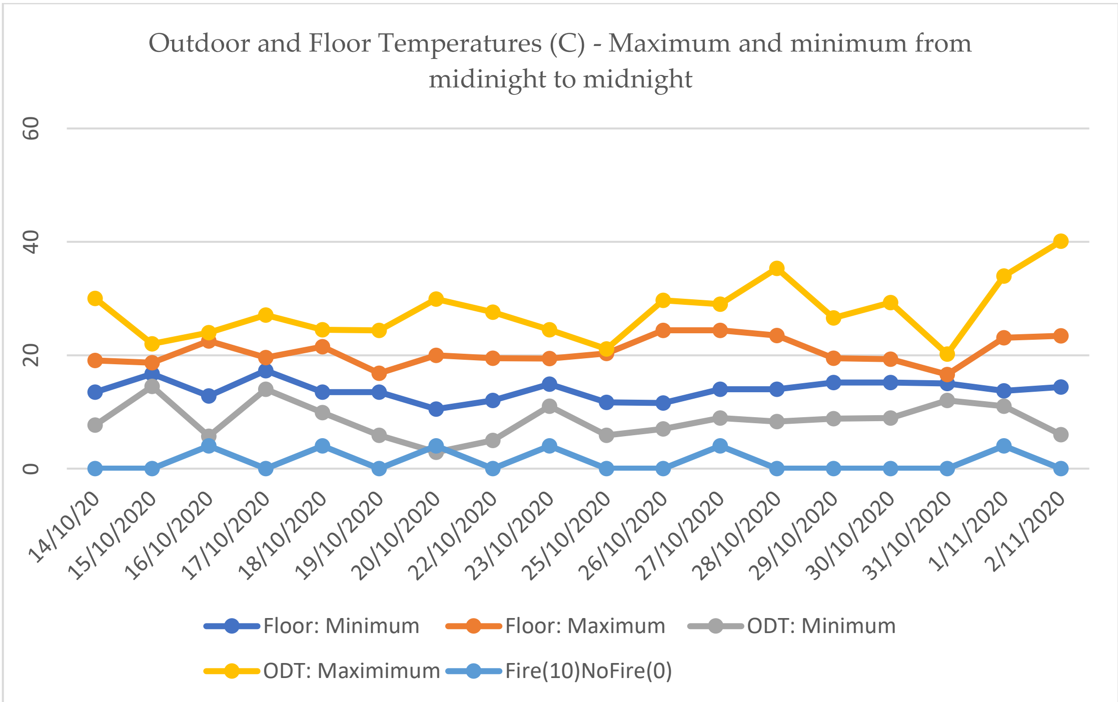

Figure 8. Temperatures during spring

Figure 8 shows the daily maximum and minimum outdoor and floor-HR temperatures in late cold months. Water is also heated by the sawdust/wood burner, mostly during the day. The author spent more time in the outbuilding than in the main house. The sawdust/wood and floor-HR provided more economical comfort than the central gas heater and ducted heating of the main house.

4.2. Results with glass covered poly solar collector

When the outdoor temperature was 26°C in the autumn of February 2020, the temperature below the polycarbonate, was 46°C. The water in a 200-liter indoor drum is circulated to this affordable flat panel at 6 liters per minute by a 40-watt pump. Measurement during sunny day of May 16^{th} and 17^{th} 2020, when the minimum and maximum outdoor temperatures are 4° C and 16°C respectively, show that the maximum temperature below the polycarbonate is 33°C and water temperature increases by only 1-2°C, similar to that claimed, without glazing, by manufacturer.
Water was not circulated through this belt during winter. On inspection in a spring day, the top half of the belt and the polystyrene had melted, i.e., a temperature of over 50°C. Before this inspection there was a hot November day. The glass is now wrapped with cloth. The cloth would also protect the glass from hail.

4.3. Results with compost pile

Kitchen and garden waste are piled up to enable entry of air, steam escapes from the center of the pile. Felt by hand, the temperature is estimated at about 50°C. This initial exothermic decomposition lasted for about a month. Whenever the height of this compost pile reduces, more organic material is added to maintain a 1-meter height. For the next two months, this compost pile cures. A compost thermometer indicates that during this curing stage, the temperature at the center of the pile is 32°C.

5. Discussion

5.1 Winter solar – Concentrate the weak radiation.

Ooi et al's simulation (2015) [9] used 30 evacuated tubes to heat the indoors to NatHERS daytime 20°C and a 2-cubic meter indoor storage to buffer across the three coldest months The test of glazing the flat belt collector, without vacuuming, shows that while in May, the water temperature is increased by 1-2°C, in November, the water temperature could reach above 50°C. The solar radiation in November is three times the average for the cold months of May/June/July, being about 180W/m2 for global horizontal radiation. A concentrator, probably a North facing parabolic trough, would be used for the next experiment. The aperture would be at least three times the area of the metallic collector.

5.2. Exothermic Heat from the Decomposition of organic waste

Matthew et al (2017) [14] did a comprehensive survey of how people have been trying to use the heat, from the exothermic decomposition of organic material by air/oxygen and water. The organic materials are green, nitrogen-rich material like kitchen waste, grass cut from the garden and brown, carbon-rich material like leaves, cardboard, paper, sawdust which can be obtained from most Melbourne homes. Cornell (2020) [15] reports that "Decomposition occurs most rapidly during the thermophilic stage of composting (40-60°C), which lasts for several weeks or months depending on the size of the system and the composition of the ingredients.

A compost pile in the backyard of the house has achieved this temperature. However, a review of the literature in the previous paragraph shows that the duration and transfer of this heat indoors, particularly for a small size compost for a residential building, must be investigated and experiments will be done in future winter 2021. Compost piles could be located beside the external walls of the experimental building. This will at least prevent the coldness from the outdoors from cooling the ground under the hydronic floor.

5.3. Ventilation Radiators, Lower Water temperatures for 20°C during the day

Besides getting the floor radiator to heat the indoors to the night heating thermostat of 15C, it is also necessary to get the indoors heated to 20°C during the day. We present some literature review below.

Jonn Are Myhren and Sture Holmberg (2013) [16] conducted laboratory experiments that confirmed CFD results that the energy efficiency in exhaust-ventilated buildings with warm water heating can be increased with a ventilation radiator; the heat output of ventilation radiators may be improved by at least 20% without sacrificing ventilation efficiency or thermal comfort. In future experiments, fins could be added to the wall radiators.

Ploskić. A and Sture Holmberg (2013) [17] found that combing air-heater with existing radiator heating systems. These systems operated at 20–22.5% lower temperatures than conventional systems Ploskić. A et. Al. (2019) [18] explored the importance of airflow rate and convector plate design on the operational performance of heating radiators equipped with an air device (ventilation radiators) With water supply/return temperatures of 45 °C/35 °C, the radiator was able to cover a room heat loss of 34 W/m² floor area. The results showed that ventilation radiators might cover a building heating load (kW) with a lower supply water temperature but not necessarily give a lower annual energy use (kWh) for the space heating of a building.

Hesaraki A. et. al. (2015) [19] tested floor heating, and ventilation radiator as very-low, and low-temperature heat emitter, respectively. They used a conventional radiator and found that floor heating required supply temperature of 30 °C and caused 22% energy savings

6. Conclusions

The sawdust/wood burner was able to heat up the hydronic floor to keep the small indoors thermally comfortable. Situating compost piles outside the walls would assist the hydronic floor particularly at the colder perimeter, warm. Sawdust and wood are factory waste material, thus will be used to warm up the ground below the hydronic floor. The 50m vertical ground heat exchanger will later be tested to see if it could heat the indoors to NatHERS night setting of 15°C. The next winter experiment would include the concentration of the weak winter solar radiation to heat water to above 20°C, for a hydronic wall, maybe with a radiator convector.

References

1. Qian Wang, Adnan Ploskić, Sture Holmberg Retrofitting with low-temperature heating to achieve energy-demand savings and thermal comfort Energy and Buildings, Volume 109, 15 December 2015, Pages 217-229
2. Dietrich Schmidt, Anna Kallert, Markus Blesl, Svend Svendsen, Hongwei Lid, Natasa Nord and Kari Sipilä. Low Temperature District Heating for Future Energy Systems. Energy Procedia, Volume 116, June 2017, Pages 26-38
3. Mats Dahlblom, Birgitta Nordquist, Lars Jensen Evaluation of a feedback control method for hydronic heating systems based on indoor temperature measurements Energy and Buildings, Volume 166, 1 May 2018, Pages 23-34
4. Matjaž Prek, Gorazd Krese Experimental analysis of an improved regulation concept for multi-panel heating radiators: Proof-of-concept Energy, Volume 161, 15 October 2018, Pages 52-59
5. Petr Ovchinnikovab, Anatolijs Borodiņecsc, RenārsMillersc (2017) Utilization potential of low temperature hydronic space heating systems in Russia Research article Journal of Building Engineering, Volume 13, September 2017, Pages 1-10 https://doi.org/10.1016/j.jobe.2017.07.003
6. M. Jangsten, J. Kensby, J. -O. Dalenbäck, A. Trüschel Survey of radiator temperatures in buildings supplied by district heating Energy, Volume 137, 15 October 2017, Pages 292-301
7. Cüneyt Kurtay, Ibrahim ATILGAN and Ö. Ercan ATAER PERFORMANCE OF SOLAR ENERGY DRIVEN FLOOR HEATING SYSTEM. J. of Thermal Science and Technology©2009 TIBTD Printed in Turkey ISSN 1300-3615
8. G.Faninger 3.12 - Solar Hot Water Heating Systems. Comprehensive Renewable Energy Volume 3, 2012, Pages 419-447. https://www.sciencedirect.com/science/article/pii/B9780080878720003127?via%3Dihub https://doi.org/10.1016/B978-0-08-087872-0.00312-7
9. KoonBeng Ooi, Patrick X.W. Zou, Mohammad Omar Abdullah. A Simulation Study of Passively Heated Residential Buildings Procedia Engineering 121 (2015) 749 – 756. Available online at www.sciencedirect.com

10. Masa Noguchi and Koon Beng Ooi. The Simulation Analysis of a Proposed 'Hydronic Radiator' System Towards Low to Zero Energy Affordable Housing Operation in Temperate and Hot Tropical Climates Journal of Green Building; 2020; Vol 15(1); Pages 73-86
11. Messaoud Badache1,, Zine Aidoun, Parham Eslami-Nejad and Daniela Blessent Ground-Coupled Natural Circulating Devices (Thermosiphons): A Review of Modeling, Experimental and Development Studies. Inventions 2019, 4, 14; doi:103390/inventions4010014
12. EnergyPlus Weather Data downloadable from www.energyplus.net.
13. Koon Beng Ooi and Masa Noguchi Verification of the Performance of a Vertical Ground Heat Exchanger Applied to a Test House in Melbourne, Australia Energies 2017, 10, 1558; doi:10.3390/en10101558 www.mdpi.com/journal/energies
14. Matthew M. Smith, John D. Aber & Robert Rynk (2017) Heat Recovery from Composting: A Comprehensive Review of System Design, Recovery Rate, and Utilization, Compost Science & Utilization, 25:sup1, S11-S22, DOI: 10.1080/1065657X.2016.1233082
15. http://compost.css.cornell.edu/physics.html viewed 20th October 2020
16. Jonn Are Myhren and Sture Holmberg Performance evaluation of ventilation radiators Applied Thermal Engineering, Volume 51, Issues 1–2, March 2013, Pages 315-324
17. Adnan Ploskić, and Sture Holmberg Low-temperature ventilation pre-heater in combination with conventional room heaters Energy and Buildings, Volume 65, October 2013, Pages 248-259
18. Adnan Ploskić, Qian Wang, Sasan Sadrizadeh A holistic performance evaluation of ventilation radiators – An assessment according to EN 442-2 using numerical simulations Journal of Building Engineering, Volume 25, September 2019
19. Arefeh Hesaraki, Eleftherios Bourdakis, Adnan Ploskić, Sture Holmberg Experimental study of energy performance in low-temperature hydronic heating systems Energy and Buildings, Volume 109, 15 December 2015, Pages 108-114