AN UPDATE OF A SIMULATION STUDY OF PASSIVELY HEATED RESIDENTIAL BUILDINGS

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Abstract

"A simulation study of passively heated residential buildings" published in Procedia Engineering 2015 showed how circulating 15-17ºC water from a 50-m deep U-tube to a floor radiator and solar-heated water from a 30 evacuated tube solar collector and a 2-m^3 indoor tank to a wall radiator could keep a 30-m^2 Melbourne, Australia house thermally comfortable. This paper presents a summary of the ongoing review of publications together with three updates: - (1) Report on that water heated by a 100-metre deep U-tube is 22-24ºC, i.e., 2-4 ºC warmer than thermal comfort temperature. (2) May 2016 experimental validations of the simulated results which show that when the outdoors is below 10ºC, the temperature of the floor radiator is 2-4ºC less than the 15-17ºC water heated by a 50-m deep U-tube and 25 W fish tank pumps could circulate the waters. (3) Simulations with the addition of phase change materials (PCM) to inside faces show that though a PCM halves the diurnal indoor temperature variations, it confirms that such PCM does not significantly increase the 20ºC temperature in a 2-m^3 storage tank at the end of winter. Therefore, the size of intersessional thermal storage would be a problem for family-sized houses. German Guidelines indicate that 1-2 boreholes could provide enough heat for family-sized houses. The heat extracted in winter can be replenished in summer. Thus the geothermal heat from about 100-m deep boreholes with 22-24ºC bottom temperature could sustainably keep residential buildings in cool climates similar to Melbourne's cool temperate thermally comfortable.

Key words: Hydronic radiators, geothermally-heated water, sustainable residential buildings, cool climates.

1 INTRODUCTION

"A simulation study of passively heated residential buildings" published in Procedia Engineering 2015 showed how waters heated by two renewable sources circulating to hydronic radiators on the inside surfaces keep the winter indoors of a 30-m^2 Melbourne, Australia house above the heating thermostats used in AccuRate®, a software engine rating the energy of Australian residential buildings. A 50-metre deep U-tube geothermally conditions the water to 15-17ºC for a floor radiator to keep the indoors of the Bedroom and Living Area above 15ºC at all times and a 30 evacuated tube solar collector heats the water in a 2-m^3 indoor tank to 50ºC by the end of summer for the bottom wall radiators of the Living Area and Bedroom. Very small pumps are required to circulate the waters and can be powered by onsite photovoltaics and batteries. Thus houses could be heated passively instead of by conventional energy-hungry heat pumps. This update summarizes the ongoing literature review, uses fish tank pumps during the May 2016 experimental validations of the simulated results; and the simulated results with the addition of phase change materials (PCMs) on the inside faces show that while a PCM halves the diurnal indoor temperature variations, the size of intersessional thermal storage cannot be reduced. The information received in April 2016 that water from a 100-metre deep U-tube at a nearby campus is 7ºC warmer than the 15-17ºC temperature from a 50-metre deep U-tube, and the German guidelines on power available from boreholes indicate that the geothermal heat could passively heat residential buildings in cool climates.

1.1 Solar and geothermally heated houses

Voss (2000), Nahar (2003), Li and Liao (2014) reported that solar collectors and solar-heated water can be used to heat residential buildings [1-3]. But solar collectors occupy roof spaces that can be used for photovoltaics. Woo et al. [4] (2013) investigated the hybrid use of geothermal and solar heat in a South Korea house.

1.2 Energy Plus Low Temperature Radiant: Variable Flow object

Baharun et al. (2011) [5] used an Energy Plus's Low Temperature Radiant: a VariableFlow object to simulate the effect of circulating 25ºC night-cooled water to pipes at the inside face of an insulated bottom wall of a single-storey house in the warm tropics. The simulations show that this bottom wall 'Surface Radiator' could cool the indoors of houses up to four stories to comfort temperatures when fans are used. Cvetkovi´c and Boji´c (2014) also used EnergyPlus to find the optimum insulation of walls, ceilings, and floor [6]. Chantrasrisalai, C. et al. (2003) validated this Low Temperature Radiant object for a 250 m2 single storey house in Carefree, Arizona, latitude of 33.8 °N and longitude of 111.9 °W [7].

1.3 Efficiency of Solar Collector and Soil Temperature

Liu et al. (2016) experimented with a system that has 1500 m^2 solar thermal collectors and 580 sets of 120 m deep ground thermal exchangers [8]. They showed that the solar energy utilization efficiency achieved 50.2% and the soil temperature raised by 0.21°C.

1.4 Cost and Savings

The Wikipedia (viewed 2016) informs that the average passive houses are more expensive upfront than conventional buildings by 5% to 8% in Germany, 8% to 10% in UK, and 5% to 10% in USA. Energy Matters provides a general guideline for the cost of a solar space heating system at around $32,000 for a 50 sq. metre home and $40,000 for a 100 sq. metre home. Aside from adding a substantial value to your home, annual energy savings of up to $2,000 per year can be made! This research aims to reduce the large amount of energy and high cost of houses in cool climates.

2 MATERIALS AND METHODS

EnergyPlus is used to model this 30 m^2 experimental house (Figure 1) in Melbourne, Australia, Latitude 37° S and longitude 145° E.

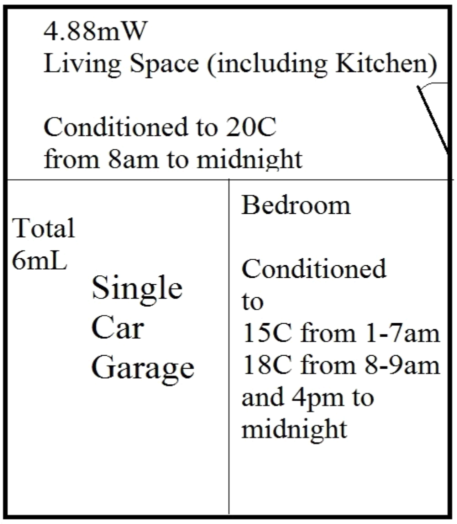

Figure 1: 30 m^2 experimental building

The roof and walls are insulated with batts or/and polystyrene and covered with wooden planks or plaster boards. Figure 2 shows the floor and wall radiators modelled by the Low Temperature Radiant: a VariableFlow object.

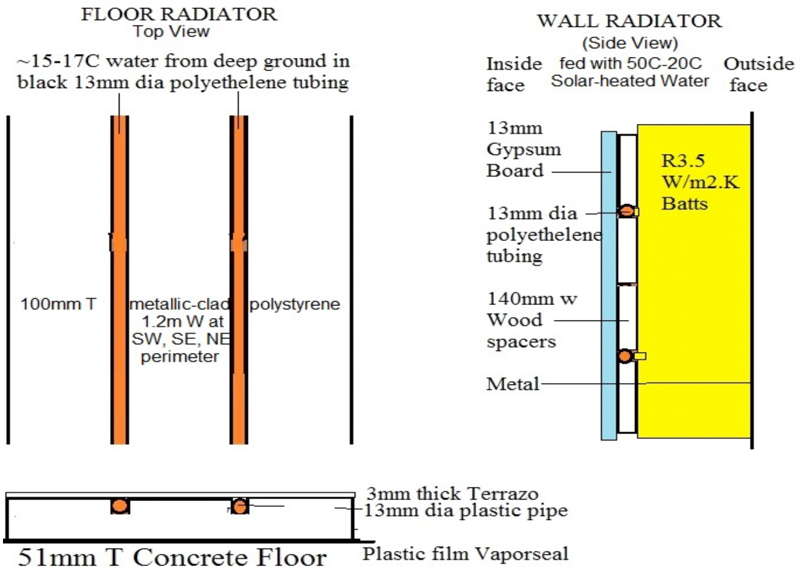

Figure 2: Construction of radiators

2.1 Method 1: Information

The Swinburne University of Technology informs that at its nearby Wantirna campus, water from a U-tube in a 100m deep borehole is 22-24ºC.

2.2 Method 2: Validations

Figure 3 shows that the ground surface temperatures are below the lower heating thermostat of 15-18ºC for more than half a year. For a conditioned indoor, the temperatures beneath the floor, found from the EnergyPlus 3-D Slab pre-processor, is used for the outside of the floor. The typical meteorological year data is used for the outside of the roof and walls. Two validations were made in the winter month of May 2016.

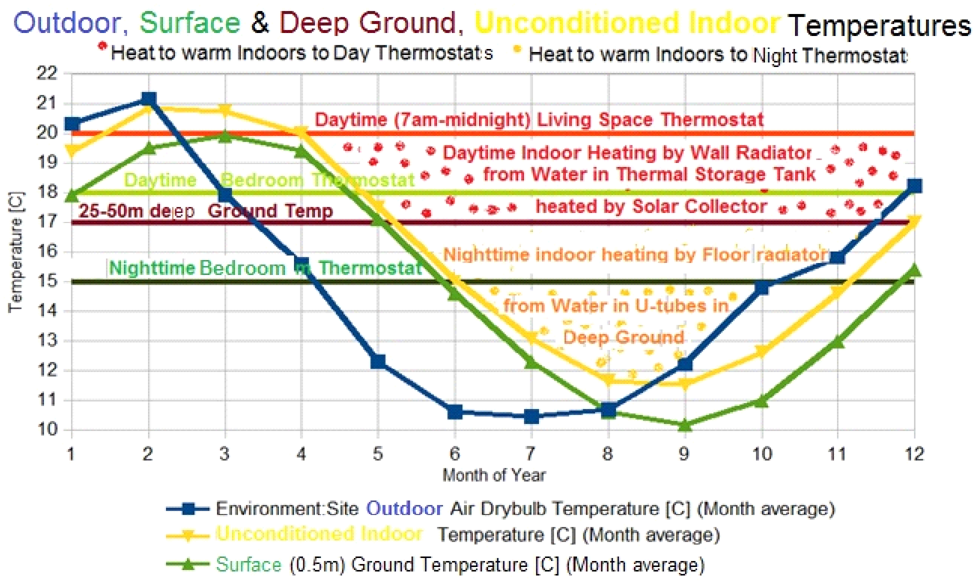

Figure 3: Outdoor, ground surface temperatures, and heating thermostats for bedroom and living area

Validation 1. When the outdoor temperatures are below 10ºC, the temperature at the top of the floor radiator is measured at around 13.5°C. Three thermal bridges between the outdoor and indoor caused this 2-4ºC cooler than the 15-17ºC measurements of the water from the U-tube. (i) The concrete floor extension beyond (a) the SW driveway (Figure 4) and (b) the SE wall (Figure 5), (ii) no insulation on the outdoor tubing from the U-tube at the East corner (Figure 5) to the floor radiator, and (iii) the white 1.2m W metal covers of the 100mmT polystyrene insulating the floor on the SW and SE perimeters (Figure 4).

Validation 2. A 25 W fish tank pump could circulate the water through the U-tube to 75 m long 13 mm dia floor radiator tubing (right in Figure 4). This avoids the heat pumps used by Metz P.D. (1982) , Bi Y, (1995), and Bi Y. et al. (2004), and the smallest heat pump requires 600W [11-13].

Figure 4: SW view of experimental building

Figure 5: Top of 1" U-tube at East corner

Figure 6 shows that at the end of summer, the solar-heated water in the 2 m^3 thermal buffer tank is 50ºC, and is about 20ºC by the end of winter.

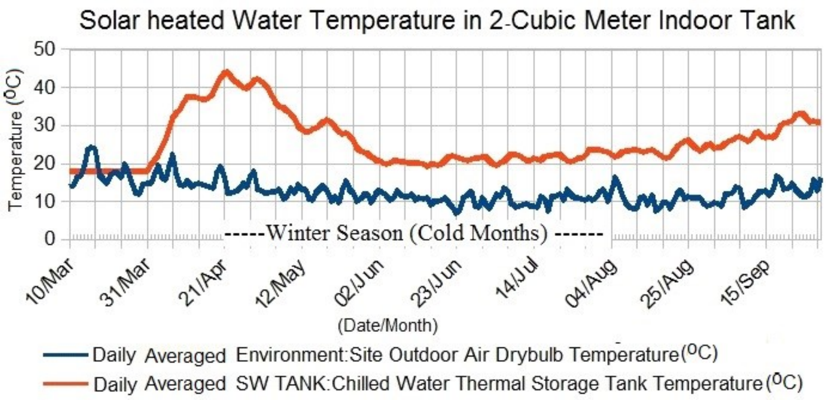

Figure 6: Temperature of solar heated water in 2 m^3 tank

To find the effect of PCM, BioPCM Q23, a PCM is added to the inside faces of the roof and walls of the EnergyPlus model for simulations. The Heat Balance Algorithm has to be changed from a Conduction Transfer Function to a Conduction Finite Difference and the simulation takes a longer time.

3 RESULTS

Figure 7 shows the simulated temperatures without and with a PCM during the coldest week. The PCM halves the diurnal range of the indoor temperatures of the bedroom and living area. Not unexpectedly, the temperature of solar-heated water in the tank is not changed and the size of thermal buffer would be a problem in family-sized houses.

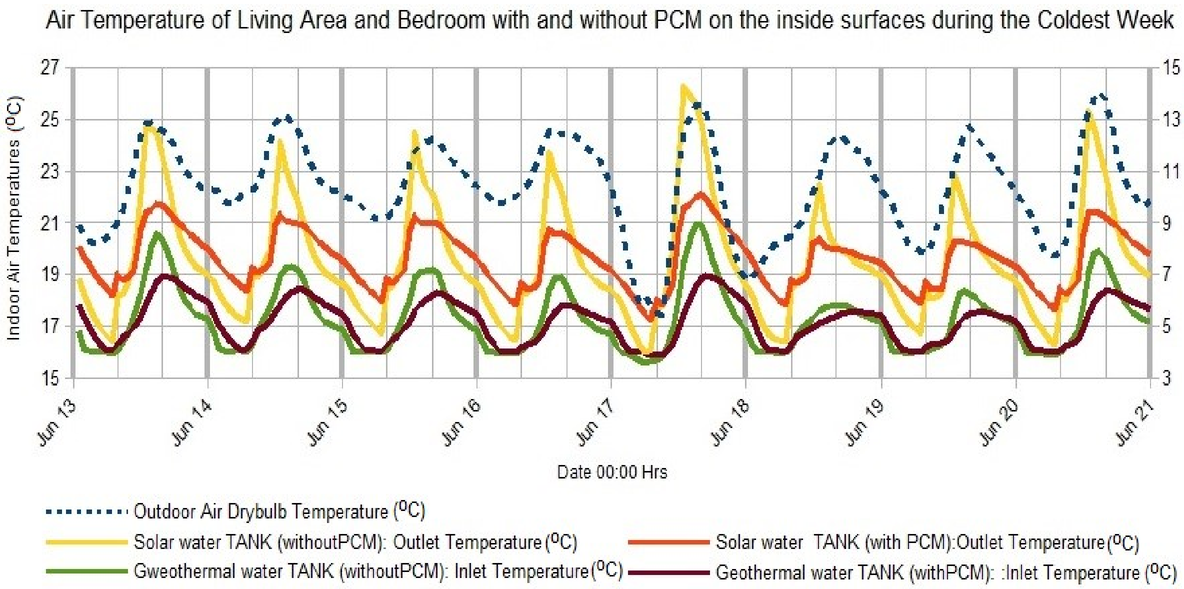

Figure 7: Temperatures of bedroom and living area air and tanks' water without and with BioPCM Q23

4 DISCUSSION

When solar-heated water is used to heat buildings in temperate climates, a thermal storage is required to buffer the diurnal and seasonal mismatches between demand and supply of solar radiation. The simulations with a PCM confirm that the PCM cannot reduce the intersessional thermal storage size, and therefore, the thermal storage could be too large for family-sized houses. The solar collector also competes with the solar photovoltaics (PV) for the limited roof space of residential buildings.

Ooi et al. [14] also showed that 30 evacuated tubes could, during summer, replenish the heat taken out from deep ground in winter. Since very low power fish tank pumps circulate the waters to the hydronic radiators, a small PV system and deep cycle batteries could provide sufficient power.

The VDI 4640 German Guidelines for Ground Coupled Heat Pumps give the power available from 1 m of borehole. For the soil conditions at the experimental site, the power from 50m borehole is from 2.4 to 2.8 KW. Heat wheels are normally used to heat outdoor air for ventilation, but the heat from an additional borehole could be used to heat outdoor air for ventilation.

5 CONCLUSIONS

The experiments show that, in cold weather, well-insulated piping and the absence of thermal bridges are needed to avoid a 2-4ºC temperature drop of water from U-tubes in deep ground when it reaches the hydronic radiator on the inside face of houses. Fish tank pumps could circulate the waters, thus the house could be passively heated. For Melbourne, Australia, a borehole to a depth of about 100 m can have a bottom temperature of 22-24ºC i.e., sufficient to keep indoors above the 20 ºC of the upper heating thermostat. The simulations show that phase change materials can significantly reduce the diurnal variation in indoor temperatures, and confirms that it cannot help to reduce the size of intersessional storage. Therefore, work should be expended to research the use of geothermal heat directly in hydronic radiators in houses in cool climates.

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