Prospect of Floor Heating System in Residential Buildings in Kathmandu Using Compound Parabolic Concentrator (CPC)

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Abstract

Underfloor heating system is more suitable for space heating because of its unique temperature gradient profile. If solar radiation can be utilized for heating of water in radiant floor heating system, the cost of electricity can be reduced. Because of the sufficient availability of solar radiation in Kathmandu Valley during winter season, underfloor heating with solar water heating can be a viable technology for residential buildings. So this paper is focused on identifying suitable system for domestic radiant floor heating system. Compound parabolic concentrator (CPC) water heating system is more suitable for heating water because tracking system is not required and sufficient water temperature can be achieved. It is also found that more studies are necessary to make the system cost effective and suitable for the residential buildings in Kathmandu.

Keywords : *Compound parabolic concentrator, underfloor heating system*

I. Introduction

Winter season in Kathmandu is regarded as an uncomfortable period by its residents. The average minimum temperature for November, December, January and February is calculated as 7.8°C, 3.7 °C, 2.4 °C and 4.5°C respectively [1]. During the winter season, common modes of room heating system used by the people in Kathmandu Valley are split air-conditioner, kerosene heater and halogen heater. One of the disadvantages of these types of heating systems is their inability to heat the floor. Cold floor adds to the discomfort level since sitting on the floor is still a common activity among the people in Kathmandu. So there is a scope for innovation in suitable room heating system for residential buildings in Kathmandu.

Underfloor heating system (also known as radiant floor heating system), a common process in other part of the world, can be an alternative heating system to combat the effect of cold floor. If underfloor heating system is run by solar energy, greenhouse gas emission and cost of electricity bills can be reduced. With annual average solar energy of 5.19 kWh/m^2/day in Kathmandu [2], there is an opportunity of utilizing solar energy for domestic space heating. So this paper examines the possibility of adopting solar powered underfloor heating system in residential buildings in Kathmandu.

II. Underfloor Heating

The origin of underfloor heating can be traced back to 900 BC – 800 BC in Korea. That time, the system used a fireplace and a smoke tunnel [3]. Modern radiant floor heating system works by heating the floor with the help of hot water pipe network concealed in the floor. Water running through the pipe is heated in boiler or in any other way. The thermal mass of the floor absorbs heat from the hot water running through the pipe and transfers heat constantly for a long time as shown in Fig. 1. Use of modern radiant floor heating system is growing since it is an energy efficient system compared to the conventional all-air system. Yet, it is used less than other conventional heating system [4].

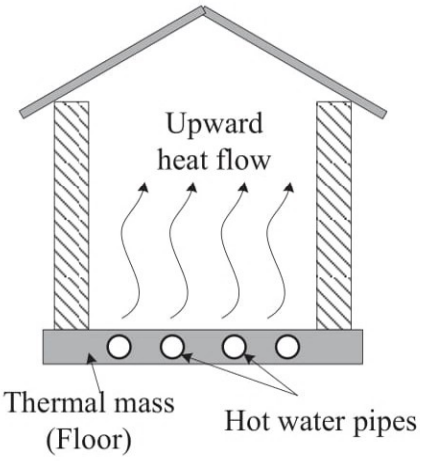

Fig. 1 Working mechanism of radiant floor heating system

Heat transfer in radiant system involves heat conduction through wall, heat convection between floor and room air and heat radiation between floor and surrounding areas [5].

Major advantage of floor heating system is its temperature gradient profile. Since hot air flows upward, temperature is higher near the floor. The temperature decreases with height and reaches minimum at ceiling level. When the temperature profile of various heating system are compared (Fig. 2), it can be observed that the radiant floor heating system closely match the optimum temperature profile [6]. The significance of temperature profile of radiant floor heating system is that our body is in contact with the higher temperature range compared with other heating system.

Apart from that, for countries where sitting on the floor is common for eating, sleeping and family gathering, underfloor heating provides an extra comfort since the floor remains warm [3].

The major disadvantage of floor heating system is higher investment cost compared to other heating system. If planning, design and installation of radiant heating system are done parallel with building construction, initial cost related to heating system can be reduced up to some extent. However, it can be installed in existing buildings with some modification of building. Another disadvantage of radiant floor heating system is that the performance of the system depends on the floor construction material. Thalfeldt et al. [7] have pointed out that according to several studies, heat transfer in underfloor heating significantly depends on floor material such as tile and laminated wood.

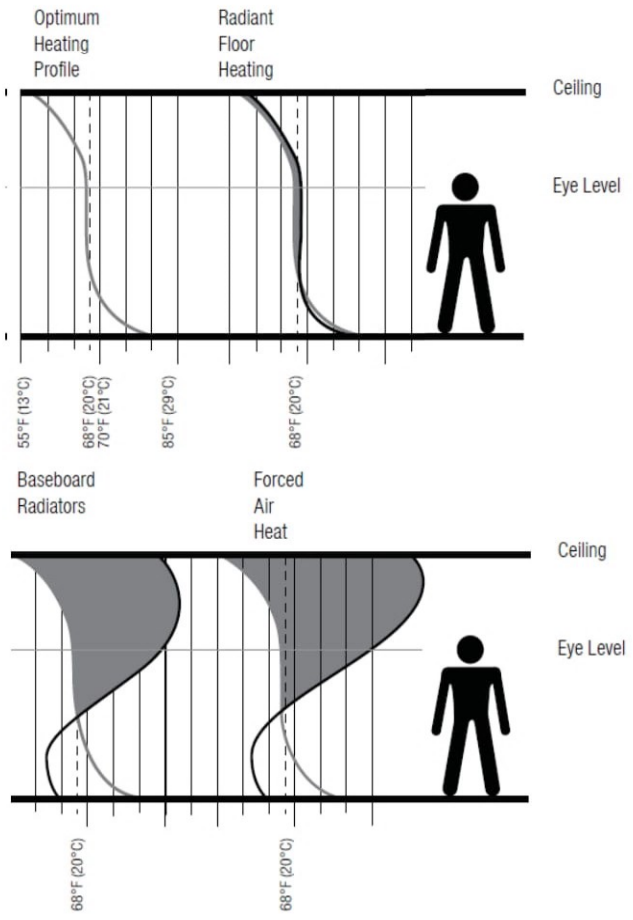

Fig. 2 Temperature profile of various heating system [6]

III. Water Heating

One of the processes of underfloor heating is supplying heat to the water. Prevalent practices are heating water in boiler with the help of fossil fuel, electricity and solar energy. Between these, solar heating system is a favourable system if reductions in green-house gas emission and utility bills are considered. Performance and output of solar water heater varies with the type of solar collector. Common types of solar collectors are flat plate collector, evacuated tube collector and solar concentrator. Solar concentrator like cylindrical trough, parabolic trough, parabolic dish and solar bowl require solar tracking system. Solar tracking system needs complex mechanism and requires electricity if it is automated so solar concentrators are not considered for domestic use. The output temperature of a flat plate collector and evacuated tube collector is low. Even all-glass evacuated tube solar collector can get the water temperature of about 100°C [8] so these systems are not suitable for underfloor heating.

Trough shaped compound parabolic concentrator (CPC), which does not require tracking system, coupled with evacuated water tube can achieve the collector temperature up to 130°C. So, CPC can be a suitable alternative for domestic water heater. Another advantage of CPC is that it can use diffused solar radiation [9] and it is useful under overcast condition too. Geometry of CPC is a combination of two parabolas as shown in Fig. 3. Composite segment of two parabolas shown by dark line is the geometry of standard CPC.

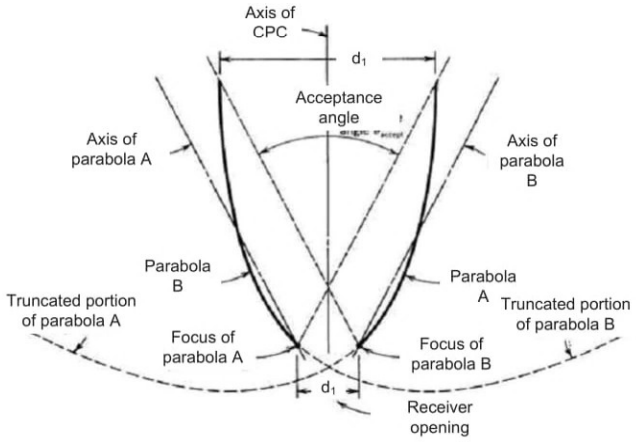

Fig. 3 CPC geometry [10]

The profile of standard CPC as shown in Fig.4 can be difficult to manufacture because of its geometry. The standard CPC can be modified by making the bottom flat and reducing the height in order to reduce the cost and improving the manufacturing ease [8].

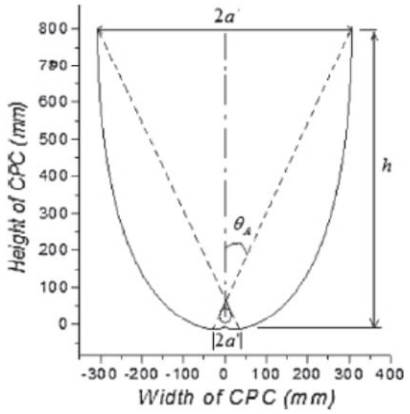

Fig. 4 Standard CPC [8]

IV. Proposed Model

Based on the above discussion, an underfloor heating system is proposed for a residential building in Kathmandu. The system consists of a pipe network laid underneath the floor. First the floor is insulated with suitable material. Then PEX (cross linked polyethylene) pipe is laid above the insulation material. The layout of the pipe depends on the number of outside wall and the areas where feet are in continuous contact with the floor [11]. After the layout is completed, concrete or gypsum cement mixture is poured to finish the floor [6].

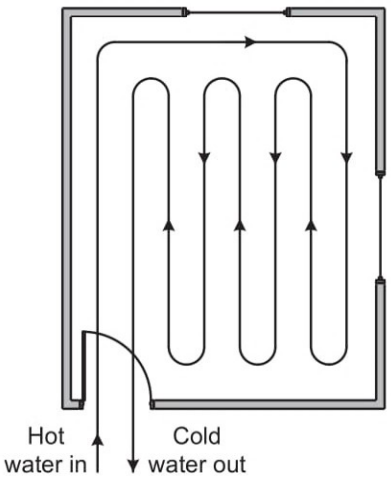

Fig. 5 Pipe network for a room

Water heating system (Fig. 6) consists of evacuated all-glass solar collector with simplified CPC fitted underneath the tube. Locally available evacuated tube can be used for this purpose. Simplified CPC can be fabricated with sheet of stainless steel mirror. Hot water from the solar heater is collected in hot water tank. Hot water is then circulated to the room with the help of water pump. The cold water coming out from the room is sent to cold water tank which, in turn, is feed to solar collector.

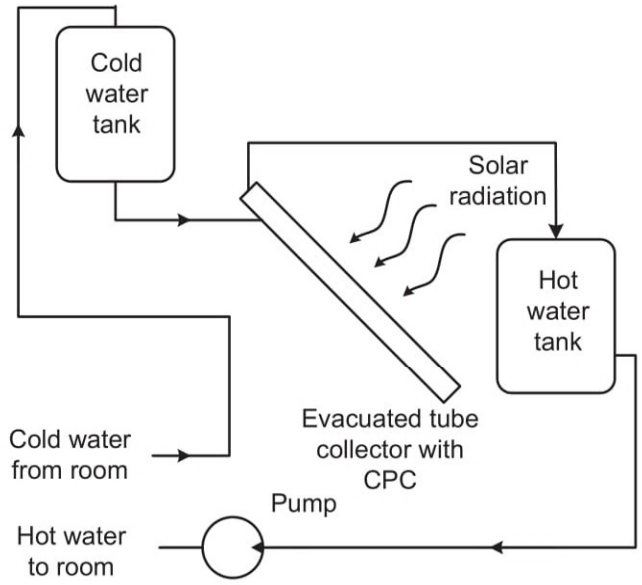

Fig. 6 Heating system

V. Design Parameters

Followings are the parameters that should be considered while designing above system.

- Heating load of the room which depends on parameters such as number of outside wall and its material, direction of wall, purpose of the room, and number of windows.
- Required floor insulation.
- Capacity of hot water storage tank for use after the solar radiation is not available and flow rate of water.
- Amount of heat retained by the thermal mass of the floor and number of hours that heat can maintain the room in desired temperature once the stored hot water is pumped out.
- Pipe layout and spacing between pipes.
- Using electrical heating as a backup system.

VI. Further Study

The major challenge of the proposed model is heating the room during night and at early morning since solar energy is not available at these durations. Moreover, heating load is higher at these times. The source of heat for these durations is heat stored in thermal mass of the floor and hot water stored in the tank. Thickness of the floor and size of the tank cannot be increased independently. The other option to keep the room heated is minimizing the heat loss through the room. Reduction of heat loss from the room largely depends on the construction materials. Existing construction materials may not be suitable for curbing the heat transfer. So, one of the future study areas can be finding out alternative building construction materials and construction practices. Apart from making the system technical feasible by proper design and selecting appropriate construction materials, another aspect is carrying out the life cycle cost analysis and heating cost comparison between fossil fuel, electricity and solar to check for the financial viability of the system.

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