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Transferring the south solar energy to the north facade through embedded water pipes

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ABSTRACT

In the cold sunny winter days, when the south wall is well insulated, a significant amount of solar energy falling on this facade is not transferred to the inside. In this study, a novel closed wall-loop system is proposed to capture this wasted energy available during non-cloudy winter days and transfer it to the cooler north facade through water pipes embedded in an exterior aerogel-based insulating coating. The coating's projection technique through spraying or plastering allows the easy implementation of this system. We present the proposed system with all the mathematical equations and numerical model. This model is then validated against experimental data found in the literature. To test its performance on a full-scale house, this MATLAB numerical model is coupled to the whole building energy simulation program EnergyPlus through co-simulation. Results show that the reductions in the annual heating load for the house adopting this system relative to the one without it are between 28 and 43% for new houses and 15–20% for old houses for Mediterranean climate. For other climates, the reductions vary between 6% and 26%. The heat losses through the north facade are reduced by about 60–88% in the Mediterranean climate and about 20–50% in the other climates.

1. Introduction

In France, the energy consumption share of the building sector is about 43% of the total energy use. This energy consumption contributes to producing around 25% of France's CO_2 emissions. France has already adopted the objective of reducing its energy consumption and greenhouse gas emissions by a factor of four to five by the year 2050 as a part of its national strategy for sustainable development introduced in June 2003, and it's Climate Plan introduced in July 2004. The new thermal regulations (French RT 2012) limit the annual primary energy consumption for new buildings to 50 kWh/m^2.

The concept of the active embedded-pipe building structure is to embed pipes within the envelope and utilize the circulating water to transfer heat to or from the inside space [1,2]. This is popular for the ceiling and floor, such as chilled ceiling systems and under-floor heating systems. Pipe-embedded structures may use various energy sources to provide the heating or cooling water such as chillers or heat pumps [3,4,11], groundwater [5,12,13], cooling towers [3,4,6], and geothermal energy produced by the ground coupled heat exchanger systems [7,8,14]. A comprehensive review of the research and application of active hollow core slabs in building systems for utilizing low energy sources is presented in Refs. [9,10].

A few studies have dealt with the active embedded-pipe systems in the building exterior fabric, particularly the exterior walls. The thermal storage and the heat removal capabilities of the building's mass can be enhanced by passing a fluid through pathways within pre-cast building's structures. Examples of this technology include those where water is passed through pipes cast into the concrete slabs [15–18].

D'Antoni and Saro [19] investigated the energy potential of using exposed concrete structures as solar energy absorbers during the heating season. They presented the design of a concrete solar collector which consists of a vertical concrete slab embedding a pipe coil. It has the capability of extracting heat from the environment. The concept aims to investigate the solar energy potential of exposed concrete surfaces and to develop a low cost solar-thermal collector to be adopted in residential buildings applications.

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Chaurasia [20] carried out a study on a solar concrete collector for the aim of providing domestic hot water. This solar collector has been tested for water heating for several years and the results are presented. This knowledge can be used by architects for designing the roof of the building which may serve as a low cost solar collector to provide hot water at moderate temperature in buildings for meeting various purposes during the daytime.

Albanese et al. [21] evaluated the performance of a passive solar space heating system utilizing heat pipes to transfer heat through an insulated wall from an absorber placed outside the building to a storage tank inside the building. Simplified thermal resistance-based computer models were constructed to simulate the performance of direct gain, indirect gain, and integrated heat pipe passive solar systems in four different climates. The heat pipe system provided significantly higher solar fractions than the other passive options in all climates, but was particularly advantageous in cold and cloudy climates. Parametric sensitivity was evaluated for material and design features related to the collector cover, absorber plate, heat pipe, and water storage tank to determine a combination that provides a good thermal performance. An experimental set-up of the heat pipe passive solar wall was also carried out in a laboratory setting.

Zhu et al. [22] presented a dynamic simplified thermal model of an active pipe-embedded building envelope with the thermal network structure of lumped thermal mass, and the parameter identification of the simplified model based on frequency characteristic analysis. These resistances and capacitances were identified in frequency domain using generic algorithm by comparing the frequency characteristics of the simplified model with the theoretical frequency characteristics of this structure obtained with Frequency-Domain Finite Difference method. Various case studies were presented to validate the accuracy of the simplified models and the effectiveness of the parameter identification for the model.

In the winter season, when the south wall is well insulated, a significant amount of solar energy falling on this facade is not transferred to the inside environment. Due to the high thermal resistance of the insulation, the majority of this energy is dissipated to the outside through convection with the cold outside air. In this study, a novel closed wall loop system is proposed to capture this wasted energy of the south facade available during non-cloudy winter days and transfer it to the cooler north facade through water pipes embedded in an outside aerogel-based insulating coating. This system is proposed for buildings adopting the exterior insulation technique. Also, it is mainly suitable for climates characterized by sunny-cold winters. The coating's projection technique through spraying or plastering allows the ease of implementation of this system for retrofitting old buildings and for new buildings as well.

In this paper, we present the proposed system with all the mathematical equations and numerical solution. This model is then validated against experimental data found in the literature. To test its performance on a full-scale house and to examine its impact on the heating load in different climates, this numerical model is coupled to the whole building energy simulation program EnergyPlus [23] through the co-simulation platform BCVTB [24]. An EnergyPlus model of a typical French house is constructed and linked to the MATLAB® [51] system's model. Finally, a parametric study is carried out to optimize the system's performance.

2. System description

Fig. 1 shows the active embedded pipe wall loop system (WALS). The exterior walls are composed of concrete or brick layer with an outside insulating coating based on the (super)-insulating materials silica aerogels. The latter has a thermal conductivity of 0.027 W/(m K), a density of 150 kg/m^3, and a specific heat of 990 J/(kg K) [28,29,30,31]. Its application on the building's facades is simple and using the ordinary techniques well-known by technicians and builders such as plastering. It is flexible with respect to unevenness, allows a continuous thermal insulation, and can fill gaps or other difficult access areas. In the south wall, water pipes are placed at just a few millimeters from the exterior surface of the insulating coating as a serpentine shape. In the north facade, they are placed in direct contact with the concrete just at the interface between the coating and the concrete layer. By means of a pump, water flows through the south facade to recuperate the heat provided by solar radiation. It then passes through the east facade to reach the north one where it dissipates its heat through the concrete layer to the inside. Also, some of the energy is stored in the thermal mass (concrete) to be used in a later time of day. Finally, the water exiting from the north facade returns to the south one through the west. For the east and west walls, the pipe is placed at the middle of the coating.

3. Mathematical model

The heat transfer within the wall structure embedding the pipes is a complex 3-dimensional problem. In our case here, we simplified the heat transfer into 2-dimensional which is coupled to the moving fluid in the water pipes. Some assumptions are made:

- The serpentine water loop is modeled as a long horizontal pipe.
- Symmetry boundary conditions are considered between the serpentine pipes.
- No heat losses in the east and west wall for the water pipes passing from the south wall to the north wall and vice versa.

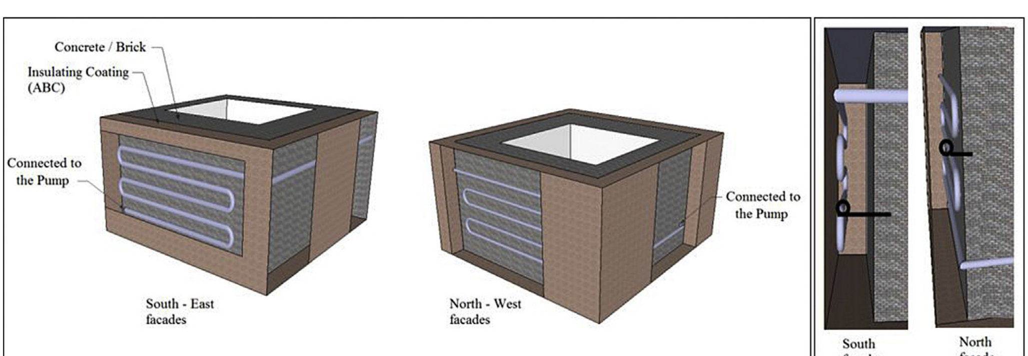

Fig. 1. Active embedded water pipe wall loop system.

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