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Optimizing energy and environmental performance of passive Trombe wall

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ABSTRACT

The energy and environmental performance is compared for buildings with and without Trombe walls. The indicator for environmental performance is a sum of primary operating energy for heating during winter and the annualized embodied energy consumed by using the Trombe walls. Two Trombe walls are used at the south side of a "Mozart" house located in Lyon, France. The house satisfies the French thermal regulation. The performances of several constructions of Trombe walls are studied. The annualized life cycle energy use by houses with Trombe walls may be lower when the core material has lower density and lower embodied energy. For heating by electricity there are much higher values of the optimum thickness of the core layer and that of the primary energy consumption than that for heating by using natural gas. When the building with Trombe walls is used, the annual final energy saving during heating is around 20%. For the electrical heating and optimum core thickness, the energy ratio is around 6 and the energy payback time is around 8 years. For the natural gas heating these values are around 3, and around 18 years, respectively.

1. Introduction

The study described in the paper is motivated by need to save energy and to use renewable energy for heating of buildings partly or completely instead of fossil energy. In this direction, passive Trombe walls are used by a building to capture energy of the sun and use it for space heating partly or completely instead of electricity or natural gas.

Large number of investigations devoted to energy saving designs of Trombe wall was so far published in literature. For instance, Koyunbaba and Yilmaz [1] experimentally compared performances of Trombe wall systems with single glass, double glass and PV panels in Izmir, Turkey, where they found that the highest energy saving was achieved by using Trombe wall system with single glass. Furthermore, Shen et al. [2] numerically compared the composite and classical Trombe walls to prove better energetic performances of the composite Trombe wall in cold and/or cloudy weather. Then, current opportunities and challenges in research and development of Trombe walls were presented by Saadatian et al. [3]. From the perspective of engineering, they suggested that the future research interest would be in the optimal thickness of various core materials of Trombe walls, such as stone, brick, adobe, and concrete for different climatic regions. It was recognized that the mass of the core wall is the most crucial component of Trombe walls. This was also concluded by Hami et al. [4] who investigated the thermal performances of a Trombe wall in Algeria.

To determine the building energy behavior, use of different types of energy was analyzed such as that of final energy, operational energy, primary energy, renewable and non-renewable energy, exergy [5], embodied energy [6], and emergy [7]. This use was analyzed by using different time scales such as that of year and life cycle. In this research, to simulate end optimize energy performance of Trombe walls in the buildings, the life cycle approach will be used together with operating energy and embodied energy [8,9].

In the archival literature, only two attempts to optimize Trombe walls can be found. In the first attempt, the optimum size of Trombe wall (the ratio of the area of Trombe wall to the area of the south wall) was determined by Jaber and Ajib [10] for a residential building, in Mediterranean region by using life cycle cost criterion. In the second attempt, for the same region, Stazi et al. [8] determined the best combination of glass, frame and core material of Trombe wall. Then they maximized life cycle energy and environmental performances of Trombe walls by using factorial plan technique. There was not research that dealt with optimization of thickness of the core layer of the applied Trombe wall system by using life cycle energy analysis published in archival literature.

This research deals with an optimization of design of a two passive Trombe walls placed at the south side of a modified "Mozart"

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Nomenclature

A	surface area of a wall layer (m^2)
AEE	annualized embodied energy (kWh of primary energy/m^2/a)
ALCE	annualized life cycle energy use (kWh of primary energy/m^2/a)
E	energy (kWh)
EPT	energy payback time (a)
ER	energy ratio (–)
F	floor area of the house (m^2)
f	life cycle of the Trombe wall (a)
h	height of the wall layer (m)
l	width of the wall layer (m)
R	primary energy factor (–)
S	specific embodied energy of the wall layer material (kWh/kg)

Greek symbols

δ	thickness of the wall layer (m)
ρ	density of the wall layer material (kg/m^3)

Subscripts and superscripts

b	basic
c	core
cb	concrete block
el	electricity
emb	embodied
g	glazing
gw	glass wool
h	heating
i	inner
m	masonry
no	not optimized
opt	optimized
o	outer
P	partial
pry	primary
s	window shade
Tot	total
TW	Trombe wall

house that will be located in Lyon, France. The objective is that the building would use the lowest annualized life cycle primary energy for heating (the sum of the annualized embodied energy due to use of the Trombe walls and the annual primary operating energy for space heating). The optimization is performed by using EnergyPlus, Genopt, and parametric algorithm. The performances of several constructions of Trombe walls are studied that differ only in the type and thickness of the core layer. The studied core layers are of different kind of concrete and of clay brick. The energy performances of these buildings are compared to that without Trombe walls. Some introduction research efforts in this topic were presented at conferences in Bucharest, Romania [11], and Guilin, China [12], to attract attention and comments.

2. Method

2.1. House description

In this research, thermal behavior of two houses is simulated. Each house is built according to a "Mozart" house design – the famous house design in France [13]. This house has a garage located next to the living room of the house (Fig. 1a). Each investigated house is slightly modified compared to the original Mozart design as it does not have the garage, and the windows toward north. The first house is without Trombe walls denoted as the basic house (see Fig. 1b). The second house is with two Trombe walls located at the south side of the house (see Fig. 2a) at the part of the external wall of the living room.

Each house is used by one family. The house has 10 rooms (see Fig. 2b). There are one living room of 36.5 m^2, three bedrooms of 10.9 m^2, 11.1 m^2, and 10.1 m^2, one bathroom of 7.2 m^2, kitchen of 9.5 m^2, two anterooms of 5.7 m^2, and 4.8 m^2, and storage room of 2.6 m^2. The total floor area for all these rooms is 99.6 m^2, where the living area of 97.1 m^2 is obtained without the storage room.

Each house has an envelope that satisfies the French thermal regulation. In addition, the house uses schedules of occupancy, ventilation rate, lighting rate, small heat gain, and minimum temperatures in the rooms according to this regulation.

The exterior walls are made (from inside to the outside) by using 0.013 m thick outer mortar, 0.14 m thick glass wool as thermal insulating layer, 0.2 m thick concrete blocks, and 0.015 m thick inner mortar. They have *U*-value of 0.226 W/m^2/K. The windows are double glazed with the air gap of 13 mm between 3 mm thick glass panes having *U*-value of 2.72 W/m^2/K, *SHGC* = 0.764, and visible transmittance of 0.812. The overall area ratio of the windows to the entire envelope walls is 0.125, where the total area of the envelope is 102 m^2 and the total area of the windows 12.75 m^2. The interior walls are made by using 0.01 m thick plaster, thermal resistance of 0.15 m^2K/W of air gap, and 0.01 m thick plaster. The roof is made by using 0.01 m of roof tiles. It has a *U*-value of 5.17 W/m^2/K. This value seems rather high for good thermally insulated house; however the thermal insulation of the upper envelope of the house is done with thermal insulation of the ceiling. The ceiling is made (from the inside to the outside) by using 0.013 m of plaster board, and 0.14 m of glass wool having *U*-value of 0.240 W/m^2/K. The floor is made (from the inside to the outside) by using 0.005 m of tiles, 0.053 m of PSE, and 0.2 m of concrete. It has a *U*-value of 0.567 W/m^2/K. The installed windows and doors on the building envelope provide the infiltration of 0.00017 m^3/s/m^2.

Each room has the internal heat load (people, lighting, and electrical equipment) according to Table 1. Maximum of 2.2 persons reside in each room during each day. In the each room, the traditional hanging lamps are used for lighting with incandescent bulbs of 1.4 W/m^2 during each day. In each room, the classical electrical household devices are used (stoves, refrigerators, TVs, radios, washing machines, freezers, and microwaves) of 5.7 W/m^2 during each day. The schedule of the people presence in rooms, using of lighting in rooms, and using of electric equipment in rooms are given in Table 1. The house ventilation is taken to be 0.15 ach through the living room, the bedroom 1, the bedroom 2, and the bedroom 3.

The heating season runs from October 1 to March 31. During the heating season, the operative temperature of indoor air is maintained from 16 °C to 19 °C by using heaters according to the schedule given in Table 1.

2.2. Trombe walls

The performances of six variants of Trombe walls are studied. Each variant consists of a window, frame, a massive (accumulation) wall, and an air space between the window and the massive wall. The window has two glass panes with a light opaque window shade between them. The between-glass window shade serves as a thermal insulation during night. Consequently, it is on during night if low outdoor temp is 19 °C and it is off during day. The frame is from PVC. The massive wall has three layers: outer mortar layer, core layer, and inner mortar layer. Table 2 lists the names of layers of window and massive wall with their thicknesses, thermal conductivity, density, and specific heat.