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Experimental study on thermal behavior of a building structure using rubberized exterior-walls

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ABSTRACT

Addition of scrap-tire pieces into cementitious composites improves their thermal insulation performance. Development of such construction materials with lower thermal transmittance reusing these wastes is a challenging issue since it provides a combined solution for today's energy saving and environmental pollution concerns. In favor of this, recent European Union directives have brought quiet strict limits to reduce energy consumption and landfill disposal of solid wastes. A model room whose exteriors are fully made with scrap-tire added concrete is built here to increase its thermal protection. A standard/conventional room at identical dimensions but surrounded by ordinary concretes is also built to examine influence of scrap tire addition on room's thermal protection. Long-term thermal behaviors of these two rooms are investigated and compared under real atmospheric environments. Their indoor temperatures reveal that addition of scrap tire pieces lowers both indoor temperature variations and the effect of outdoor conditions. As an example, mean values of yearly thermal time lag are found to be 3.28 and 2.96 h, respectively for the rooms built with and without using scrap tire pieces, corresponding to nearly 11% improvement in thermal protection. Results in overall verify that scrap tire addition improves thermal protection of the room and it is a cost effective solution for people with low income and/or individuals living in rural areas.

1. Introduction

Energy use in buildings is a significant factor in world's overall energy consumption and a major contributor to greenhouse gases. Nowadays, approximately 25–30% of the total energy consumed in world is used in buildings. About 80% of the energy consumed in the commercial and residential buildings is used for space heating and cooling. Enhanced thermal protection is a therefore pre-requisite to construct or rehabilitate buildings to reach a reasonable energy consumption, satisfactory thermal comfort conditions and low operational costs. Energy saving can be obtained by insulation since significant part of heat losses or heat gains occurs through walls and ceilings [1].

The new European energy regulation (EPBD: energy performance of buildings directive) considers a high standard of thermal protection in order to advance more sophisticated energy saving measures and to stricter energy performance limits [2]. The EPBD is indeed the main community legal tool that provides for a holistic approach towards efficient energy use in the buildings sector. The EPBD's main objective is to promote the cost effective improvement of the overall energy performance of buildings. Its provisions cover energy needs for space and hot water heating, cooling, ventilation and lighting for new and existing, residential and non-residential buildings. Most of the existing provisions apply to all buildings, regardless of their size and their use (residential or non-residential). The energy efficiency requirements of the building shell or envelope have always been an essential part of nearly all regulations since the improvement of these parts represent a major saving potential [3].

Requirements for energy efficiency in a building envelope surrounding the heated and cooled parts of the building is generally set based on resistance or contribution to heat transparency through a unit of the construction, respectively *R*-value or *U*-value. In heating season, low *U*-values or high *R*-values prevent heat from escaping from buildings, and in cooling season they prevent heat from entering buildings. The typical *U*-values required by the national regulations in most European countries have been sharply dropped in the last two decades. This has caused in increasing thermal insulation thicknesses in conventional building shells. Many advanced insulation materials exist in the market to fulfill these requirements. Nevertheless, their high investment costs have always been a significant burden to some low income households and to people living in rural areas [4].

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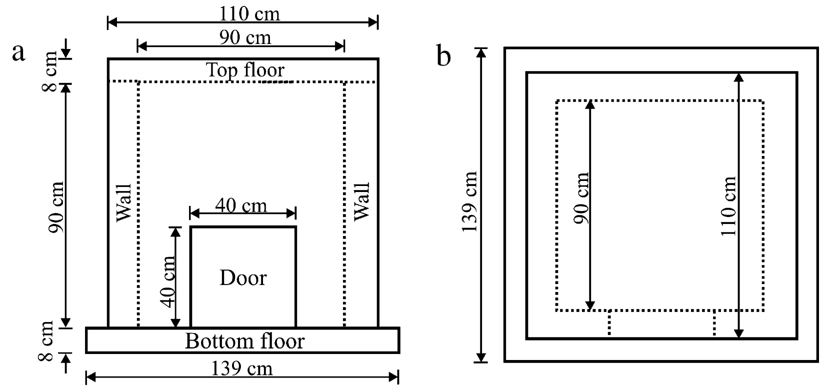

Fig. 1. Dimensions of the constructed model rooms; (a) front-view, (b) top-view.

Addition of scrap-tire pieces into cementitious composites is known to improve thermal insulation performance with almost no extra material cost and can thus provide an alternative cost-effective solution for today's energy saving need, especially for low cost buildings. It also provides an alternative safe way of utilizing a waste material to help environmental protection [5]. A series of significant restrictions on the disposal of used tires in landfills, stockpiles, or illegal dumping grounds are also imposed in recent European Union Directives, since scrap-tires hold significant part of industrial solid wastes [6]. The development of composite construction materials with lower thermal transmittance reusing these wastes is thus a challenging issue and subject of the present study.

Accumulation of a large amount of used tires annually generated is a major environmental concern for all countries. It is roughly estimated that more than 10,000,000 tires are discarded each year in Turkey, and less than 10% of these tires are currently recovered, leaving the rest to the environment. Reusing these tires in building sector would create dual benefits of reducing both the energy consumption and the environmental pollution [7,8]. Scrap tires have long been investigated as an additive to concrete to form 'Rubcrete' for various applications and have shown promising results. Addition of rubber particles has a disadvantage of leading degradation of mechanical properties, especially lowering compressive strength of the concrete. Most studies [9–12] have therefore focused on measuring physico-mechanical properties of rubberized specimens at different shapes (i.e. flat, cylindrical). They have collectively [9–14] indicated that the rubberized concrete mixtures possess lower density, increased toughness and ductility, more efficient heat and sound insulations but lower compressive and tensile strengths, which make them suitable mostly for non-load-bearing walls. Its potential thermal protection ability has therefore been disregarded for long-time, with the exception of few recent works [4,7,8,10,15–17]. These studies have mostly attempted to characterize thermal performance of rubber-added cementitious products. Up to now no work has dealt with the investigation of an end-use whole structure with rubberized concretes, such as the one presented here.

A room whose exterior walls are fully made with scrap-tire added concrete is constructed here for obtaining better thermal protection. Whole part of a scrap tire is distinctively utilized in the concrete products, without any need for removing the steel belts. This approach eliminates extra cost of removing steel belts in the whole tire, which is pre-required operation for grinding process to reach the form of crumb rubber. Thermal behavior of this rubber-added room is examined and compared with a conventional reference room at identical dimensions but surrounded by ordinary concretes.

Table 1
Mixture proportions for the concretes used in bottom and top walls.

Cement (kg/m^3)	Water (kg/m^3)	W/C	Sand (kg/m^3)
573	242	0.45	2293

2. Materials and methods

2.1. Construction of the rooms

A rubberized room (RR), whose envelope is fully made with scrap-tire added concrete, is built here to increase its thermal protection. A standard room (SR) at identical dimensions but surrounded by ordinary concretes is also built to examine influence of scrap tire addition on indoor thermal behavior. The interior dimensions of the both rooms are 90 × 90 × 90 (in cm) as schematically illustrated in Fig. 1.

Two types of rubberized concretes, slabs with shredded tire rubber (as bottom and top walls) and slabs with crumb tire rubber (as side walls), are used in construction of the RR. The mixture proportions of concrete used in the bottom and top walls are given in Table 1. In processing of a scrap tire before reusing it in concrete, an original approach is applied here to benefit from all parts of a scrap tire without removing the steel belts. According to this approach; the whole tire is first splitted into three pieces by a simple cutting process: a single piece of a planar front wall and two pieces of annular side wall. Planar front wall include treads and steel belts whereas annular pieces have no metal inclusion at al. The planar surface is shredded in perpendicular by a simple mechanical process into the desired lengths without removing steel wires. These planar tire pieces are set into fresh concrete with desired distance and arrangements before pouring the top layer. The possible use of this composite material is to enhance heat insulation performance of non-loaded concrete blocks, such as floor, roof and precast concretes. The annular side sections of a scrap tire are directly grinded into crumb rubber of desired size by a simple cracker mill process. No additional separation process to remove steel fibers is necessary since this part of the tire already has no steel fragments at all. These crumb rubbers as aggregates are then used in manufacturing of side walls of the RR.

The dimensions of planar tire pieces with steel-belt used in bottom and top walls are 1.5 × 15 × 35 (in cm). Their placements into half-thickness of the walls are schematically shown in Fig. 2. These planar tire pieces are smoothly arranged on the fresh poured in half-thickness of 3.25 cm into a mould. The other half of fresh concrete in thickness of 3.25 cm is then poured over the surface with rubbers. The fresh concrete is compacted and its surface is then finished.

The concrete mixture proportions of the crumb rubber added concrete used in side walls of the RR are given in Table 2. The phys-