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Research Article

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Energy Performance Study of Passive Cooling Technique Applied to the Roof of a Test Cell in Marrakech Climate

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Abstract

This work aims to investigate the inactive cooling technique effect on the thermal comfort of buildings by constructing two identical test cells in semi-arid climate of Marrakech, Morocco. The first cell was kept as reference cell (bare roof), while the second one was covered on its roof with 40 mm layer of white gravel. A dynamic mono-zone model was also created in the TRNSYS 18 software and validated against experimental data obtained from the two test cells, and using external climatic condition measured by a meteorological station installed near the two studied test cells. The chosen period was from 31 July to 05 August 2021. The validated model assesses the thermal performance throughout the summer period using standard weather file of Marrakech, known as Typical Meteorological Year representing statistically the meteorological variations over at least 10 years. The results analysis shows that the implementation of 40 mm layer of white gravel on the roof of the cell-test has a remarkable effect on the indoor air temperature and air conditioning energy loads. Indeed, the indoor air temperature was reduced by about 8.31 °C and the total energy gain by around 42.94 kWh/m^2 was observed, during this summer period.

Keywords

Test cell, White gravel, Thermal modeling, Thermal performance, Passive cooling, TRNSYS

Introduction

Living in the thermal comfort leads to growth in energy demand. Therefore, in the building sector, this energy needs representing 33% of the country's total energy consumption [1]. Morocco's dependence on energy from abroad imposes major challenges in terms of reducing energy [2]. With this in mind, improving the building envelope has become a necessity to minimize the impact of the external climatic conditions. In addition, the introduction of energy efficient practices and the integration of passive techniques could significantly reduce energy consumption in buildings. In this regard, several researchers have carried out the experimental studies on the thermal performance using passive techniques applied to roofs of test cells in real climatic conditions. Gari et al. [3] studied a (20 x 20 x 3) cm^3 reinforced concrete roof, insulated with a 5 cm thick layer of glass wool on the four outer sides of test cell, in Saudi Arabia. Five concrete roofs covered with several types of different gravel diameters (4.5 to 12.5 mm) were tested and compared to a reference roof (Bare slab). The effect of the gravel layer on the measured temperature in different points shows that there is a difference of about 10 °C between the external temperature and the measurement ones. Four (0.6 x 1 x 1) m^3 structures, each equipped with passive cooling technology, in Amman are studied by Hamdan et al. [4]. A-Standard roof without treatment (Reference) of 8 cm thick concrete, B-Roof covered with a thin layer of white cement, C-Roof with broken pieces of white glazing glued to it, and D-Roof covered with a layer of 3 cm thick clay were studied. The authors have revealed that the D technique is the best as it leads to a good cooling of the air in the hot and arid climates. Kachkouch et al. [5] in Morocco, evaluated the thermal performance of three passive techniques applied to roofs, using four identical test cells. Namely white paint, shading, thermal insulation, and the fourth test cell is set as a reference. The authors concluded from this study that the white painted roof diminishes the heat flow through the roof until 66% compared to the bare roof. Han et al. [6] have conducted the thermal performance of a test cell, and the effect of the absorptivity of its external surface on space cooling load in the hot humid area. The results showed that the space cooling load reduction ratio for light painted envelop could reach 9.3% compared to the black painted one. Another study led by Sabzi et al. [7] in Iran, investigated three passive techniques: water basin, water pockets, and shade. The results revealed that the technique of the water pond allows a great energy saving in terms of cooling. In hot and semi-arid climates, a study was conducted by Benhamou and Bennouna [8] where the effect of some passive techniques on the thermal load of a residential building located in the city of Marrakesh was carried out. They found that the thermal insulation of the roof reduces the thermal load by about 40%. Other techniques have been studied by Sakami et al. [9] who examined the energy performance of a partially buried house in the various Moroccan climatic zones. Their findings indicated that the thermal loads of the semi-buried building are reduced compared to those of the on-ground building in all the climatic zones of Morocco with a decrease rate between 23% and 39%, except the Atlantic climate. The reed panels use as a passive technique to insulate the roof of a classroom combined with rammed earth walls has been evaluated by Benaddi et al. [10]. The results indicated that the considered techniques have a remarkable effect on the annual thermal loads as well as the indoor air temperature, especially in summer season. The total heat loads have been reduced by 53% compared to the standard case.

The main goal of this work is to evaluate the cooling potential of a building using local natural material such as white gravel as a passive technique applied to roof of a test cell in the semi-arid climate of Marrakesh, in Morocco.

Materials and Method

Experimental protocol

Two identical test cells were built to study the thermal performance of the inactive technique applied to roofs. The first cell is kept as reference (Bare roof), while the roof of the second one is covered with a layer of white gravel of 4 cm. The choice of this material was made on the basis of several criteria, including its availability in the Moroccan market, its cost, durability and the porosity created during the implementation, and the sustainability of its optical properties over time. Figure 1 illustrates the studied passive technique as implemented. Table 1 shows the different layers of the walls and the low floor of the cells. Each test cell contains a watertight door which allows access to the interior as shown in this figure 1. The slabs are identical with 70 mm thick reinforced concrete; they were built to cover the upper part of the test cells. Each slab represents the roof of a test cell.

Figure 1: Cell 2 with 40 mm of white gravel.

Table 1: Test cell characteristics.

Thickness per layer (mm)	Galvanized steel (external surface)	Glass wool	Galvanized steel (internal surface)
Low floor	2.30	40.00	1.60
Vertical walls and door	1.60	40.00	1.60

Measurement systems

To evaluate the thermal performance of the passive technique applied to the roofs, different sensors were fixed in the test cells. Figure 2 shows the location of these sensors and also the two PT100 probes (with an accuracy of 0.5 °C) which were used to measure the inside and outside surfaces temperatures of the roof. These probes were linked to a data acquisition chain programmed to record surface temperatures every 30 minutes. In addition, a TESTO 174H Datalogger

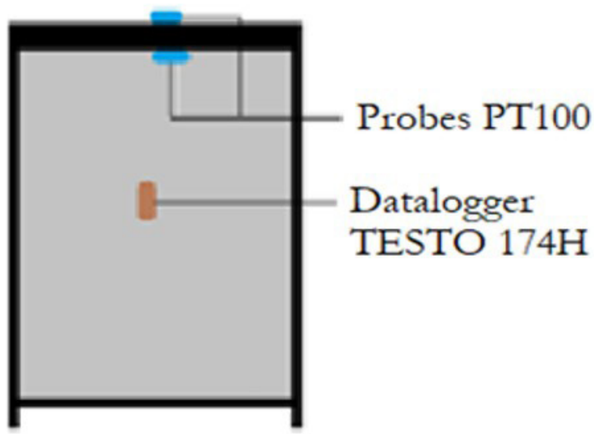

Figure 2: Location of temperature probes in the test cell.

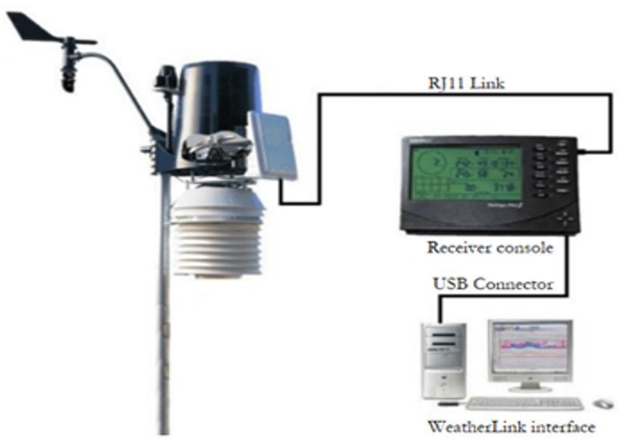

Figure 3: DAVIS Vantage Pro2 weather station and connection.

was hooked into the middle of the slab and halfway up the test cell to measure indoor air temperature every 30 minutes with an accuracy of 0.5 °C. Heat exchange takes place on a nanometric scale.

The meteorological data were measured using a DAVIS Vantage Pro2 weather station presented in figure 3. This weather station is installed on the roof of the National Center for Water and Energy Studies and Research (CNEREE) near the test cells and measures, every 30 minutes, the air temperature, the humidity, the air pressure, the speed and direction of the wind, the global solar radiation on a horizontal plane, and the precipitation. The measurement errors are 0.5 °C, 3%, 5% and 1 W/m^2 for air temperature, humidity, wind speed and solar radiation, respectively.

Climate zone

The test cells and the weather station were installed on the roof of the CNEREE. This center is located in Marrakech (31°37' N latitude, 8°2' E longitude and 468 m altitude) characterized by a semi-arid climate, very hot summer and cold winter; and marked by large temperature variations.

Modeling

The TRNSYS software was used to model our white gravel-covered cell. In order to define the cell, all its characteristics were introduced into TRNBuild. This interface allows describing all the characteristics of the envelope composition. In this regard, a dynamic mono-zone model was created, with the same thermal behavior as that achieved experimentally. For these aims, the real climatic conditions measured on site during the period from 31 July to 05 August 2021 were used. The found results revealed that the difference between the experimental and simulated temperatures in two cells does not exceed 1.5 °C, indicating that our model is well validated. The variations of the simulated and measured indoor air temperature in the two test cells (1: reference, 2: with white gravel) are displayed in figure 4. The thermal evaluation throughout the summer period was carried out by this model.

Results and Discussion

The effect of white gravel on the thermal performance was studied by performing a simulation during the summer period

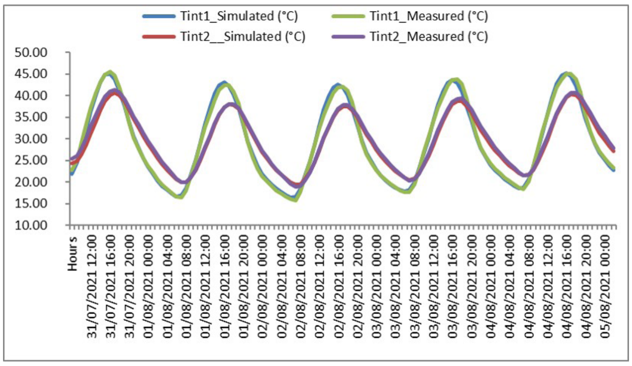

Figure 4: Simulated and measured indoor air temperature changes in test cells from July 31 to August 05, 2021: 1: reference and 2: with white gravel.

(June, July, and August) based on the set point temperature of 26 °C for cooling needs. The Typical Meteorological Year weather file of Marrakech city was used [11].

Air temperatures inside the test cells

The simulation of different hourly temperatures fluctuations in both cells during the period varying from June to August was carried out. Three hot days from this period were chosen to present the hourly variations temperatures on the external surface of the test cells with the ambient temperature in figure 5. It can be seen that with the increase in ambient temperature, the surface temperature of the bare slab increases considerably compared to the surface temperature of the slab covered with white gravel. Thus, at 4 p.m. the ambient temperature, the surface temperature of reference cell reached respectively 44.60 °C and 56.74 °C. whereas the roof's surface with the studied technique don't exceed 47.79 °C. this result can be explained by the fact that the dark grey color of the bare roof absorbs an important radiation compared to the roof with white gravel which reflects the solar radiation. This drop affects directly the temperature of the indoor air in the same cell. Figure 6 indicates the hourly variations of indoor air temperatures on a typical day, July 07, when this fluctuation has a maximum deviation of 8.31 °C between the two studied cells.

These results align with findings from previous studies [3, 5-6]. The authors demonstrated that the color of the building envelope affects the temperature of its external surfaces. Specifically, they found that a black-painted envelope (with high absorptivity) exhibited higher temperatures compared to a white-painted envelope (with low absorptivity) during the

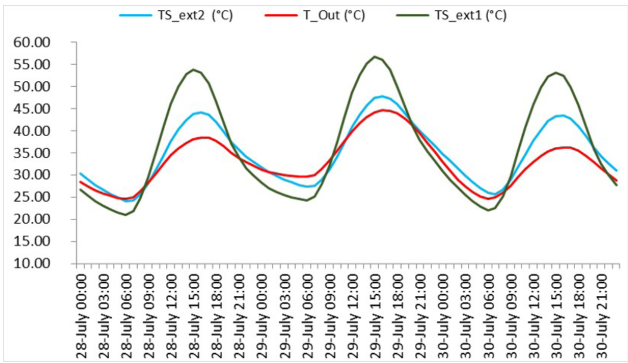

Figure 5: The hourly variations temperatures on the external surface of the test cells (1: reference, 2: with white gravel) and outdoor temperature.

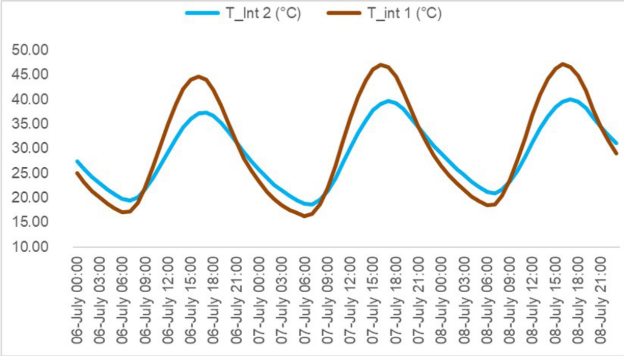

Figure 6: The hourly variation of simulated indoor air temperatures of the test cells (1: reference, 2: with white gravel).

day. Furthermore, analysis of figure 6 reveals that applying a layer of white gravel on the roof introduces an approximate one-hour phase shift between the peak internal temperature of the studied cell and that of the reference cell. This reduction in time helps optimize the operation of cooling systems.

Energy gains

Reducing a building's internal temperature plays a significant role on its energy consumption when it comes to air conditioning. Table 2 presents the simulated energy loads in the two studied test cells. It can be remarked that the air-conditioning loads are reduced compared to the reference cell from 48.77 kWh/m^2 to 34.12 kWh/m^2, from 64.47 kWh/m^2 to 49.65 kWh/m^2 and from 56.50 kWh/m^2 to 43.03 kWh/m^2, respectively during June, July, and August. Furthermore, figure 7 illustrates the energy cooling savings by placing 4 cm of white gravel on top of the cell. The analysis of the obtained results discovers that this technique reduces the cooling load by about 25.30% compared to the reference cell.

These results are consistent with findings from [6, 12, 13], where the authors demonstrated that the absorptivity coefficient (color) impacts the cooling load of buildings. However, Kachkouch et al. [5] recommends regular cleaning and renewal of the white paint to maintain consistent performance throughout the summer period.

Table 2: Energy loads relating to cells 1 and 2.

Month	June	July	August	Total
Q1 (kWh/m^2)	48.77	64.47	56.50	169.74
Q2 (kWh/m^2)	34.12	49.65	43,03	126.80

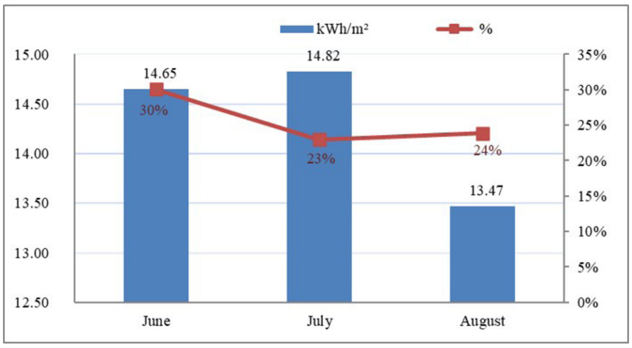

Figure 7: Cooling energy gains by adding 4 cm of white gravel to the test cell roof.

Conclusion

The use of 4 cm white gravel as a passive technique to cover the roof of a test cell was evaluated in this study. The TRNSYS software was chosen in order to simulate the thermal performance of this technique in climate zone of Marrakesh during the summer period. The found results show that in the semi-arid climate of Marrakesh, the implementation of a layer of white gravel on the roof of the test-cell has a remarkable effect on the lessening the indoor air temperature by up to 8.31 °C and on the air conditioning loads by about 25.30% compared to the refence test cell.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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