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# Passive climatization using a cool roof and natural ventilation for internally displaced persons in hot climates: Case study for Haiti

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ABSTRACT

The 2010 Earthquake in Haiti caused catastrophic damage to the metropolitan area of Port au Prince. The earthquake destroyed approximately 105,000 homes, causing more than 2.3 million people to live as Internally Displaced Persons (IDPs). Today, more than 1.3 million people still live in tents. Low cost buildings can provide a housing solution for these people. This paper proposes a low cost building solution intended for hot climates, using concrete as the only material. Due to the lack of facilities at these locations, no conventional energy or cooling systems can be installed; thus, only passive cooling technologies can be used to increase thermal comfort. A low cost cool roof and combined natural ventilation is proposed, and simulations show an improvement of 16% in the thermal conditions inside the building. The simulation is performed using the software package EnergyPlus and shows that cool roofs can be a good solution for improving living conditions in low cost houses for IDPs.



## 1. Introduction

Internally Displaced Persons (IDPs) are a common problem around the world due to military conflicts, natural catastrophes and political conflicts. In many countries around the world, IDPs still live in tents or transitional shelters in very poor conditions, with a general lack of thermal comfort.

The purpose of buildings is to provide shelter and comfortable living conditions for the people inside. Most of the tents and transitional shelters used in Camps of Internally Displaced Persons (CIDPs) are characterized by very poor indoor air quality. In general, the building materials are extremely substandard and have high water absorption, high thermal conductivity and low compressive strength. In very few places, some type of energy supply is available for the CIDPs, but where it is available, the cooling and heating systems have very high energy consumption and poor thermal performance. There are two different aspects to address in this situation. The first such consideration is the building itself (for example, cracking walls), and the second consideration is related to the energy performance and thermal comfort inside, typically involving significant indoor temperature fluctuations. In these situations, the house design does not follow passive solar design features, which implies higher energy consumption, higher costs during the life of the building and low-comfort indoor conditions. As a result, there is a need to improve the thermal efficiency of these low cost shelters or provide a cost efficient solution. When no energy supply is available in the CIPD and no renewable energy systems can be used due to economic restrictions, a passive design is the only way to optimize the thermal conditions. Simple design considerations such as northern orientation in the southern hemisphere and correct material choice can significantly increase the comfort conditions in buildings. In extreme conditions, which are typical in countries undergoing military conflicts or after a natural disaster, there is usually no choice about these issues.

One of these cases is Haiti, where the January 12th 2010 earthquake caused catastrophic damage to the Port au Prince metropolitan area and underscored the endemic weakness of the infrastructure and tenure regime of the country. In addition to existing problems, the earthquake created a host of new challenges. The earthquake destroyed approximately 105,000 homes and severely damaged more than 208,000, exacerbating the already substantial housing deficit and causing an estimated $4.3 billion in damage to physical infrastructure. The destruction displaced roughly 2.3 million Haitians, of whom 1.3 million still live in tents or transitional shelters. CIDPs are scattered across the landscape. These emergency settlements offer insecure living conditions and perpetuate social decline. The lack of available shelter options for people who have lost both their livelihood and home has impeded the return of IDPs to sustainable shelter. IDPs must return to safe, durable shelter in their communities or find sustainable shelter in

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**Nomenclature**

| | |
|---|---|
| ASHRAE | American Society of Heating, Refrigerating and Air Conditioning Engineers |
| CFD | computer fluid dynamics |
| CIDPs | camps of internally displaced people |
| EPS | expanded polystyrene insulation |
| IDPs | internally displaced persons |
| $h$ | heat transfer coefficient |
| HVAC | heating, ventilation, air conditioning |
| $M$ | metabolic rate (W/m$^2$) |
| $P$ | pressure (Pa) |
| PMV | predicted mean vote |
| PPD | predicted percentage dissatisfied |
| RH | relative humidity |
| $T$ | temperature |
| $U$ | global transmittance value (W/m$^2$K) |
| $W$ | external work (W/m$^2$) |

*Subscripts*

| | |
|---|---|
| a | air |
| c | comfort |
| cl | clothing |
| d | door |
| fra | frame |
| glaz | glazing |
| m | mean outdoor temperature |
| op | operative |
| r | radiant |
| w | partial water air pressure |

new economically viable areas. Providing safe shelter for those displaced is a difficult, costly and humane challenge for the building designers. This paper aims to analyze and optimize the construction of 204 homes arranged in building lots, as shown in Fig. 1. The scenario is based on a real location in Haiti that is intended for IDPs camps. The exact north location is shown in the figure.

In this paper, passive cooling techniques are studied and applied to optimize the indoor conditions. Different passive heating and cooling technologies are reported in the literature. In the hot and humid climate conditions of Haiti, passive cooling is intended for the proposed solution. Table 1 shows the main climatic conditions for the location.

Passive cooling systems in buildings can generally be studied in two different ways. The first way is to consider any system intended to reduce the cooling load as a passive cooling technique. The second way considers an integrated building design and the use of renewable energy systems to enhance heat loss from the building. Lowering the indoor temperature can be achieved using the ambient air, the upper atmosphere, water evaporation and under-surface cooling coils. Some of these cooling systems include naturally ventilated buildings, nocturnal ventilation cooling, indirect evaporative cooling, direct evaporative cooling and the use of cooled soils. In the proposed building, no active cooling systems or renewable energy systems are used. Table 2 shows the most important passive cooling techniques, their description and their energy saving potential.


**Fig. 1.** Lots plan.

Due to the low cost requirements for the building and the location, the use of a cool roof, roof insulation and natural ventilation was selected. Due to the lack of economic and financial resources, the government and the United Nations (UN) proposes the construction of low cost buildings for the IDPs that could become future stable buildings when any means of energy supply is reestablished or installed. The cost must be extremely low, and the building techniques should not be difficult because the buildings will be constructed by unqualified people with a lack of resources. Light weight concrete buildings provide a cost-effective solution because they are easy to build and have a high thermal inertia. Ten inhabitants are intended to live in each shelter, and there will be no Heating Ventilation Air Conditioning (HVAC) systems, electricity or primary energy used. In this paper, a low cost solution for improving thermal conditions is proposed, evaluated and simulated. For the location considered, the building distribution in the lots is analyzed using an external Computer Fluid Dynamics (CFD) simulation to optimize wind distribution and ventilation. Natural ventilation for the building itself is simulated and optimized, and the use of EPS insulation in the roof is compared with the base case. A cool roof technology using a coating intended for that specific feature is proposed. Comfort parameters are evaluated for every case to obtain more detailed results than are possible using only dry or wet bulb temperatures. For a simulation combining the effects of natural ventilation and a cool roof, comfort conditions are 20% better than those attained in the base case; the operative temperature is 25.85 °C on the hottest day of the summer, while it is 28.75 °C for the base case. For the natural ventilation technique, the wind velocity, frequency and direction are important to ensure correct behavior. The wind data for the location are shown in Fig. 2, and the speed frequencies are detailed in Fig. 3. The most frequent direction of the wind is east, which has been considered in the distribution of the buildings in the lots.

## 2. Building design

### 2.1. Fundamentals of thermal comfort

Air temperature and relative humidity have a significant impact on the perception of thermal comfort by human beings. A relative humidity (RH) below 30% may cause dry skin, eye irritation and/or respiratory problems. On the other hand, a RH above 60% may provide an environment prone to the growth of mold, mildew and dust mites and cause allergic reactions. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) recommends indoor comfort values [1,2].