AN INNOVATIVE COOLING ROOF REDUCING THE ENERGY DEMAND FOR A NON-RESIDENTIAL BUILDING IN TROPICAL CLIMATE

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In tropical climates, high temperatures and high levels of humidity, coupled with inadequate design of buildings, lead to an increase in thermal loads. The roof is the element of the building that receives the greatest amount of solar radiation throughout the year. As a result, the roof receives excessive thermal gain, which is then transmitted to the rest of the building and leads to an increase in final energy demands. Much of this can be solved with passive design strategies. With respect to the main problem of the building roof, natural ventilation can provide improvements in reducing temperatures in this area and the structure below. First, through correct orientation, a reduction of the building’s annual energy consumption by 24.32% was achieved. Secondly, by applying different configurations of the roof a reduction of 78.09% in roof cooling loads was obtained. This was brought about through a combination of optimization of the roof design for natural ventilation and the application of reflective materials with a U value of 0.13 W / m²K. From the second scenario it was reduced by 14.74% with the applied strategy.

Keywords: Bioclimatic design, Natural ventilation, Effective area, Sub-tropical climate, Thermal comfort, Building performance.

1 INTRODUCTION

The tropical climate conditions lead the buildings have a highly energy consumption, specifically in the cooling loads (Al-Obaidi et al. 2014), and several problems in terms of the materials that are applied. The percentage of energy consumption of some countries that are located in this region, was found that the non-residential and commercial buildings share approximately “one-fourth of the total electrical energy consumption” (Rattanongphisat and Rordprapat 2014). In Ecuador, the energy consumption of the residential area is of 28.78% from the final consumption and the commercial and public services 21.78% (IEA 2016). The architectural manufacture in terms of materiality and shape of the building itself, are key to arrive with an appropriate design. Regarding to the materiality in the tropical climate the most common and suitably used in that location are clay, wood, bamboo and some others local materials (Al-Obaidi et al. 2014), but nowadays those materials are not considered in new cities that are being developed in that location, the materials that are currently being used are the steel, concrete, glass, metals and other different materials that are more suitable for another location. With a correct passive design for the building in this location (Rattanongphisat and Rordprapat 2014), this can improve the performance and reduce the energy demand in order to achieve a low carbon building (Yeang 2008). The roof receives during the year highly radiation due to the location and climatic conditions, the main reason for discomfort of the occupants is the poor passive design,
specifically regarding to the roof design, the heat is directly transmitted from the roof surface and it creates higher temperatures in the interior and in the upper part of the building (Sadineni et al. 2011, Zingre et al. 2015, Roslan et al. 2016). From all the architectural elements, the roof is one of the main issues that need to be studied in order to achieve a better energy saving and performance in the building. By looking and understanding to the future urbanistic building development it is clear that the cities in a tropical climate are going to grow and the issues that the residential and non-residential buildings in terms of energy performance carry, will grow as well. It was found in a study of the international energy agency (IEA 2016) that in 2005 in Ecuador the energy consumption demand of the residential area was 3701 GWh, in 2010 increased to 5114 GWh and in 2013 to 5880 GWh, the trend grows through the years. This demand can be mitigated with a well-done passive strategy of the buildings and importantly in the tropical climate of Ecuador setting which strategies can be better applied to a future design of the buildings in that location and highly important to focus on the main issue of the buildings that are the roofs.

2 METHODOLOGY

The aim of this work is to prove that with an appropriate design of the roof it can be minimized the energy demand in the building by applying a combination of different passive strategies and passive cooling technologies with natural ventilation. This would take place with a case study of an office building in Santo Domingo de los Tsáchilas – Ecuador that has a tropical climate, coordinates 00°15’15”S and 79°10’19”W. One of the best passive techniques that are going to be incorporated further for this proposal are the naturally ventilated roof, the reflective roof, and the attic ventilated roof, also one of the important factors is the modification of the roof shape of the roof that can enhance a better ventilation.

The case study for this work is an office building, Figure 1. The building is conformed by four floors, west façade that is the main access façade of the building is composed of a glazing wall. The roof as it can be seeing is the typical roof that many others building offices have in that location, further the roof will be explained in detail.

Figure 1. (a) Initial building South view, (b) Initial building West view.

The material components of the initial roof are the steel purlins + metal panel + roofing felt, the total of these materials make a thickens of the roof of 0.26 cm, with a heat transfer coefficient value (U) of 21.68 W/m²K, the thermal resistance (R) is of 0.04 W/m²K and a thermal mass of 87.60 (kJ/W). The roof is a compressed flat roof without any natural ventilation and with a high U-value coefficient, the measures are 12.85 m x 15.43 m, with an area of 198.27 m². It was determined three relevant scenarios in order to prove the main task, that can provide with outcomes and then it can be able to compare between them.
2.1 Evaluated Scenarios

For the scenario 1, initial building case study will be evaluated in terms of energy consumption and performance in the specific climate and location with a relevant software’s, such as Revit 2016. The energy analysis will determine the demand that generates the roof, and mainly the monthly cooling loads that this evaluation is looking for. In the outcomes of the energy analysis can be obtained the wind frequency of this location, with this outcome we can determine the best orientation of the building that can enhance a better natural ventilation.

![Figure 2. Analyzed scenarios.](image)

During the scenario 2, the building will be correctly oriented in order to enhance the wind conditions of the location. Rotated building will be analyzed in terms of energy performance with the software Revit 2016, during the analysis the building will not have any change in terms of materials and in the shape of the building, the important factor that is going to be analyzed is how the rotation to the most frequently wind conditions in order to enhance the natural ventilation in the building affects the energy performance of the building.

For the third scenario, the rotated building will be improved with an appropriate roof design. In first instance it has been designed five proposals having into account the form and shape of the roof that it will be needed to be enhanced the wind flow, as well it need to have into account the different material conditions according to the reflective materials and importantly of the U value configuration of the roof. Five roof geometrical proposals are going to be evaluated in CFD Ansys Fluent in order to understand the behavior of the roof shape with the wind conditions of the location, the parameters evaluated in CFD will be by steady conditions, and only one variable the wind speed, at 1, 2 and 3 m/s from the north – east and from the south - west, in order to analyze the roof, attic temperature reduction and the inner roof behavior with the wind speed. After evaluating all the roofs proposals, it can be determined which roof provides with a better wind flow and temperature reduction.

With the appropriate roof that was determined with the parametric analysis in CFD Ansys Fluent, now with the building proposal of the scenario 2, it will be improved with the appropriate roof and analyzed in Revit 2016 in terms of the energy performance. It is important to mention that in this evaluation, are going to be analyzed four different types of roof materials by having into account the U- value of the material configuration, in order to understand which of them provides a better energy performance in the building and mainly the reduction of the cooling loads required for the roof. The rotated building with the appropriate roof and material will be compared with the Scenario 1 and 2 in order to see how with the improvement of the roof in the building can reduce the total energy consumption of the building and enhance a better performance.
3 RESULTS

In the scenario 1 for the initial analysis of the building, Figure 3 presents the monthly cooling load required for the roof and Figure 4 presents the monthly energy consumption of the building.

![Figure 3. Monthly roof cooling load (Revit 2016).](image1)

![Figure 4. Initial Model Consumption (Revit 2016).](image2)

For the scenario 2 it is important to understand the wind conditions that this location has, by knowing the natural wind conditions that this location has it can be improved and enhanced in terms of natural ventilation of the building and therefore the reduction of the energy consumption of the building. It was rotated 45 degrees to the Northeast to the most frequent wind direction.

In the scenario 3, the analysis of the roof geometries proposal, will be made in accordance with the orientation that the roof is located, from North – East and from South – West Figure 5. From north – east is important to highlight that is the side for more wind frequency and the south – west is the possible side that can be natural ventilated.

![Figure 5. Roof analysis proposal.](image3)

The analysis that was conducted for this study is with the parameters of wind-driven natural ventilation CFD under steady conditions, the conditions for the evaluation are the following (Gan 2016). Parameters for the analysis: 1) Outdoor air temperature: 25°C – 298 K, 2) Building temperature: 30°C – 303.15 K. Air properties: 1) Air density at 25°C: 1.1849 (kg/m³), 2) Specific heat (Cp) at 25°C: 1006.43 (J/kg.K), 3) Density at 25°C: 1.1845 (kg/m³), 4) Thermal conductivity at 25°C: 0.025(W/m.K), 5) Viscosity at 25°C: 1.8444 (kg/m.s), 6) Heat gain of the roof: 40 W/m². 7) Ceiling of the last floor heat gain: 20 W/m².

![Figure 6. Comparison of the roofs A, B, C, D, E internal surface temperature K at velocity of 3 m/s.](image4)
Figure 7 presents the monthly cooling loads required for the roof with the configuration of the material “D”, Figure 8 presents the monthly energy consumption of the building.

4 DISCUSSIONS OF RESULTS
In scenario 1 the Figure 2 shows monthly roof cooling load for the initial building, it can be seeing that the roof demand varies from 6000 MJ during January and increases to reach a peak of 12000 MJ during July, then decreases to 6000 MJ during December. Figure 3 shows the monthly electricity consumption of the building during the year, it can be seeing that variation depends on by different components such as the occupants, windows, the walls, floors and the roof. The total electricity consumption for the initial building is of 141689.67 (kWh).

For the scenario 2 the Figure 5 shows the monthly roof cooling load for the initial building, it can be seeing that the roof demand varies from 5000 MJ during January and increases to a peak of 10100 MJ during July, then decreases to 5500 MJ during December. Figure 6 shows the monthly electricity consumption of the building during the year, the total electricity consumption for the rotated building is of 107230.044 (kWh). In scenario 3 in the Figure 7 shows the comparison of the roof internal surface temperature K at velocity o of 3 m/s, the roof D maintains an adequate and stable temperature of an average of 303.80 K, while the Roof A, B, C, E still having variations of the temperature. The material configuration type “D” have analytical properties: U – value of 0.13 W/(m² K), this configuration has as well a thermal resistance R of 7.47 (m² K)/W, with a thickness of 0.24 cm. In the analysis of the cooling load (MJ) for the roof configuration D, it can be seen in Figure 8, during winter the cooling load required for January is of 351.14 MJ and during summer with a peak during July of 744.32 MJ. Then the total annual electricity consumption with the roof configuration D is of 91631.035 (kWh) it can see in Figure 9 that shows the monthly electricity consumption of the building during the year.

After evaluating the scenarios, it has been determining the total energy consumption during the year, the scenario 2 shows a reduction of 24.32 % from the scenario 1, the third scenario demonstrates a reduction of 14.74 % from the second scenario.
5 CONCLUSIONS
During the evaluation of the third scenario, it was found that by designing a dynamic roof shape concave and convex, this can enhance an important temperature reduction in the roof, the attic, and the ceiling surface, at the speed of 1 m/s it was found that there were not any important temperature reduction, but at 2 and 3 m/s it was found that the temperature reduction is important, this study can validate that with a minimum of 2 m/s it can work for reducing the temperature of the roof, it was found that at a velocity of 2 m/s and 3 m/s it can be reduced in 6.4 K and 8.8 K, finishing in 306.4 K and 304 K respectively the roof temperature. However, as the wind speed is not constant, for the passive cooling roof could be a problem, in that order to supply with an optimum temperature at the moment that there is not the sufficient wind speed, the possibility of using an active cooling strategy could be important. That is one of the main limitations of natural ventilation that depends on certain factors in order to see a proper efficiency. With a lower U-Value of the material configuration, it can be reduced to a 78.09 % the cooling loads required for the roof, this is important to highlight that the combination of the concave and convex roof plus the roof material configuration it can be reduced the energy consumption of the building in 14.74%, the use of a corrugated metal panel and the insulation are one of the main components for reduction of the cooling loads.

References
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