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COMPARATIVE ANALYSIS OF TEMPERATURE AND HUMIDITY OF TWO PROTOTYPES OF GREEN ROOFS

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Abstract: Green roofs are small gardens or orchards that are adapted to the roofs of houses, companies, shops and buildings, with the purpose of reducing the temperature and humidity inside the place. Among the benefits provided by the implementation of green roofs is the reduction of carbon dioxide, creating microenvironments for insects and small birds, reducing energy consumption and reducing the heat island effect of cities. In this research, the design and simulation of a house with one room was carried out in SolidWorks software. Likewise, 2 prototypes of houses were built at a 1:10 scale and were instrumented with humidity and temperature sensors (Dht11), to compare the temperature and humidity variables with the implementation of an extensive green roof, a flat concrete roof. and a modular green roof, taking data every 5 minutes during the month of May. The three models used were installed in the back of the renewable energy workshop of the TecNM Campus Progreso to compare the temperature and humidity of the models in environmental conditions. The extensive and modular green roof prototype achieved a temperature reduction of 17.85 and 10.90% with respect to the flat concrete roof prototype and a reduction of 8.64% with respect to the average outdoor temperature for the month of May in the municipality of Progreso Yucatán.
Keywords: Humidity, Green roof, Temperature.

INTRODUCTION

Urbanization and climate change are closely related. Currently, more than half of the world's population lives in cities. Over the next 40 years, the global urban population is projected to increase by more than three billion people (Buettner, 2015). This will almost double the current urban population and lead to massive land use changes in and around current urban settlements. Urban areas are expected to increase by 250% and cover approximately one million square kilometers by 2030 (Angel et al., 2005). This corresponds to the development of more than four hectares of new urban land every minute over the next 20 years. Ninety percent of future urban expansion is expected to take place in Asia and Africa. New urbanization is mainly a problem in developing countries, while 70-90% of the developed world's population lives in urban settlements. Therefore, mitigation and adaptation to climate change is an equally important issue in both the developed and developing world (Brenneisen et al., 2013). Hence the need to reestablish an ecosystem balance in areas interrupted by population growth and its real estate expansion has favored the adoption of green roofs as a sustainable alternative, which contributes to energy efficiency in buildings. In recent years, the application of green roofs has increased thanks to the economic and environmental benefits they provide (Ziogou et al., 2018). Understanding the effect of climate change on cities requires knowledge, not only of the climate scenarios and meteorological conditions that will mark day-to-day life in the urban environment in the future, but also the understanding and weighting of each of the agents that make it up such as: architecture, materials, heat sources, anthropic factors and vegetation. Likewise, currently the "Heat Island" phenomenon is occurring, which is produced as a result of the increase in the flow of sensible heat from the earth's surface to the atmosphere in cities and their immediate surroundings, especially during the nighttime period. This phenomenon is continually increased by the massive replacement of vegetation areas by buildings and impermeable surfaces (Villanueva and Ranfla, 2012; Kóhler and Andrew, 2013), which absorb heat during the day and return it in the form of infrared radiation during the night. night without allowing the nocturnal cooling that thermally regulates the urban ecosystem (Córdova, 2011). This effect also severely impacts not only the thermal comfort of city residents, but also the demand for electricity for cooling in buildings, which increases. (Robert, 2001). Buildings are the cause of 40% of energy consumption in developed countries and, consequently, 40% of carbon emissions (Seweryn y Collante, 2012), These figures are increased due to the increasing contribution of the real estate sector, which has a greater demand for cooling to maintain thermal comfort in this warming scenario. In addition to this, in the state of Yucatán, the BS (dry or arid) and AW (warm subhumid) climate of the Koppen classification (Canto, 1997) predominates, so most of the year is spent in high temperature conditions. and relative humidity. Due to its latitude, and because buildings usually have almost flat roofs, heat gain in buildings occurs through the roof and the south and west walls, which leads to investing significant amounts of energy for thermal comfort. of users (Ordóñez-López and Pérez-Sánchez, 2015). Green roofs, natural roofs, garden or ecological roofs are systems that have been used for many years in numerous regions of the planet both for ornamental purposes and for energy savings, buffering water runoff, and compliance with regulations. Regarding the percentage of green areas (Fernández-Cañero and Emilsson, 2008), contribute to the reduction of greenhouse gases, as well as the creation of spaces for species of insects and small birds. Hence the importance of the implementation of green roofs since they bring many benefits, mainly for urban areas (Getter and Rowe, 2006). Currently, there is much research on the implementation of this technology in places where environmental conditions are different from those that prevail in the Yucatan Peninsula. Although there is some work carried out in climates similar to that of this region, it is notable that there is a need to carry out more in-depth studies and acquire experiences regarding the application of green roofs as a means to reduce the flow of heat caused by solar radiation, towards the interior of buildings in the State of Yucatán (Ordóñez-López et al., 2012). Therefore, this research work consists of the implementation of 2 prototypes of green roofs (extensive and movable), with the purpose of making a comparison of temperature loss in the two models and comparing it with a common roof model (concrete)., these will be placed outdoors, to record the temperature and humidity data that provides us with a comparison of the 2 chosen models, to later show the benefits that come with implementing green roofs in the state of Yucatán.

MATERIALS AND METHODS

The present work consists of an experimental investigation, since it involves designing or replicating a phenomenon whose variables are manipulated under controlled conditions. Just like this project was built to generate knowledge that can be put into practice in order to drive impact in everyday life. This work is divided into two experimental phases: the design and analysis phase of the prototype and the construction and instrumentation phase.

PROTOTYPE DESIGN AND ANALYSIS PHASE

The project was carried out in the computer laboratory and renewable energy workshop of the Instituto Tecnológico Superior Progreso, where the prototype was first designed at a 1:10 scale taking as reference a room with dimensions of 3 x 4 x 4m, in which SolidWorks software to be able to implement the green roof and the sensors for their respective analysis

(Machado et al., 2020). Figure 1shows the views of the prototype with their respective measurements, and the proposed prototype in 3D and 2D.

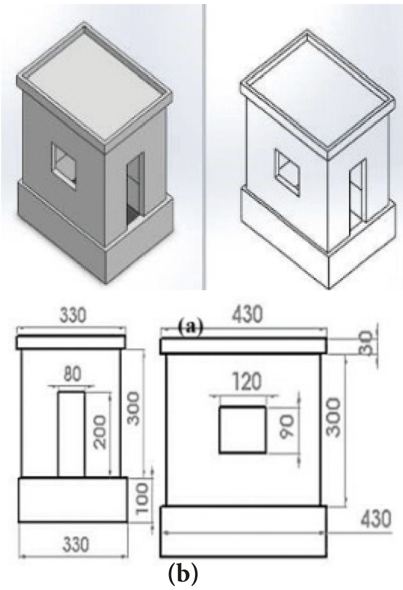
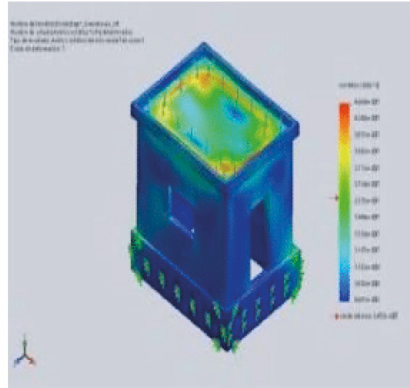
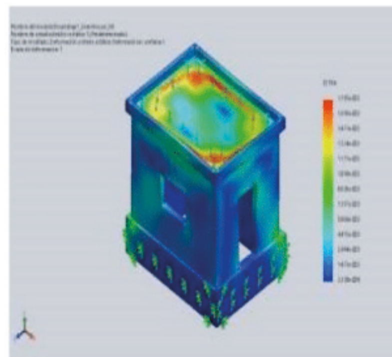


Figure 1. Design made in SolidWorks software: (a) right side and front view in millimeters and (b) prototype design in 3D.

The resistance analysis of the roof was carried out, since Kóhler and Clements in their work Green Roofs, Ecological Functions (2003) mention that, for extensive green roofs, the force that the roof structure must support must be 40 kg/ m2 due to all the sublayers that this type of roof has. For the analysis, the SolidWorks program was used, a force of (40kg/m2) was used, for extensive roofs, the following colors red, yellow-green, light blue and strong blue are marked on the part of the roof, this means that in The red parts would be the affected part or where there could be a deformation, therefore the stress and deformation analysis was carried out to guarantee that the prototype design is capable of resisting the force exerted by implementing a green roof, in Figure 2 shows the analyzes carried out.



(a)



(b)

Figure 2. Analysis performed in SolidWorks: (a) static stress analysis and (b) static unit strain analysis.

CONSTRUCTION AND INSTRUMENTATION PHASE

For the construction of the two prototypes, the mold of the 2 x 4 cm and 3 x 6 cm blocks, which were made with cement and powder, was first designed and printed in order to make the walls of the house. In the same way, the base for the foundation of the house was built with 33 x 44 cm falsework, as shown in figure 3. Chicken wire was installed inside the base, then the mixture of cement and powder was made to fill the plywood base for the foundation, letting it dry for a day, after having the foundation ready, the four castles were made to reinforce the roof of the house by putting four iron rods and wire, to make an armex castle, which was then Place a wooden base on the sides of the castle so that you can then cast it, repeating this process 3 more times, as seen in figure 4.

Figure 3. Mold of cement blocks and powder, for construction of the prototype walls and base for the foundation.

Figure 4. Construction of the four castles to support the roof of the prototype.

Having ready the four castles, we proceeded to make the walls of the prototype of the house, gluing the blocks horizontally, with cement, placing one on top of the other until we had the wall, in the same way we let the walls dry for four hours. On the sides we leave the space where the windows will be, putting a wooden frame so that the space is not occupied. In the front view, the space was left the same with a wooden frame to leave the space where the door would be free, then it was given a fine plaster to improve the aesthetics of the house. Once the walls of the prototype of the house and the foundation were finished, the construction of the roof continued, where first the assembly of the plywood frame was carried out in order to be able to cast the roof. After that, wire rod was placed with the purpose that the roof has greater resistance. Finally, the mixture of powder, gravel and cris cement was prepared to place it on the structure that would form the roof of the prototype. Blocks were also glued around the roof to leave a space to place the layers that the green roof models have. Figure 5 shows the process described above.

Figure 5. Stages of construction of the prototype roof.

When construction was completed, the roof was painted white, the door brown., The house was painted blue and 4 mm thick glass windows were installed. Subsequently, for the implementation of the layers of the extensive green roof prototype, the following layers were incorporated: vegetal layer, substrate layer, anti-root sheets, protective blanket, drainage layer, support filter layer (roof structure). Likewise, for the modular green roof prototype, 8 pots with four layers were implemented: plant layer, substrate, filter layer and support (Beltrán-Melgarejo et al., 2014). Figure 6 shows the layers used for the extensive green roof prototype.

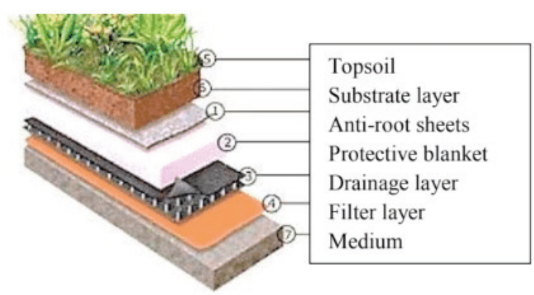


Figure 6. Layers of the extensive green roof (Ramón, 2018).

Ordóñez-López et al. (2012) mentions that "The native species of the wild flora of the State of Yucatán are: Portulaca pilosa, Portulaca rubricaulis, Tradescantia bicolor and Comelina repens." It also mentions "the ornamental species that can be easily obtained in nurseries in Mérida Yucatán are: Briophylum pinnatum, Portulaca grandiflora, Portulaca umbraticola, Aptenia cordifolia, Kalanchoe fedtscenkoi purple, Kalanchoe expensenis bonnieri, Kalanchoe daigremontiana and Kalanchoe thyrsiflora." For this reason, the vegetation used for the modular green roof prototype was: portulaca pilosa (Flor Diez del Día) and Aptenia cordifolia. For the extensive green roof prototype, Miscanthus Sinensis (Chinese grass) was used as a vegetal layer and the substrate was composed of compost and Californian worm humus (Sánchez, 2012). Likewise, for the instrumentation of the prototypes, 2 temperature and humidity sensors (Dht11), Arduino uno, 2 switches, SD reader module, submersible pump, relays, LCD display (20x4), cables, relay, etc. were used. The system (datalogger) was implemented in each of the prototypes, just as an irrigation system was implemented for the extensive roof, the Arduino software was used to carry out the program and save the temperature and humidity variables every 5 minutes in a period of time from nine in the morning to 5 in the afternoon to make the comparison of which type of roof reduces temperature and humidity the most. In the same way, the Fritzing program was used to make the electronic circuit and subsequently assemble it on a board to improve its operation.

RESULTS AND DISCUSSION

The construction of the three prototypes was completed, one with the implementation of the extensive green roof with its sprinkler irrigation system, the modular green roof and the flat concrete roof. The three models were also installed in the environment, locating it in the back of the renewable energy workshop of the TecNM Campus Progreso, in a period of time from 9:00 am to 5:00 pm during the month of May. In the same way, the data obtained was saved in a micro SD memory to later compare the humidity and temperature data between the models as seen in Figure 7. In addition, Figure 8 shows the electrical circuit used for the instrumentation, which allowed the comparative analysis of temperature and humidity in the prototypes under ambient conditions. Figure 9 shows the control box where the data is stored, the irrigation system is controlled, and the variation in temperature and humidity of the proposed models can be seen in real time.

Figure 7. Finished prototypes, located in the renewable energy workshop of the TecNM Campus Progreso.

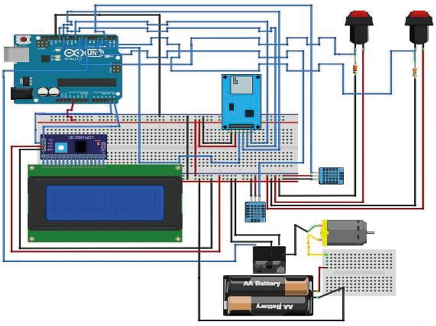


Figure 8. Design of the control system developed in the Fritzing program.

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Figure 9. Electronic circuit control box.

Table 1 shows the statistical data derived from the analysis of every 5 minutes of the three prototypes used for the comparison of temperature and humidity in environmental conditions, to verify if what the literature says that the temperature and humidity of green roofs compared to a conventional roof which, on the contrary, gains greater temperature due to the material it is made of.

Extensive green roof				
Variable	**Average**	**Median**	**Mode**	**Standard deviation**
Moisture (%)	59	61	69	0.0989
Temperature (°C)	26.22	28.30	30.1	3.9075
Flat roof				
Moisture (%)	80	81	81	0.0572
Temperature (°C)	31.92	31.4	34.9	4.9774
Modular green roof				
Moisture (%)	77	79	82	0.0572
Temperature (°C)	29.33	31.4	34.9	4.9774

Table 1. Statistical data of the temperature and humidity of the three prototypes used, using as a comparator the conventional flat roof used by the homes of Progreso Yucatán.

The results obtained from the comparison of both temperature and humidity of the different models are seen in Figures 10 and 11. The extensive green roof prototype on average obtained a temperature of 26.22 °C and 59% humidity, the flat roof of concrete 31.92 °C and 80% humidity and the modular green roof a temperature of 29.33 °C and 77% humidity, this indicates that the temperature of the house where the extensive green roof was implemented is the most efficient as a thermal insulator and It even reduces the humidity inside the enclosure.

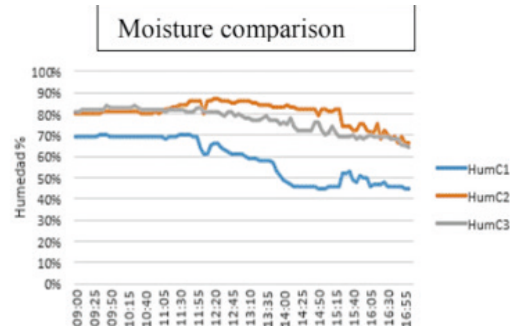

Figura 10. Datos de comparación de la humedad entre los tres tipos de modelos implementados donde: HumC1 es "techo verde extensivo", HumC2 "techo plano" y HumC3 "techo verde modular."

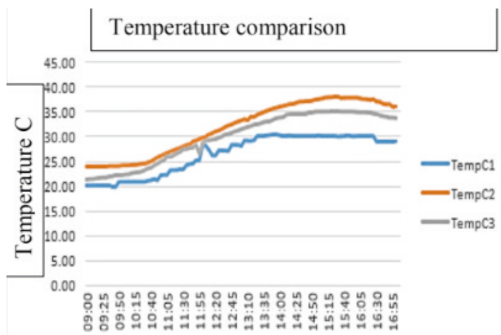

Figure 11. Temperature comparison data in degrees Celsius between the three types of models implemented where: TempC1 is "extensive green roof", TempC2 "flat roof" and TempC3 "modular green roof."

The average temperature and humidity inside the housing prototypes under study, evaluated in the month of May in the municipality of Progreso Yucatán, was significantly higher in the two green roof prototypes than in the one with a flat concrete roof. This is an indicator that the proposed green roof prototypes effectively mitigated the thermal load of the roofs used. The temperature reductions in the extensive and modular green roof prototypes were 5.7 and 2.59 °C respectively with respect to the flat concrete roof prototype and a decrease of 2.48 °C with respect to the average outdoor temperature of Progreso Yucatán. These results are greater than those reported by Rosatto et al. (2016) in their work carried out in Buenos Aires Argentina on thermal regulation using extensive vegetated roofs with an irrigation system where they obtained a temperature reduction of 3.3 °C with respect to the concrete roof. Likewise, Abraham-Beltrán et al. (2014) reported a temperature reduction of 3.4 and 4.5 °C using 4x4x3 m house-room prototypes, where the modular green roof, extensive roof and concrete roof were implemented in a dry-subhumid climate. These results are similar to those obtained in this study, but with a greater temperature decrease in the extensive roof prototype used in this research. Just as the temperature reductions reported were lower than Alpuche et al. (2010) in their work "Thermal analysis of affordable housing in Mexico using green roofs" made a comparison between two 43m2 houses where an extensive roof was implemented and another concrete one, reporting a temperature decrease of 6°C with respect to the concrete house, the study was carried out in Hermosillo Sonora for one year. The National Research Council of Canada conducted a 2-year study comparing the effects on the interior temperature of a building, finding that the use of extensive green roofs on average managed to reduce the temperature by 5°C compared to a roof with clear waterproofing. Likewise, this result is lower than what was reported in our work using the extensive roof with vegetal cover (Chinese grass). Another feature of this research is that the plants used in the vegetation layer for this study resisted the environmental conditions of the port of Progreso Yucatán, therefore, portulaca pilosa (Flor Diez del Día), Aptenia cordifolia and Miscanthus Sinensis are a good option to implement on green roofs. The results obtained from this study suggest that the implementation of green roofs in the port of Progreso and in general in the Yucatan Peninsula, would contribute to the reduction of temperature inside the enclosure and in turn this would allow the generation of small ecosystems of plants, insects, reduce the consumption of air conditioners and reduce the carbon footprint. As a follow-up to this research, it is proposed to carry out a one-year study with the three prototypes to have a more precise study of the temperature and humidity, as well as varying the vegetation that would be used in the layers of the green roofs, seeking to incorporate more endemic plants of the state of Yucatán. Likewise, a sound sensor would be implemented to verify if what the literature says about green roofs that function as acoustic insulation, said study would last one month and carry out a cost-benefit study of the types of green roofs, through of the prototypes made to be able to visualize if the implementation of green roofs in Progreso Yucatán is feasible.

CONCLUSIONS

The design carried out in SolidWorks and the simulation were efficient because the proposed models were able to support the weight of the two types of green roofs.

The extensive and modular green roof prototype achieved a temperature reduction of 17.85 and 10.90% with respect to the flat concrete roof prototype and a reduction of 8.64% with respect to the average outdoor temperature for the month of May in the municipality of Progreso Yucatán. As less heat gains are obtained through green roofs, there is less energy expenditure due to a decrease in the use of air conditioning, which ultimately represents savings that are reflected in the billing of electrical energy and thus contribute to the reduction of greenhouse gases.

Thermal comfort cannot be achieved simply by implementing a green roof under the environmental conditions prevailing in the summer in the Yucatan Peninsula, since the use of mechanical ventilation devices is required to achieve thermal comfort of the occupants, however, the Implementing these allows reducing the need for air conditioners.

In addition to this, in the state of Yucatán, at the level of scientific research and implementation of this technology, it is in an early stage, therefore, a range of possibilities and opportunities opens up for future research regarding the benefits that can be obtained based on in the environmental, social and economic conditions of the state of Yucatán.

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