HS

32

Revista Hábitat Sustentable Vol. 9, N°. 1. ISSN 0719 - 0700 / Págs. 32-45
https://doi.org/10.22320/07190700.2019.09.01.03

CC BY SA

Recibido 12/03/2019
Aceptado 20/06/2019

EL TECHO ESCUDO COMO CAPTADOR PLUVIAL EN CIUDAD JUÁREZ, MÉXICO

THE DOUBLE ROOF AS A RAINWATER COLLECTOR IN CIUDAD JUÁREZ, MEXICO.

SALVADOR TOBIAS RAMIREZ
Sustentante de Maestría en Arquitectura
Docente del programa de arquitectura de la Universidad Autónoma de Ciudad Juárez
Juárez, México
https://orcid.org/0000-0002-7382-3329
stobias12@hotmail.com

JUDITH GABRIELA HERNÁNDEZ PÉREZ
Doctora en Arquitectura
Docente investigadora del programa de Arquitectura de la Universidad Autónoma de Ciudad Juárez
Juárez, México
https://orcid.org/0000-0003-4841-7422
juhernan@uacj.mx

RESUMEN

El problema del abastecimiento de agua dulce existe en diversas partes del mundo, la escasez de dicho recurso es evidente, tal como evidencia el Foro Económico Mundial (WEF por sus siglas en inglés), en su reporte de riesgos globales del año 2018, donde se expresa que en la última década, la crisis del agua ha estado siempre dentro del top cinco de riesgos globales en términos de impacto social. Este problema no es ajeno a México y mucho menos a Ciudad Juárez donde se desarrolló esta investigación.

Visualizando desde la arquitectura, la necesidad de generar edificios sostenibles que puedan mitigar el sobre explotamiento de los mantos freáticos, se desarrolló la idea de utilizar el sistema del techo escudo como captador pluvial, creando así un modelo multifuncional que tuviera una captación pluvial eficiente y un mejor comportamiento térmico.

Para validar dicha primicia se desarrolló una investigación aplicada de corte cuantitativo, donde se elaboraron tres modelos experimentales con la capacidad de medir la cantidad de lluvia cosechada y el comportamiento térmico en el interior de los mismos, con la finalidad de comparar la combinación del techo escudo con la captación pluvial y su comportamiento por separado.

Palabras clave
Aguas pluviales, Techos, Cosecha lluvia, Ventilación

ABSTRACT

The fresh water supply is a problem in various parts of the world. The shortage of this resource is evident, as seen by the World Economic Forum´s Global Risks Report (2018) which states that in the last decade the water crisis has always been one of the top five global risks in terms of social impact. This problem is not foreign to Mexico and much less so to Ciudad Juárez where this research was carried out.

Visualizing this problem from an architectural point of view, there is a need to create sustainable buildings that can mitigate the overexploitation of the water table. Therefore, the idea to use a double roof system as a rainwater collector was developed, and a multifunctional model with efficient rainwater catchment and better thermal behavior was created.

To validate these first steps, an applied quantitative study was carried out in which three experimental models were developed to measure the amount of rainwater harvested and the thermal behavior within the models, in order to compare the combination of the double roof with and without rainwater catchment.

Keywords
rainwater, roofs, rainwater harvesting, ventilation

Revista Hábitat Sustentable Vol. 9, N°. 1. ISSN 0719 - 0700 / Págs. 32-45
https://doi.org/10.22320/07190700.2019.09.01.03

INTRODUCTION

It is estimated that only 2.5% of the total water resource is potable, 70% is frozen in the glaciers, about 30% is underground and only 1% is surface, Clarke and King (2004). This does not mean that the minimum percentage of drinking water is disappearing from the planet, since it is known that water is a renewable resource. However, the situation is much more complex than stating, just like that, it is an unlimited resource. Although the hydrological cycle is responsible for keeping water moving through the hydrosphere, this cycle is reduced in the water tables of many countries due to changes in the climatic patterns of some regions. Such is the case of droughts, a phenomenon that has been prolonged due to global warming, since "climate change causes changes in the frequency, intensity, spatial extent, duration of climatic events and can result in extreme weather conditions in the climate event "(IPCC, 2014: 5). Another factor that affects the availability of water is excessive pumping, either due to waste of the resource or due to high demand due to overpopulation; if it is considered that in 2017 the world population was 7,550 million and a projection of 9,771 million people is considered by 2050 (United Nations Organization, 2017), it is evident that cities will continue to grow increasingly and with this, the demand for water.

Although Mexico is listed as a country with low pressure on the water resource1, it is not in excellent condition in relation to the rational and sustainable use of it. It is enough to point out, in that sense, that of the 653 aquifers the country has, 32 have saline soils or brackish water, 18 have marine salt water intrusion and 105 are overexploited (CONAGUA, 2016). The depletion of aquifers is a difficult problem to solve, considering that in Mexico there is a water footprint of consumption of 1978 m3 of water per inhabitant per year (ibid.). In addition, precipitation in Mexico does not provide for the recharge of aquifers, mainly in the Northern part of the country where the average water pressure level is 63.76%, including the hydrological-administrative regions of the Baja California Peninsula, Northwest and Balsas. It should be remembered that, if the pressure percentage is greater than 40%, it is considered a high pressure degree (CONAGUA, 2014). The infiltration of rainwater by natural means is very complex, as stated in the document Statistics on water in Mexico (CONAGUA, 2013: 16): "It is estimated that 71.6% evapotranspires and returns to the atmosphere, 22.2 % flows through rivers or streams and the remaining 6.2% infiltrates the subsoil naturally and recharges aquifers." Thus, it is clear that the recharge of groundwater is a slow and complicated process where the water supply can be reduced by the abuse of an exhaustive pumping and a minimum recharge of aquifers. To this we must add that, like the entire planet, the country tends to population growth. In 2010, in Mexico there was a population of 114,255,555 citizens and it is estimated that there will be an increase by 2050 of 36,581,962 people, which will reach a total of 150,837,517 (Consejo Nacional de Población, CONAPO, 2010). This translates into a greater number of dependents of the water resource and, consequently, a greater demand and a pressure on water supply in the near future. Meanwhile, Ciudad Juárez, whose population is 1,391,180 inhabitants (Instituo Nacional de Estadística y Geografía, INEGI, 2015) and growth projection for the year 2050, of 1,593,238 people (CONAPO, 2010), is no stranger to these situations, because here also the population density tends to increase and, likewise, the demand for water.

Ciudad Juarez is located in the Chihuahuan Desert, (figure 1), it has a maximum average temperature of 40.9°C in the month of June and a minimum average of -2.6°C in the month of December, according to data from the normal weather (Servicio Meteorológico Nacional, SMN, 2010). Considering that the thermal oscillation can reach up to 14°C, this panorama becomes very characteristic of a desert; indeed, here the rains are scarce and there is an annual average rainfall of 251.69 mm per year. According to the classification of Köpp this locality is identified with the type Bwkx '(e'), which is defined as follows:

Bw = Very dry or desert climate

k = Temperate, with warm summer, average annual temperature between 12º and 18°C; the temperature of the coldest month ranges between -3 and 18°C, and the temperature of the hottest month is greater than 18°C.

x' = Intermediate rain regime between summer and winter.

e' = Very extreme, temperature fluctuation greater than 14°C.

(IMIP, 2016)

Figure 1. Weather map of the state of Chihuahua and its municipalities. Source: INEGI (by its initials in Spanish) (2010)

[1] It should be noted that "the pressure on water resources is quantified by dividing the extraction of the resource between renewable water and availability" (Comisión Nacional del Agua, CONAGUA, 2016: 128).

Figura 2. Mental map of methodology. Source: Tobías (2019: 48).

As Salas mentions, “it is estimated that by 2013 the usable water in the aquifer will be depleted” (2006:11). If more water resources are extracted than what it is infiltrated, sooner or later the removable limit will be reached, which is a latent problem in Ciudad Juarez. Therefore, since 2009, the Conejos Médanos aqueduct has been in operation, which extracts 1000 liters per second from the Bolsón de Mesilla aquifer, the equivalent of 20 percent of the city’s total supply.

The crisis in the supply of fresh water faced by the people of Juarez becomes noticeable with the Conejos-Médanos aqueduct, since it pumps such liquid approximately forty kilometers away to the west of the urban spot, in order to supply the city, promoting unsustainable investment for future generations, due to its high cost, maintenance, energy consumption and its damage to the ecosystem.

In that context, it becomes vital, as Serrano argues, “reusing the rainwater resource offers a double solution, on the one hand, floods are avoided and, on the other, water is saved and provides an increase in the reserves of this vital liquid ”(2014: 26). These actions would contribute to mitigate the depletion of groundwater and improve the use of water resources.

Rain, being the main source of fresh water supply on the planet, in addition to being considered the purest water in its natural state, generates the recharge of aquifers. It supplies rivers and also supplies, through runoff, lakes and lagoons, thus acting as an important part of the hydrological cycle. In this way, this water resource certainly plays a fundamental role for the survival of the living beings of the planet.

METHODOLOGY

This investigation contemplates four parameters to follow for the fulfillment of the objectives of the investigation. The conceptual map in Figure 2 below illustrates the suggested methodology for the experiment.

In order to achieve step 1 of this study, relevant research is conducted on examples of experiments and measurements in terms of rainwater uptake and thermal behavior of the shield roof. In this way, it is sought to generate a base that supports the design of the experiment elaborated in this work and that allows us to reflect on optimal materials, dimensions and characteristics of the models.

For step 2 the design of the models is materialized and, subsequently, an initial test is carried out with the objective of knowing its operation and identifying possible errors that, if found, would be corrected here.

The models were oriented in the North - South axis with the highest part of the roof to the north, and were positioned equidistant in the East - West axis at a separation distance between them of 1.50 m. Walls with the same height, dimension and shape of the models were used to eliminate the shading variable on the surfaces of walls, as exemplified in Figure 3.

El techo escudo como captador pluvial en Ciudad Juárez, México.
Salvados Tobias Ramirez, Judith Gabriela Hernández Pérez
Revista Hábitat Sustentable Vol. 9, N°. 1. ISSN 0719 - 0700 / Págs. 32-45
https://doi.org/10.22320/07190700.2019.09.01.03

In addition, Figure 4 shows the image of the immediate environment, which was duly analyzed to avoid posible errors in the measurement due to the generation of shading in experimental models. Therefore, the experimental models were placed on the roof of a house, giving priority to be free from obstacles.

The witness model, or MT (by its initials in Spanish) (Figure 5), has a slab of reinforced concrete with 12 cm cantilever and asphalt waterproofing coating, and a wooden structure that forms a volumetric space of 1 m3 (because the roof surface measures 1 m2, a unit of measurement used nationally and internationally for the rain harvest) and it is covered with a 2" thick polystyrene plate with a density of 24 kg. Finally, the model has a collection system based on a PVC channel with a half-round 4" diameter, PVC pipe that leads the runoff to rain storage, with a maximum capacity of 45 liters..

The model with a shield roof and a 2% slope or TE2 (Figure 6), is exactly the same as the witness (MT), but with the addition of the galvanized sheet-based shield roof, with a 2% slope covered and only a ventilation access and exit of 5 cm in the North and South face.

Finally, the model with a 27% (15 °) shield and slope roof, or TE15 (Figure 7), is also the same as the witness, with the difference that the galvanized sheet-based heat discharge system has a slope of 10% for the measurement of the month of July and 27% of slope for the month of August. It has covered sides and only a 5 cm ventilation access and outlet in the North and South face.

Figure 3. Example Graph of location of models. Source: Tobías (2019: 49).

Figure 4. Environment image of models. Source: Tobías (2019)

Revista Hábitat Sustentable Vol. 9, N°. 1. ISSN 0719 - 0700 / Págs. 32-45
https://doi.org/10.22320/07190700.2019.09.01.03

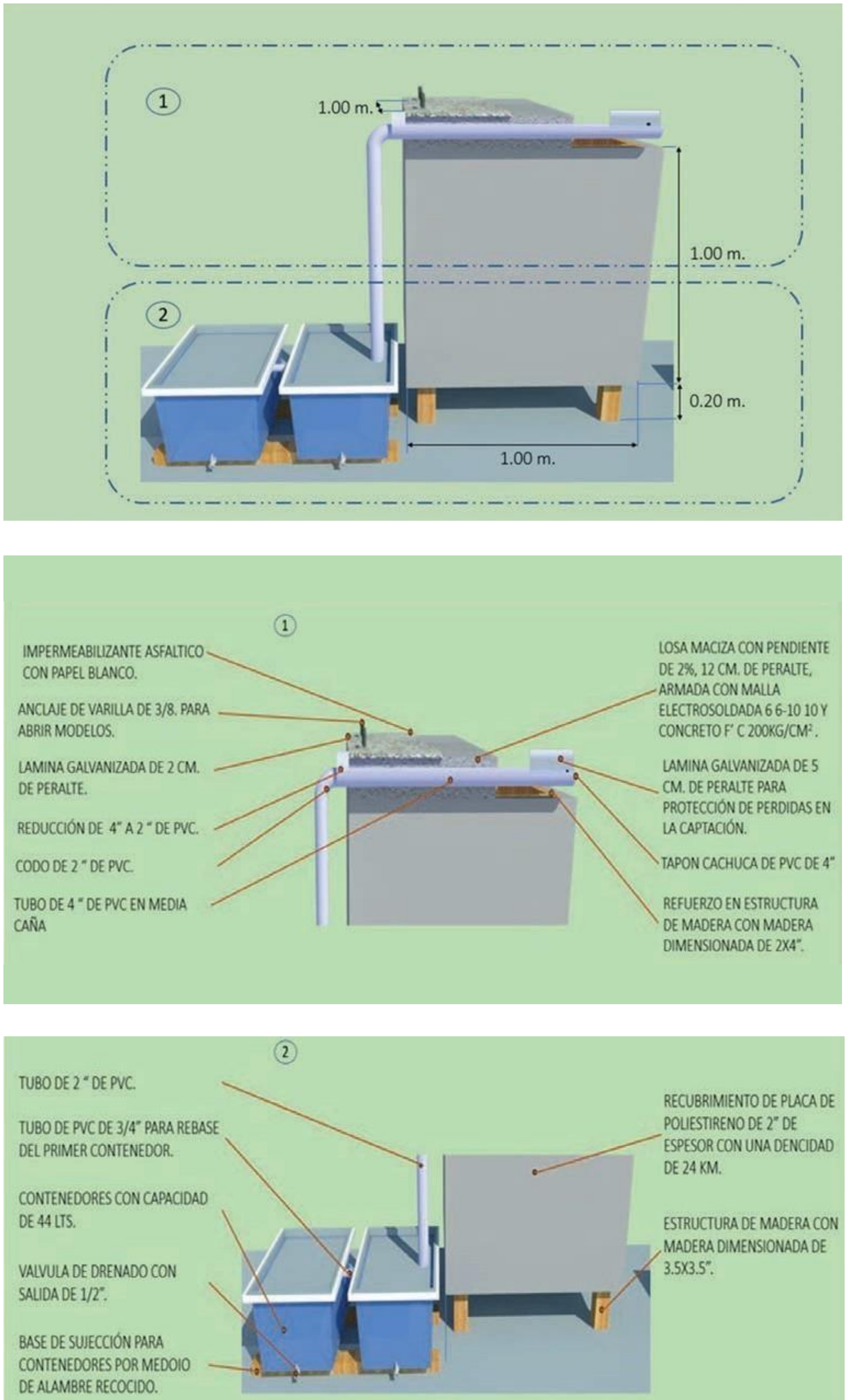

Figure 5. MT Model Graph (West location). Source: Tobías (2019: 51).

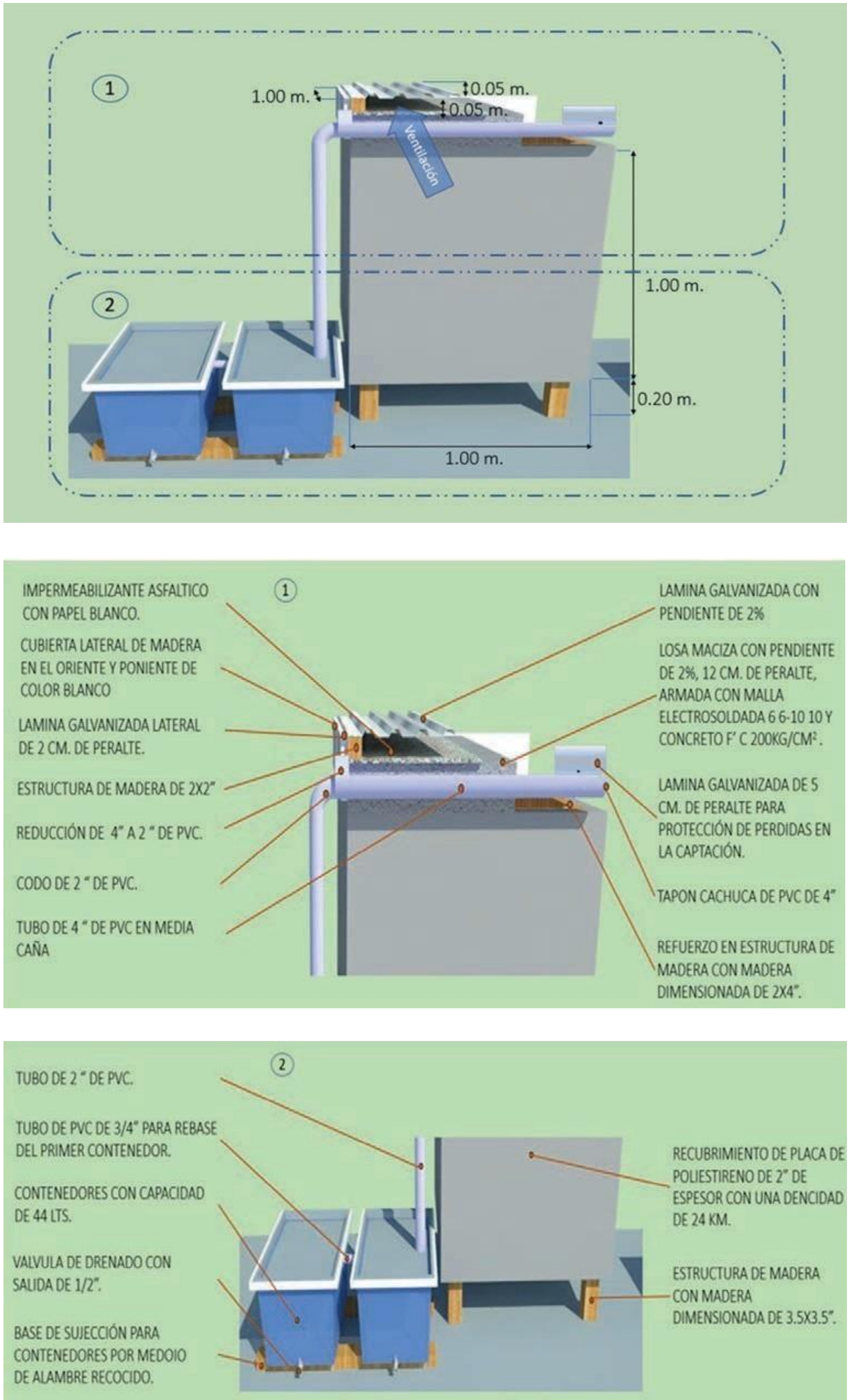

Figure 6. Graph of the TE2 model (Center location). Source: Tobías (2019: 53)

Revista Hábitat Sustentable Vol. 9, N°. 1. ISSN 0719 - 0700 / Págs. 32-45
https://doi.org/10.22320/07190700.2019.09.01.03

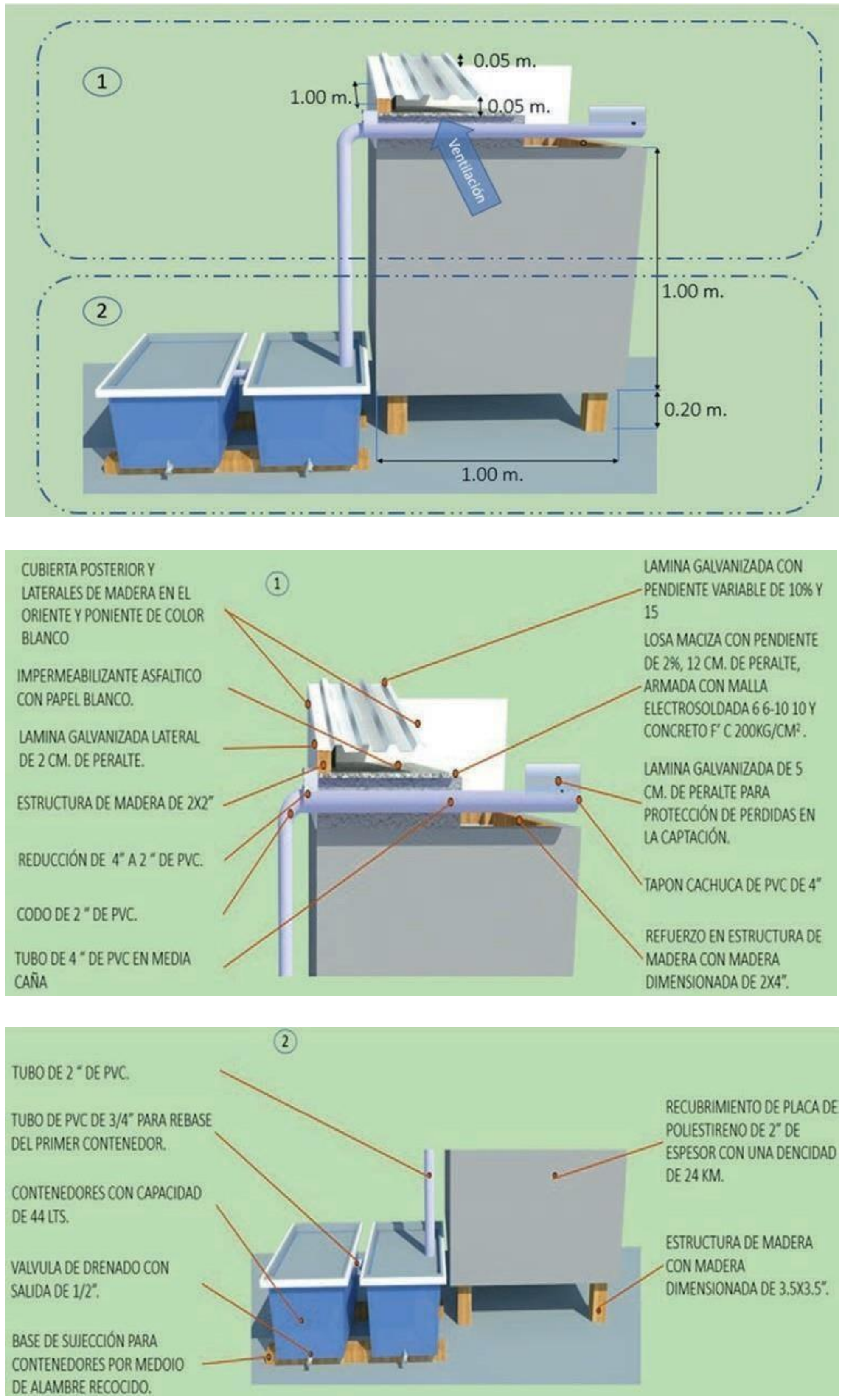

Figure 7. Graph of the TE15 model (East location). Source: Tobías (2019: 55).

Once the models are manufactured, step 3, the measurement, is carried out. For collection, rainwater storage facilities are graduated liter per liter in order to eliminate any variation caused by some unevenness. For temperature measurement, data logger hobos are placed inside the models, together with thermocouples that measure the surface temperature of the roofs. In addition, with the purpose of comparing these data with the outside, a micro meteorological station will be available that will allow to know the temperature, relative humidity, precipitation, wind speed and direction.

Step 4, and final one, proposes to group the information collected and generate a database from which an information matrix can be built that, in turn, serves to compare the thermal behavior and rainwater collection of each of the proposed models.

BACKGROUND OF RAINWATER CAPTURE

In recent years, rainwater harvesting in homes, from architecture and engineering, has been subject to the sole purpose of collecting the hydrological resource without seeking maximum use of the system. For example, Novak, Geisen and Debusk (2014) state that the amount of rain that can be collected is closely related to the material of the impermeable surface where runoff is channeled for storage, so they use the coefficient of measurement as a runoff measurement parameter (Figure 8). Similarly, Worm and Hattum (2006) (Figure 9) use their own values in the most common roofing materials.

Novak's team has similarities in the runoff coefficient in the metal with Lancaster (2009), whose value is 0.95. Unlike previous authors, Burgess mentions that "as a general rule, one can expect to capture an average of 75-80 percent of the actual rainfall" (2012: 22), due to the materials that cover the rain harvesting surface and system losses.

Thanks to these runoff coefficients, formulas have been developed to estimate the amount of rain that can be collected per year. Novak team uses the following formula1:

$$V_{supply} = A \times P \times C \times 0.623 \quad (1)$$

Where:
Vsupply is equal to the amount of rainwater available to capture.
P is equal to the annual rainfall. A is equal to the capture area.
C is equal to the runoff coefficient.
0.623 is the conversion value to gallons (this value is used by the authors since they are from the United States and use the English measurement system).

Meanwhile, Burgess uses the following formula 2:

$$PWC = A \times P \times CE \quad (2)$$

Where:

PWC It is the potential of rainwater harvesting. A is equal to the capture area.

P is equal to the annual rainfall.

CE is equal to the capture efficiency of the 75-80%

Roofing Material	Runoff Coefficient
Metal	0,95
Asphalt	0,90
Concrete	0,90
Membrane Type EPDM, PVC, ctc.	0.95-0.99
Tar and Gravel	0.80-0.85

Figura 8. Table of runoff coefficients by material. Source: Novak, Geisen and Debusk (2014: 89).

Type	Runoff Coefficient
Galvanised iron sheets	>0.9
Tiles (glazed)	0.6-0-9
Aluminium sheets	0.8-0.9
Flat cement roof	0.6-0.7
Organic (e.g. thatched)	0.2

Figura 9. Table of runoff coefficients by material. Source: Worm and Hattum (2006: 31).

This demonstrates the importance of the unit of measure according to each author and their nationality. For the English metric system, the catchment is measured on a surface area per ft^2 and per inch of annual rainfall, unlike the metric system, where it is measured on a surface area per m^2 and per mm of rainfall per year.

Krishna (2005) states that for the potential catchable rain, other factors (and not just the material of the catchable surface) should be considered, such as evaporation of water or water splashing out of the capture area, which can reduce the amount of rain that is stored. In addition to this, one aspect to take into account is that explained in the rainwater collection guide developed by the Environment Agency England (2010) where the efficiency of the filter is measured as a coefficient of 0.90 within the system of channels that, therefore, decreases the volume of the rain harvest. It is interesting to mention, in this line, that for Vasudevan (2002) the quality of the water captured

Revista Hábitat Sustentable Vol. 9, N°. 1. ISSN 0719 - 0700 /Págs. 32-45
https://doi.org/10.22320/07190700.2019.09.01.03

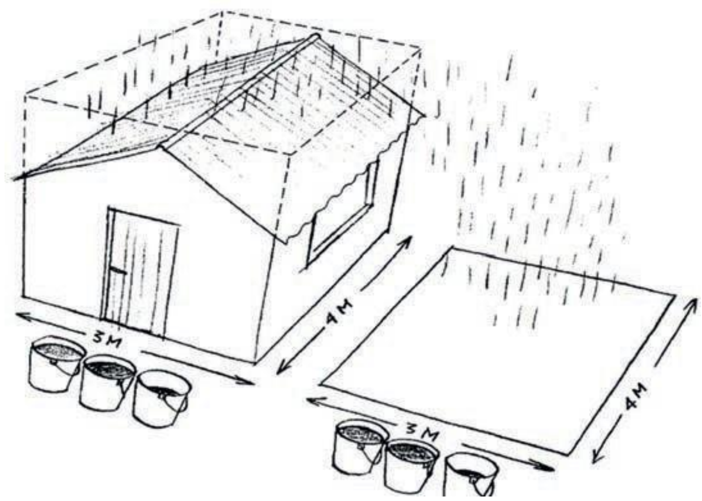

Figure 10. Graph of capture area on roofs with slope. Source: Worm and Hattum (2006: 29).

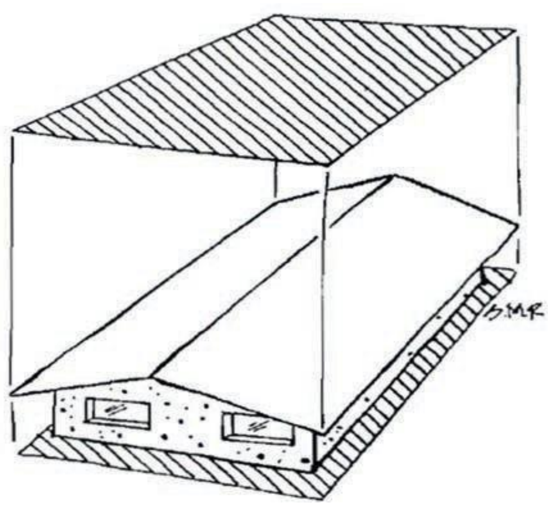

Figure 11. Graph of catchment area on roofs with slope. Source: Lancaster (2009: 50).

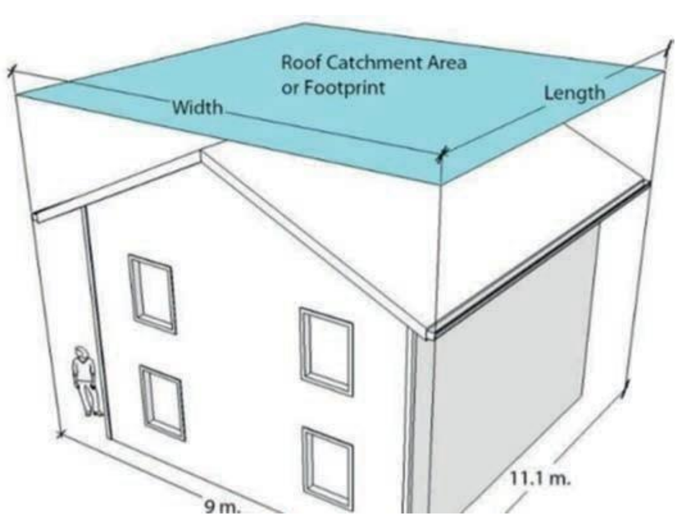

Figure 12. Graph of catchment area on roofs with slope. Source: Burgess (2012: 21).

on a surface is closely related to weather conditions, the surrounding environment and the roofing material.

In Figures 10, 11 and 12 it can be seen how rainwater collection is considered without seeking maximum efficiency. In fact, it is identified how in a roof with little slope or with a more pronounced inclination, this should be measured in the horizontal plane of the catchable area, regardless of whether the roof has a longer length because it has a slope, compared to a flat roof.

BACKGROUND OF THE SHIELD ROOF

With respect to the shield roof or heat discharge system, this has been measured in research through a methodology where it is experimented with a scale model, either in an outdoor site or in a controlled place where solar radiation is simulated, which in turn is complemented by the analytical model, based on calculations necessary to measure its operation. Such is the case of Hernández et al. (2011) (Figure 13) and Chi-ming, Huang and Chiou (2007) (Figure 14), who carry out a comparison of their experimental measurement with authors who have carried out studies based on calculations, such as Morrone, Campo and Manca (1997).

Hora (hrs)	G	Tα	Tt°C	Tc°C	Tp°C	Ta°C
9:00	100	22	20,5	22,1	29,3	23,2
10:00	180	21,8	21,7	21,9	36,5	30,2
11:00	290	23,3	23,9	24	47	35
12:00	380	23,5	24,5	24,6	56,1	43,5
13:00	430	25	25	25,3	58,5	44,2
14:00	410	25,6	25,1	25,8	57,3	46,6
15:00	350	25	25,6	26	53,4	39,7
16:00	240	24	24,2	24,5	44,3	34,2
17:00	180	22,8	23,8	23	38,1	29,2

Hora (hrs)	G	Tα	Tt°C	Tc°C	Tp°C	Ta°C
9:00	100	22	20,5	20,52	27,27	26,11
10:00	180	21,8	21,7	21,963	34,78	27,28
11:00	290	23,3	23,9	23,796	44,37	34,27
12:00	380	23,5	24,5	24,33	51,11	37,41
13:00	430	25	25	24,79	56,23	40,2
14:00	410	25,6	25,1	25,98	55,38	39,47
15:00	350	25	25,6	25,46	50,43	37,69
16:00	240	24	24,2	24,42	41,44	32,98
17:00	180	22,8	23,8	23,76	35,88	29,86

Figure 13. Comparison chart of results of the experimental and analytical model. Source: Hernández (2009: 38).

Revista Hábitat Sustentable Vol. 9, N°. 1. ISSN 0719 - 0700 / Págs. 32-45
https://doi.org/10.22320/07190700.2019.09.01.03

	θ = 30°	θ = 45°	θ = 60°
Present study	6,56	7,5	8,56
Eq. (16) by Morrone et. Al. [8]	6,32	6,66	7,1
Sum of thermal boundary layers	7,25	7,63 3	8,62

Figure 14. Graph of optimal dimensions between authors. Source: Chi-ming (2007: 1754).

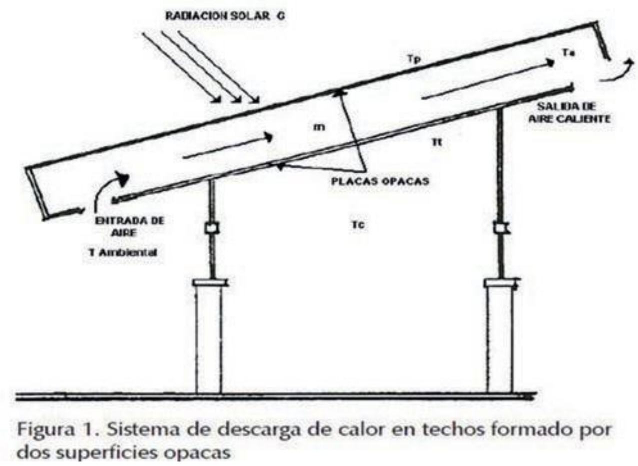

Figure 15. Graph of the experimental model. Source: Hernández (2009: 34).

The model used by Hernández's team presented a 30° slope with a gap between the two 5cm covers and an area of 2.40 m^2 (Figure 15). Instead, the Chi-ming team, which sought maximum system efficiency, made measurements from a model with slopes of 30°, 45° and 60°; a gap between roofs of 5.0 cm, 6.56 cm, 7.5 cm and 8.56 cm, consecutively; an area of 0.80 m^2 and the addition of the radiant barrier that further decreases the entry of heat into the lower roof. They warned that the shield roof is more efficient the higher the speed of the flow of ventilated heat (Figure 16). Meanwhile Morales (1993) measured the shield roof in one of the cubicles of the Solar Energy Laboratory of the I IM-UNAM in Temixco, within the framework of an investigation proposed through the analytical and experimental model. At the time of carrying out the field measurements, he carried out the monitoring of a hollow roof, with a construction system of joist and top slab forging, which had a slope of 9° 35', with North-South orientation; to the South the lowest part of the roof and to the North the highest part of it. This choice (of the construction system) was due to the general objective that was defined, where the heat discharge system should be for warm weather, using the materials and labor available in the local market, which, unlike the other authors aforementioned, generate a dialogue with the environment where the experiment is inserted (Figure 17).

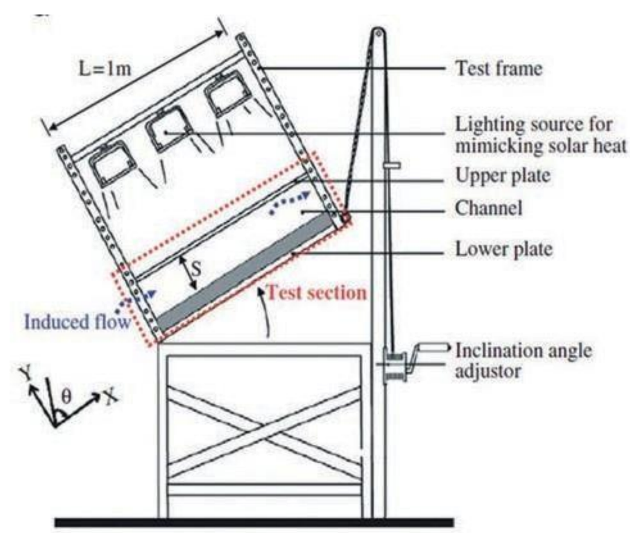

Figure 16. Graph of the experimental model. Source: Chi-ming (2007: 1750).

RESULTS

The experiment carried out in the summer season of 2017 contemplated the months of July, August and September, and measured the rain catchment with 3 experimental models: the so-called “Model TE15”, which has a shield roof with a 10% variable slope and 27%; the “Model TE2”, which has a shield roof with a 2% slope without the possibility of changing such inclination; and, finally, the “MT Model” that has a roof with asphalt waterproofing without a shield roof.

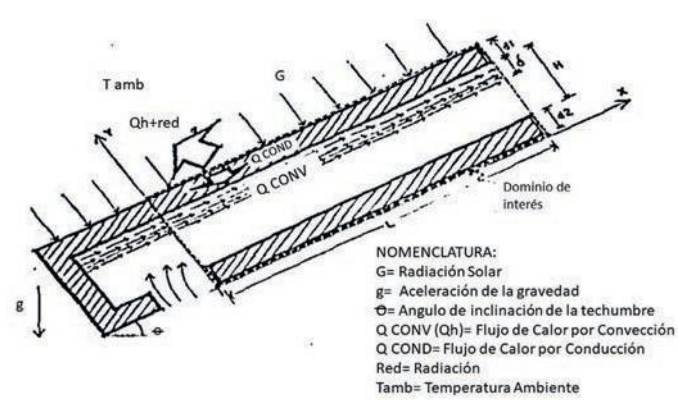

Figure 17. Graph of how the shield roof works. Source: Morales (1993: 20).

RAINWATER CAPTURE IN EXPERIMENTAL MODELS THE MONTH OF AUGUST 2017								
DAY	MODEL TE15 (EAST) 15° - 10 %	MODEL TE2 (CENTER) 2%	MODEL MT (WEST) 2%	PLUVIOMETER	HIGHER CAPACITY		INTERMEDIATE CAPACITY	LOWER CAPACITY
1	5.90 LTS.	4.43 LTS.	4.42 LTS.	6.40 LTS.	M. TE15		M. TE2	M. MT
5	1.31 LTS.	1.17 LTS.	0.69 LTS.	1.00 LTS.	M. TE15		M. TE2	M. MT
7	0.47 LTS	0.98 LTS.	0.25 LTS.	0.40 LTS.	M. TE15		M. TE2	M. MT
11	1.37 LTS.	1.47 LTS.	1.07 LTS.	1.00 LTS.	M. TE2		M. TE15	M. MT
12	2.00 LTS.	2.00 LTS.	0.71 LTS.	1.20 LTS.	TE15	TE2	-	M. MT
14	3.60 LTS.	2.71 LTS.	3 .00 LTS.	1.20 LTS.	M. TE15		M. MT	M. TE2
15	24.25 LTS.	17.65 LTS.	19.67 LTS.	29.00 LTS.	M. TE15		M. MT	M. TE2
20	8.35 LTS.	6.20 LTS.	7.00 LTS.	5.80 LTS.	M. TE15		M. MT	M. TE2
21	5.45 LTS.	3.67 LTS.	4.00 LTS.	4.40 LTS.	M. TE15		M. MT	M. TE2
24	2.40 LTS.	2.27 LTS.	1.96 LTS.	1.60 LTS.	M. TE15		M. TE2	M. MT

Figure 18. Chart of the rainwater catchment for the month of August. Source: Tobías (2019: 64).

In Figures 18 and 19 it can be seen that, in August, the TE15 model caught on average 21.94% more rain than the TE2 model and 31.03% more than the MT. The day with the highest rainfall was August 15, when 29 mm were recorded, of which the TE15 model captured 24.25 liters; the TE2, 17.65 liters and the MT model, 19.67. Thus, it turns out that the TE15 model captured 4.58 liters more than the MT, that is, 18.88% more.

Temperature measurements made in the summer time of 2017 also included the months of J uly, August and September, recording the outside temperature, the indoor temperature of the models, the indoor and outdoor relative humidity, as well as the surface temperatures of the galvanized sheet covers and asphalt waterproofing covers. On July 26, it was found that: in relation to the interior temperature of the three models, the MT model had a temperature increase greater than 10 degrees Celsius in the critical hours of the afternoon, compared to the TE15 model, as shown in Figure 20.

It is also observed in the graph how, at dawn, the temperature drops in all three models in a similar way, even the MT model has an interior temperature lower than the models with the shield roof at 7:00 am, but at 8:00 am the temperature starts to rise and the MT model rises out of proportion with respect to the TE15 and TE2 models.

With respect to the relative humidity of July 26 of the 2017 period, it can be seen (Figure 21) how this behaves in a constant way within the experimental models, without abrupt variations, being the TE15 model the one that presents the lowest relative humidity, on average 79.14%, and the MT model, the highest relative humidity, 88.30%

Revista Hábitat Sustentable Vol. 9, N°. 1. ISSN 0719 - 0700 / Págs. 32-45
https://doi.org/10.22320/07190700.2019.09.01.03

CONCLUSIONS

The situation in Ciudad Juárez shows an uninviting panorama for the town in relation to the supply of fresh water and the depletion of the Bolsón del Hueco aquifer. The limited water resource available, either superficially in the Rio Grande, which is not used for city consumption, or underground, in the Bolsón del Hueco and Conejos-Médanos aquifers, is a clear alarm indicator for the region. Geographically, this is inserted in the latitude zone of 31 degrees north, which is world renowned for the large deserts that houses, in this particular case, the Chihuahuan Desert, especially characterized by low rainfall and extreme temperatures recorded.

Given this panorama, it is of utmost importance the use of rainwater for the Juarenses and therefore also to devise a system that can improve the conditions of a roof in terms of collection and thermal behavior, either in a building constructed as in a building project stage. In addition to the aforementioned, the multifunctionality that manages to be generated with the shield roof, which goes beyond just using an optimal material to capture rain on a roof, undoubtedly, can improve the conditions of typical roofs with asphalt waterproofing in Ciudad Juárez.

From this perspective, the exposed work showed that the rainwater collection system combined with the shield roof achieves greater rain collection, in addition to a better thermal behavior, compared to the rain harvesting system without the shield roof. Indeed, the results of this study show that the control model (MT), which did not have the shield roof, was the one that presented a lower rainfall and a lower thermal efficiency. It is important to note that the TE2 model achieved a better efficiency in terms of thermal behavior than the MT, however, the efficiency of this behavior is lower when compared to the TE15 model.

With respect to the difference in rainfall collected between the experimental models MT and TE15 in rainfall events, it is concluded that this is due mainly to two factors. First, the use of an optimal material for a higher runoff coefficient and, second, the degrees of roof inclination determined for this case study.

Based on the research proposed, it has been possible to verify the feasibility of the model developed, which seeks to improve rainwater collection and, at the same time, improve the thermal characteristics of the building. Consequently, this proposal aims to develop a system that promotes both the optimization of the comfort characteristics of an architectural space, and the reduction of water waste, with the ultimate goal of mitigating the negative effects on the environment.

Figure 19. Graph of the rainwater catchment of the month of August. Source: Tobías (2019: 65).

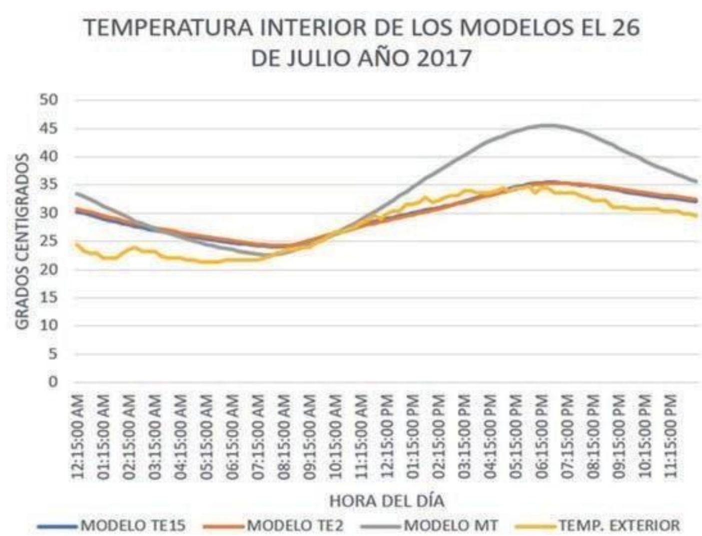

Figure 20. Graph of indoor temperature of the models on July 26, 2017. Source: Tobías (2019: 67).

Figure 21. Graph of relative humidity inside the models on July 26, 2017. Source: Tobías (2019: 68).

Revista Hábitat Sustentable Vol. 9, N°. 1. ISSN 0719 - 0700 / Págs. 32-45
https://doi.org/10.22320/07190700.2019.09.01.03

BIBLIOGRAPHIC REFERENCES

Arnold, J., Chester L. y Gibbons J. (1996). Impervious Surface Coverage. The Emergence of a Key Environmental Indicator. Journal of the American planning association. 62 (2),(1996). 243-258.

Burgess, B. (2012) Rainwater Harvesting BEST PRACTICES GUIDEBOOK. British Columbia: REGIONAL DISTRICT OF NANAIMO.

CANAPO. (2010) Proyecciones de la Población 2010-2050. Recuperado de http://www.conapo.gob.mx/ES/CONAPO/PROYECCIONES

Chi-ming, J. y Huang, J. 2007. Optimal spacing for double-skin roofs. Building and Environment, 43 (2008), 1749-1754.

Clarke, R. y King J. (2004). The Water Atlas. Los Angeles: University of Califronia Press.

CONAGUA. (2013). Estadísticas del agua en México edición 2013. México D.F.: CONAGUA.

CONAGUA. (2014). Estadísticas del agua en México edición 2014. México D.F.: CONAGUA.

CONAGUA. (2016). Estadísticas del agua en México edición 2016. México D.F.: CONAGUA.

Environment Agency England. (2010). Harvesting rainwater for domestic uses: an information guide. Almondsbury: Environment Agency.

Hernández, V.,Contreras, C., Gonzáles, G,. Morillón D. y FernándezJ. (2011). Modelo analítico que describe el comportamiento térmico de un sistema de descarga de calor en techos. Ingeniería Investigación y Tecnología, 33 (1), 33-42.

IMIP.(2016) Plan de Desarrollo Urbano sostenible de Cd. Juárez, Chihuahua. Cd. Juárez: IMIP.

INEGI. (2010). Clima Chihuahua. Recuperado de http://cuentame.inegi.org.mx/monografias/informacion/chih/territorio/clima.aspx?tema=me&e=08

INEGI. (2015). Censo de población 2015. Recuperado de http://cuentame.inegi.org.mx/monografias/informacion/chih/territorio/div_municipal.aspx?tema=me&e=08

IPCC. (2012) Special Report of the Intergovernmental Panel on Climate Change. New York: IPCC.

Krishna, J. (2005). The Texas Manual on Rainwater Harvesting, Austin Texas.: Texas Water Development Board

Lancaster, B. (2009). Rainwater Harvesting for Drylands and Beyond Volume 1. Tucson: Rainsource Press.

Morrone B, CAMPO A, y Manca O. (1997). Optimum plate separation in vertical parallel-plate channels for natural convective flows: incorporation of larger spaces at the channel extremes. International Journal of Heat and Mass Transfer 40 (5): 993–1000.

Morales, J. (1993). Estudio de Techos de Edificios Construidos para Operar en forma Pasiva. Tesis publicada. Ciudad de México: UNAM.

Novak A, DeBusk, K. y VanGiesen E. (2014). Designing Rainwater Harvesting systems: integrating Rainwater into Building systems. New Jersey: John Wiley & Sons.

Organización de las Naciones Unidas - ONU. (2017). La población mundial aumentará en 1.000 millones para 2030. Recuperado de https://www.un.org/development/desa/es/news/population/world-population-prospects-2017.html

Salas J (2006). Problemática del Agua y Crecimiento Urbano en Ciudad Juárez, Chihuahua. Cd. Juárez: UACJ.

Serrano, S. (2014). Aprovechar el agua de lluvia. Doble solución. Impluvium. Recuperado de http://www.agua.unam.mx/assets/pdfs/impluvium/numero01.pdf

SMN. (2010) Información Climática por Estado. Recuperado de https://smn.cna.gob.mx/es/informacion-climatologica-por-estado?estado=chih

Tobias, S. (2019). Comparativa entre el sistema tradicional de captación pluvial y la combinación de la cosecha de lluvia con el techo escudo. caso de estudio: Ciudad Juárez. Tesis publicada. Ciudad Juárez: UACJ.

Vasudevan, L. (2002) A study of Biological Contaminants in Rainwarer Collected from Rooftops in Bryan and College Station. Texas: Texas A&M university.

WEF. (2018). The Global Risks Report 2018 13th edition. Switzerland, Geneva: World Economic Forum.

Worm, J. y Hattum, T. (2006). Rainwater harvesting for domestic use. Netherlands: Digigrafi.