286: Assessment of Bioclimatic Applications in Buildings and the Consequent Reduction in Water Consumption when Using Evaporative Cooling Systems

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Abstract

Chihuahua is found in the north of Mexico. It has an extreme hot dry climate. The hot season lasts for approximately 5 months. The high temperatures and common inadequate thermal envelope of buildings, obliges the use evaporative cooling to obtain comfort. The high water consumption that evaporative cooling requires (6 to 452 l/h) has been surprisingly ignored by the Mexican authorities. During the summer, a water saving program is implemented and the water supply is rationed of 4 to 6 hours per day, which obliges the use of tanks and cisterns. However, an extremely high percentage of stored water is used for evaporative cooling and not for other basic human needs. The experiment consisted of applying different bioclimatic criteria in five houses with identical characteristics: insulating the evaporative cooling equipment, installing window shading devices, applying additional insulation to the roof, increasing exterior wall mass and ventilating the house at night, where a evaporative cooling equipment were employed. The results demonstrated that the evaporative cooling equipment consume 50% more water than estimated by the suppliers and that the bioclimatic strategies employed indicate a maximum water saving of 32.1% in these conditions, and an average saving of 20.4 -21.93%.

Keywords: water savings, evaporative cooling, bioclimatic strategies

1. Introduction

Chihuahua City Mexico is located at the latitude of 28ºN, longitude of 106ºW and at an altitude of 1423m above sea level. Its climate is considered to be extreme warm and dry, with high temperatures in summer and scarce rainfall with recurrent periods of drought.

Table 1, Meteorological Data of Chihuahua (C.N.A., 2003).

Bioclimatic Parameters	Average
Average Temperature	24.7° C
Maximum Temperature	32.0° C
Maximum Extreme Temperature	41.3° C
Minimum Temperature	17.5° C
Minimum Extreme Temperature	4.5° C
Temperature Oscillation	14.5° C
Average Relative Humidity	52.80%
Minimum Relative Humidity.	16.30%
Maximum Relative Humidity	89.10%
Annual Rainfall	313.1 mm
Wind Direction	Northeast
Wind velocity	2.6m/s

The hot summer period lasts for 5 months with an average extreme maximum temperature of 32ºC, a diurnal oscillation temperature of 14.5ºC, an average minimum relative humidity of 14%. The annual rainfall is 313.1mm. (Refer to table 1)

The high summer temperatures and common inadequate thermal design of buildings obliges the occupants to recur to the use cooling equipment such as evaporative air-conditioning to obtain comfort.

Evaporative cooling systems require considerable electric energy and a significant constant clean water supply. The high energy consumption has caused socioeconomic tension which has captured the attention of Mexican authorities. Surprisingly, the high water consumption seems to have been ignored

2. The water consumption of an evaporative cooling system in an arid zone.

The Company IMPCO estimates that evaporative cooling systems consume from 6 to 452 liters per hour according to its capacity of 3000fcm to 42000fcm respectively. On the other hand the Partnership for Research Housing when considering cities like Albuquerque, Cheyenne and Phoenix, in the south of the United States, claims that the average water consumption is 12.6 l/h, whereas in Arizona it was found that evaporative cooling systems required 16.67l/h (Karpiscak, 1994).

In the City of Juarez, Chihuahua, a study analyzing 4000fcm found that the average water consumption was 72.71 l/h (Martinez, 2007). These results are similar to those published by

IMPCO industry (Manual IMPCO, 1999). In Chihuahua, the most commonly installed systems consume 13.2 to 39.7 liters per hour when operated.
It is estimated that in the Mexican Republic, more than a million and a half houses have evaporative cooling systems with a range of capacities. The majority are found in medium to low social class housing.
The problem with the high water consumption is that not only is the available water supply to the City of Chihuahua is dwindling at an alarming rate but also the authorities are implementing a water rationing program during the summer period of 4 to 6 hours per day of available water to each suburb. For this reason, buildings require tanks and cisterns. It appears that an extremely high proportion of stored water is used for evaporative cooling. This affects families in a very direct way and generates an environmental and social conflict (Herrera, 2006).
If the present design of housing incorporated bioclimatic strategies, the water consumption required by evaporative cooling would be reduced significantly. If passive thermal design strategies are implemented creating a totally different form of housing, the use of evaporative cooling could become the exception and not the norm in cities like Chihuahua. At present, the deficient thermal performances of the building envelop means that the domestic water wastage is extremely significant.

2.1 Objectives.
The present investigation proposed the following objectives:

- Evaluate the relationship between the water consumption of a direct evaporative cooling system and the thermal performance of the building envelop.
- Determine the quantity of water that can be saved by implementing different bioclimatic strategies.
- Analyze which bioclimatic strategies are more efficient in reducing the need of evaporative cooling to obtain comfort with the aim of reducing the excessive water consumption.
- Establish parameters that could be used to measure the thermal performance of the building envelop in relation with the variable water consumption used in evaporative cooling equipment.

3. Method.
It was assumed that a full-scale-modeling technique was required in a real environment. Therefore, during the summer months of June to August 2007, five unoccupied standard houses built by the Chihuahua Institute of Housing were selected and studied with the previously stated objectives. These identical houses were selected because they provided controlled conditions for testing the energy efficiency and water consumption of the evaporative cooling system with different bioclimatic strategies. House 1 (C1) was the control house and the other four houses (C2, C3, C4, and C5) were altered slightly by each having a different bioclimatic strategy (more details are given later on).
Another reason for selecting these houses is that they are constructed massively though out Mexico. For example during the last three years the government claims to have built over 170,000 houses of this type in the State of Chihuahua. This raises the questions: What is the social and environmental impact of this type of housing? How many more houses requiring evaporative cooling are likely to be built in the future?

Figure 1.Pphotographs of the houses studied during the investigation.

The selected houses had identical building construction such as hollow concrete block walls (12x20x40cm block size); a 12cm thick concrete slab roof lightened with Styrofoam blocks, concrete slab floor, and aluminum window frames with single glazing of 4cm thick. The exterior door was Multypanel (a door with a timber frame with sheet metal surfaces and Styrofoam core)
Each house has 23.75m^2 in constructed area, was situated in adjacent sites with a frontage of 7m and a depth of 17.15m. Each rectangular house was situated 1m and 2.87m from the side boundaries, 5.5m from the street and 4.06m from the back boundary. The orientation of the house is defined by the direction of the principal façade facing the street. In order to obtain the same environmental conditions, the five houses were chosen to be situated in the middle of the same block.

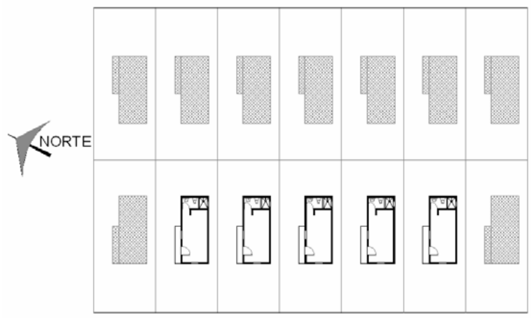

Figure 2.Location of the houses.

In each house, one of the most popular evaporative cooling equipments in residential buildings in Chihuahua, commonly called "swamp coolers", was installed. Each one of them has a capacity of 3,800 cfm of airflow. In hot desert climates, as this of Chihuahua, three to four cfm per square foot is suitable, so this equipment is appropriate to correctly insulated houses, if they occupy an area of 950 to 1265 ft^2 (88 to 120 m^2). Improperly sized equipments will waste water and energy and may cause excess humidity or other discomfort problems.

The area of studied houses is much lower than the recommended areas for this size of equipment, but its constructive system does not include enough insulation. As the temperature conditions in the summer are 40 C (104 F) dry bulb, and 19 C (66 F) wet bulb, thermal load calculations demand about 30,000 Btu/hr of cooling power (8.78 Kw). According to the principle of convection heat transfer, 30,000 Btu/hr are equivalent to 4,000 cfm of evaporative cooling. So, in a house of 60 m2 (645 ft^2), and 2.7m (9 ft) high, it means a change of air every 1.42 minutes, or 42 air changes per hour. This amount of air flow is normal if evaporative cooling is used.

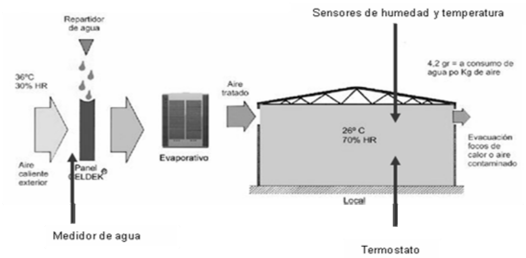

Figure 3.The internal temperature and relative humidity sensors and evaporative cooling automated switching on/off. (www.metmann.com, 2008)

In each house, the following measurement sensors and equipment were installed: a meteorological sensor class C that uses a volumetric oscillating piston, evaporative cooling with an automatic thermostatically switched on/off and a data logger Hobo U12 that registers the internal temperature and relative humidity, On the exterior of the house was placed a data logger Hobo H32 to register the external temperature and external relative humidity.

Figure 4.Water consumption meter.

At the beginning of the investigation the evaporative cooling and data systems were calibrated. The calibration showed that this type of evaporative cooling uses an average of 15 l/hr. As stated previously, House 1 (C1) was left as a control (ST) and the other houses were altered slightly using different bioclimatic strategies. The changes were as follows:

House 2 (C2) had its evaporative cooling system insulated with fiberglass and reflective foil. (Figure 5)

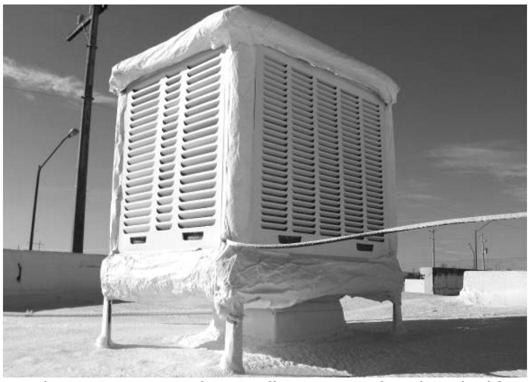

Figure 5 Evaporative cooling system insulated with fiberglass and reflective foil.

House 3 (C3) had external horizontal and vertical solar protection devices added to its windows (Figure 6)

Figure 6.Solar protection device added to the windows.

House 4 (C4) had a covering of 1" thick polisocianurate mat added externally to the flat roof without applying reflective paint (fig.7)

Figure 7.Additional insulation applied to the roof.

House 5 (C5) had its wall mass incremented by filling the internal cavities of the blocks with earth. (Fig. 8)

Figure 8.Concrete blocks filled with earth

The experiment was organized with four test periods with duration between 2 to 5 days for each test. During the first test (2nd – 6th July 2008) the thermal performance and respective water consumption was measured as originally planned. During the second test (9th – 10th July 2007) House 2 had solar protection applied to the already existing insulated evaporative cooling system. During the third test (11th – 15th July 2007) the windows were opened at night and closed during the day to see how effective nocturnal convection cooling is. During the fourth and last test (19th - 21st July 2007) the windows were kept closed in all houses except house 5 with increased thermal wall mass. House five maintained its nocturnal convection cooling. (Refer to table 2)

The consumption of water data was collected hourly by direct meter reading and the temperature and humidity was also taken hourly with data loggers.

Table 2.Field Tests of bioclimatic strategies applied during the investigation.

Test / House	2-6 Jul.	9-10 Jul.	11-15 Jul.	19-21 Jul.
	1	**2**	**3**	**4**
C1	ST	ST	VN	ST
C2	AE	AE+PC	AE+PC+VN	AE+PC
C3	PSV	PSV	PSV+VN	PSV
C4	AC	AC	AC+VN	AC
C5	MT	MT	MT+VN	MT+VN

ST Without treatment
AE Evaporative cooling system insulated
PSV External shading device applied to windows
AC Additional roof insulation
MT Increased external wall mass
PC Shading device applied to evaporative cooling equipment.
VN Night ventilation.

The following formula was applied to determine the efficiency of the strategies used. (Refer to fig. 9)

1. The work area per hour of the cooling system was determined with the following equation:

$$A_w = \frac{(To_1 - Ti_1) + (To_2 - Ti_2)}{2}$$

A_w= Work Area in °C / hr
To_1= Outside Air Temperature.
Ti_1= Initial Internal Air temperature.
To_2= Final External Air Temperature.
Ti_2= Final Interior Air Temperature.

2. The Water consumption in the given work area was determined with the following formula

$$A_c = \frac{C_1 + C_2}{2}$$

A_c= Area of water consumption liters/hour
C_1 = Initial Water Consumption
C_2 = Final Water Consumption.

3. The Efficiency per hour of the strategy was determined by dividing the area of water consumption by the work area.

$$E_{hr} = \frac{A_c}{A_w}$$

E_{hr} = Efficiency of the Strategy in liters/hour

4. The work efficiency in liters/ºC during the investigation period was determined by averaging the hourly work efficiencies.

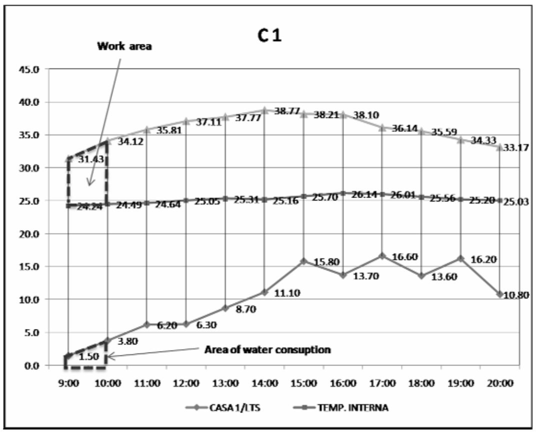

Figure 9.Comparison of the efficiency of the different bioclimatic strategies.

4. Results

4.1 Test 1

The results of test 1 show that the strategy of applying window shading devices to house 3 proved to be the most efficient (Refer to table 3). This situation is not surprising due to three main factors:

- The main windows faced South West allowing deep penetration of solar radiation into the interior. The shading devices eliminated the direct component of the solar radiation.

Table 3. Test 1 Efficiencies of the applied bioclimatic strategies.

Strategy	Average cost work L/ ºC	Water Consumption %	Water Saving %
C1-ST	1.03	100.0%	0.0%
C2-AE	0.81	78.3%	21.7%
C3-PSV	0.76	73.7%	26.3%
C4-AC	0.79	77.0%	23.0%
C5-MT	0.87	84.5%	15.5%
Average	0.81	78.4%	21.6%

ST Without treatment
AE Insulating the evaporative cooling system
PSV External window shading devices
AC Increased roof insulation
MT Increased wall mass

- When considering the external surfaces of the building envelop, the walls have a greater area than the roof, therefore the devices that help shade the walls become more significant.
- The original construction materials of the roof had some insulating materials such as Styrofoam panels therefore the reduced solar radiation on the walls reduced a greater amount of conducted and radiated heat all of which made house 3 more efficient.

House 5 with earth filled concrete blocks had the worst thermal behavior and efficiency because the walls were too thin to be effective heat dampener (12cm). The decreased insulation and increased mass meant that the heat conducted more readily through the walls and accumulated inside the house. When there was no nocturnal ventilation, there was no effective way of dissipating the accumulated heat (Givoni, 1977).

4.2 Test 2

Once again House 3 with window shading was the most efficient and House 5 with increased wall mass the least efficient. When solar protection was added to the cooling system as in House 2, its efficiency not only didn't improve, it worsened as can be seen in Table 4.

Table 4. Test 2 Efficiencies of the applied bioclimatic strategies.

Strategy	Average cost work L/ ºC	Water Consumption %	Water Saving %
C1-ST	0.88	100.0%	0.0%
C2-AE+PC	0.71	80.0%	20.0%
C3-PSV	0.60	67.9%	32.1%
C4-AC	0.71	80.0%	20.0%
C5-MT	0.80	90.4%	9.6%
Average	0.71	79.6%	20.4%

ST Without treatment
AE Insulated Evaporative Cooling System
PSV Window Shading Devices
AC Increased Insulation applied to the roof
MT Increased wall mass
PC Shading device applied to the insulated evaporative cooling system

4.3 Test 3

During this test all the houses including the control (House 1) were ventilated at night by opening the windows and closing them during the day. In this case, the results show that House 4 with additional thermal insulation applied to the roof was more effective.

Although House 5 with increased wall mass still presented the worst efficiency, its own performance improved in respect to the previous test when night ventilation had been denied. (Refer to Table 5)

Table 5. Test 3 Efficiencies of the applied bioclimatic strategies.

Strategy	Average cost work L / ºC	Water Consumption %	Water Saving %
C1-ST+VN	0.78	100.0%	0.0%
C2-AE+PC+VN	0.64	82.5%	17.5%
C4-AC+VN	0.56	71.5%	28.5%
C5-MT+VN	0.64	82.6%	17.4%
Average	0.62	79.5%	20.4%

ST Without treatment
AE Insulated Evaporative Cooling System
PSV Window Shading Devices
AC Increased Insulation applied to the roof
MT Increased wall mass
PC Shading device applied to the insulated evaporative cooling system
VN Night ventilation

4.4 Test 4

As a consequence of the third test, the fourth test kept House 5 (with increased wall mass) with night ventilation to compare its efficiency in regard to the other houses without night ventilation. (Refer to Table 6)

Table 6. Test 4 Efficiencies of the applied bioclimatic strategies.

Strategy	Average cost work L / ºC	Water Consumption %	Water Saving %
C1-ST	0.68	100.0%	0.0%
C2B-AE+PC	0.51	75.2%	24.8%
C3-PSV	0.48	70.7%	29.3%
C4-AC	0.53	77.8%	22.2%
C5B-MT+VN	0.60	88.6%	11.4%
Average	0.53	78.1%	21.9%

ST Without treatment
AE Insulated Evaporative Cooling System
PSV Window Shading Devices
AC Increased Insulation applied to the roof
MT Increased wall mass
PC Shading device applied to the insulated evaporative cooling system
VN Night ventilation

Once again House 3 with window solar devices was the most efficient and House 4 with additional roof insulation decreased its efficiency (Table 6)

Although House 5 had night ventilation its efficiency was once again the lowest of the group. Its own efficiency improved in respect to its own performance when it had no night ventilation.

4. Conclusion

The use of direct evaporative cooling systems implies undeniably high water consumption. According to the results obtained during this experiment, the results obtained during the calibration phase showed that the evaporative cooling system employed used 15 liters/hour, 50% more water than the suppliers indicate for an arid zone which is 8 to 10 liters per hour (IMPCO, 2000). If one considers other factors such as potential leaks, other imperfections, incorrect user use and increased external wind velocity, the water consumption could increase by at least 20%.

Because of the increased water use in situ and the saving of water obtained by insulating the cooling system it becomes apparent that this kind of devices need standards and regulations for their manufacture and functioning. Not only the energy consumption needs to be standardized but also the water consumption and the thermal interchange with the exterior needs urgent attention.

Improving the thermal properties of the building envelop significantly decreased the water consumption when using evaporative cooling. Architects and planning authorities need to address these issues.

Window shading proved to be the most efficient bioclimatic strategy because of the adverse orientation of the houses. However, night convection cooling turned out to be a fundamental strategy in an extreme climate. This indicates that the uses need to be educated in how to use their homes more efficiently. The educational process could begin by the show homes and attendants actively educating potential buyers on the benefits of window shading devices and night ventilation.

Since water is a vital, scare, nonrenewable source it was decided to dedicate this investigation to the water consumption of evaporative cooling systems. It was assumed at the time that the energy consumption had been adequately investigated by others because there seemed to be a social awareness of the problem.

Completing the investigation it became apparent that a complementary investigation of energy use needs to be effected because if the water consumption varies to such an extent by applying bioclimatic strategies, the expected energy use will not correspond with the manufactures specifications.

It would also be interesting to amplify the bioclimatic strategies used such as insulating the walls, uniting the houses to reduce the exterior wall area and increase thermal mass internally, employing barrel vaulted roofs to reduce direct incident solar radiation and the planting of trees in the street and back garden. Another parallel investigation also needs to analyze the water and energy use of houses being occupied by real families.

The value of this investigation is that it highlighted the problem of the extent of water consumption with evaporative cooling and it proposes and analyses bioclimatic strategies for reducing this water consumption.

5. Acknowledgements

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