317: Thermal performance of houses located in Florianópolis, southern Brazil

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Abstract

This paper shows a comparison of thermal performance of three ordinary houses with a house - called Efficient House - where bioclimatic design strategies were used. All houses are located in Florianópolis, southern Brazil. Internal and external air temperature and air relative humidity were measured over a ten-week period by using HOBO data loggers. The measurements were performed in twelve rooms. By using the Analysis Bio computer programme it was possible to verify the percentage of time in which the internal climatic conditions cause thermal comfort for the users, and the more appropriate bioclimatic design strategies to improve thermal comfort. The building bioclimatic chart developed by Givoni, which is the base for the computer programme used, allowed for the comparison of comfort and discomfort in the rooms considered in the four houses. According to the results, the Efficient House presented comfort conditions from about 50% to 60% of the time while it ranged from about 30% to 65% in the other houses during the measurement period. The recommended bioclimatic strategies include ventilation, high mass and evaporative cooling. The main conclusion obtained from this work is that the Efficient House presents a slightly better thermal performance when compared with the ordinary houses.

Keywords: thermal performance, thermal comfort, bioclimatic design strategies, houses

1. Introduction

In the last decades there have been some attempts to include bioclimatic design strategies in the design process of buildings. This approach was first proposed by Olgyay [1] in the 1950s. His method was based on a bioclimatic chart where the comfort zone was established according to certain limits of air temperature and air relative humidity. Then, Milne and Givoni [2] developed a bioclimatic chart based on a psychometric chart, which has been widely used. In more recent works, there also been contributions by Szokolay [3], Evans [4] and others.

Thermal performance of buildings by applying bioclimatic design strategies has been a matter of concern in many countries such as the UK [5], Brazil [6], Greece [7] and others. Research to evaluate the influence of natural ventilation on internal air temperatures have been performed by Bansal et al. [8] in India, Bouilly et al. [9] in France, Liping et al [10] in Singapore, amongst others. In India, Prasad and Jones [11] have developed a methodology to improve thermal comfort conditions in dwellings.

A simple method to evaluate the use of bioclimatic design strategies in dwellings is by measuring internal and external climatic data or by comparing such data with others measured in dwellings with no bioclimatic strategies.

2. Objective

The objective of this paper is to compare the thermal performance obtained in three ordinary houses with a house - called Efficient House - where bioclimatic design strategies were used.

3. The climate

The four houses are located in the city of Florianópolis, which is a small island in southern Brazil located at the latitude 27°36' south, longitude 48°33' west and average altitude of 7m. Fig. 1 shows a map of Brazil indicating the location of Florianópolis.

The climate is temperate tropical, with hot summer and cold winter. Average air temperature is 20.5°C with maximum 36.4°C and minimum 2°C. Average air relative humidity is 83% [12].

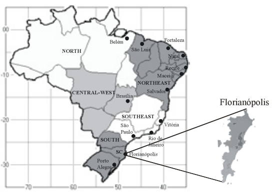


Fig 1. Map of Brazil and Florianópolis

4. The houses

The Efficient House was built in order to be an example of a dwelling designed to consider the climatic conditions of the site. Bioclimatic design strategies such as proper solar orientation of the rooms, natural ventilation for summer, solar heat gain for winter, thermal mass, thermal insulation of walls and roof, external solar protection for windows were used. Rainwater harvesting, greywater reuse, low water consumption equipment, photovoltaic-generated energy were also considered in the Efficient House. Fig. 2 shows a view of the North façade of this house.

Fig 2. North façade of the Efficient House

The Efficient House has double walls (U=1.24W/m²K) with absorptance of 60%. Windows are composed of double glass panes (U=2.84W/m²K) with solar factor of 0.75. It has different types of roofs. In general, there is reflective insulation (U=0.75W/m²K) but some rooms have green roof to increase thermal mass and evaporative cooling. The rooms selected for monitoring were the living room, dining room, two bedrooms, the kitchen and the toilet.

The other three houses (herein called house 1, 2 and 3) were selected according to solar orientation and proximity to the Efficient House, thus having the same macroclimate and mesoclimate. These three houses have walls composed of 15-20cm ceramic bricks with thin inside and outside coating, (U=2.00 to 2.50W/m²K); windows composed of single glass panes (U=4.50 to 5.00 Wm²/K); and thin wooden ceiling with roofs made of fibro-cement panels or ceramic tiles (U=2.00 to 3.00Wm²K).

All four houses are two-storey high. As for occupation, the Efficient House is occupied during the day and unoccupied at night. The other three houses are occupied all day long.

Fig. 3 shows the location of the four houses and the weather station. House 3 is about 7km away from the Efficient House. Due to different distance to the sea and hills, the houses are subjected to different wind, rain and solar radiation conditions.

As the Efficient House is used as a model and centre for dissemination of bioclimatic design strategies and it is not occupied as an ordinary house, it would not be possible to find houses similarly occupied. Therefore, houses 1-3 were selected for comparison although they are not under identical conditions to the Efficient House.

5. Methodology

The method is based on measurements of air temperature and air relative humidity in some rooms in the four houses. In order to evaluate the thermal comfort conditions and bioclimatic design strategies, the measured data were plotted on a bioclimatic chart by using the Analysis Bio computer programme [13].

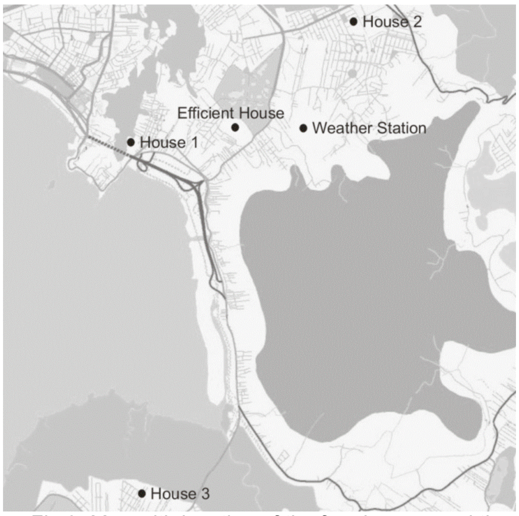


Fig 3. Map with location of the four houses and the Weather Station

5.1 External climatic data

External air temperature, air relative humidity and solar radiation were obtained from a weather station located at the Federal University of Santa Catarina (Solar Energy Laboratory). This station is located about 1km distant from the Efficient House.

5.2 Rooms selected for measurements

Table 1 shows the 12 rooms selected for measurements. Each room has the same solar orientation of a room at the Efficient House allowing the comparison.

Table 1: Solar orientation of rooms selected for measurements.

Room in the EH	Room in the other houses		Solar orientation	Room floor
	House	Room		
Dining	1	Living	South	1st
Living	2	Living	North	1st
Double bedroom	3	Dining	Southeast	1st
Single bedroom	1	Bedroom	Northeast	1st
Bathroom	2	Bedroom	Northwest	2nd
kitchen	3	kitchen	West	1st

Note: EH stands for Efficient House.

5.3 Internal climatic data

Air temperature and air relative humidity were measured by using 12 HOBO data loggers. One data logger was placed in the middle of each room at a height of 2m. Prior to the measurements the data loggers were calibrated and one of them was taken as a reference.

Measurements took place over a ten-week period, from 17/02 to 30/04/2007, and the data were registered every 5 minutes.

5.4 Air temperature analysis
The thermal performance of the houses due to weather variations was assessed by comparing external and internal air temperature in the rooms.

5.5 Daily thermal amplitude
Thermal performance of the houses was also evaluated by comparing daily thermal amplitude for the rooms.

5.6 Bioclimatic chart
Measured data were converted to a Test Reference Year (TRY) in order to be used in the Analysis Bio computer programme, where input data are air temperature and air relative humidity in a TRY format. Output data are the bioclimatic chart as proposed by Givoni and the percentage of time in which the data provide thermal comfort and also the bioclimatic strategies recommended for each room.

6. Results

6.1 External climatic data
Fig. 4 shows external average temperatures (maximum, average and minimum) and solar radiation over the period considered for measurements. It can be noticed that the amplitude is high and temperature reached about 38°C in some days. The five bands in grey scale indicate cold fronts (20/2, 19/03, 08/04, 15/4 and 27/04). The lower temperatures towards the end of April indicate the coming winter.

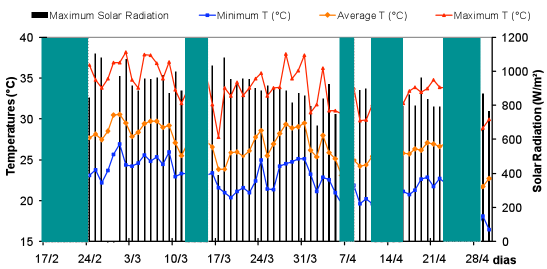


Fig 4. External daily average temperatures and solar radiation over the period 17/2 to 30/04/2007

The external daily temperature amplitude varies between 4°C and 14°C following the external temperature variation and gets to its lower values during cold front periods.
As for the air relative humidity, it ranged from 25% to 100% with 80% average.
Fig. 5 shows the external data obtained over the ten-week period on a bioclimatic chart, which is the output of the Analysis Bio computer programme. Most of the measurements lie outside the comfort zone (91.1% of the time) and natural ventilation is the bioclimatic strategy indicated for 75% of the time. Only in 8.9% of the time there are thermal comfort conditions.

6.2 Internal air temperatures
Internal temperatures were analysed over a short period of high temperatures and high solar radiation (27/03 to 31/03) and over a short period with a cold front (12/04 to 16/04). Figs. 6 and 7 show such a variation for the rooms in the Efficient House. It can be noticed that there is a high inertia in this house due to the high thermal mass. Over the hot period (Fig. 6), temperatures during the day, when the house is open, tend to increase but they are still lower than the external temperature.

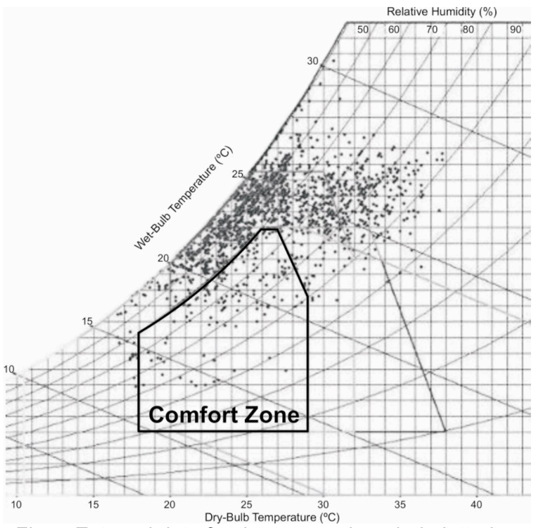


Fig 5. External data for the ten-week period plotted on the bioclimatic chart as provided by Analysis Bio

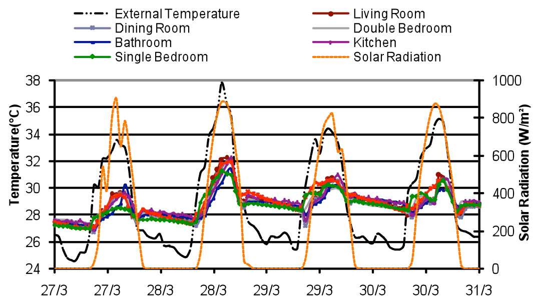


Fig 6. Internal temperatures in the rooms in the Efficient House including external temperature and solar radiation over the period 27/03 to 31/03/2007

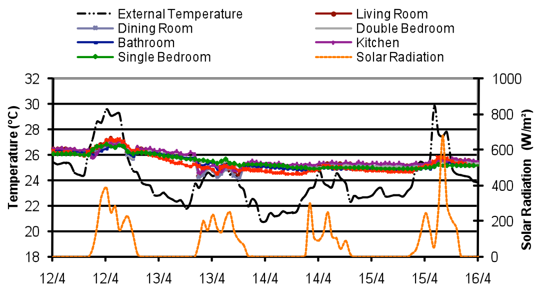


Fig 7. Internal temperatures in the rooms in the Efficient House including external temperature and solar radiation over the period 12/04 to 16/04/2007

The same analysis was performed for the rooms in the other houses. In general, rooms in the Efficient House have a better thermal performance, but the living and dining rooms, which are North and South oriented, have higher temperatures. This happens because these rooms have large windows and as they are open during the day, internal temperatures tend to be similar to the external ones.

Figs. 8 to 13 show the temperature comparison between rooms with same orientation. As an example, only North, Southeast and West orientations are shown.

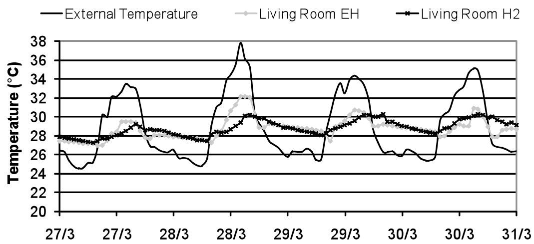


Fig 8. Internal temperatures in North oriented rooms including external temperature over the period 27/03 to 31/03/2007

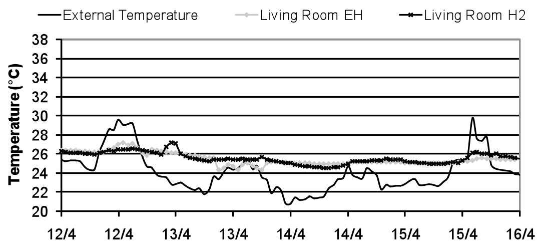


Fig 9. Internal temperatures in North oriented rooms including external temperature over the period 12/04 to 16/04/2007

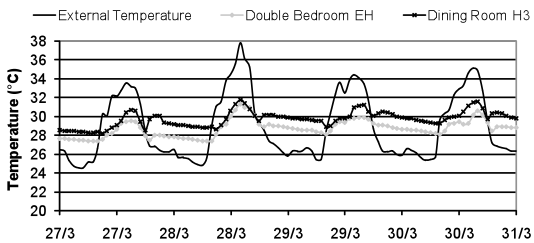


Fig 10. Internal temperatures in Southeast oriented rooms including external temperature over the period 27/03 to 31/03/2007

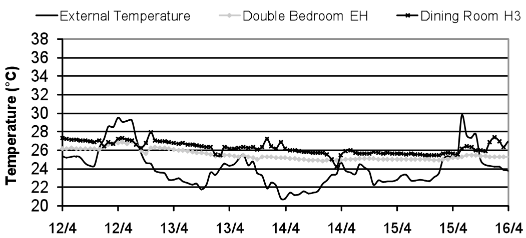


Fig 11. Internal temperatures in Southeast oriented rooms including external temperature over the period 12/04 to 16/04/2007

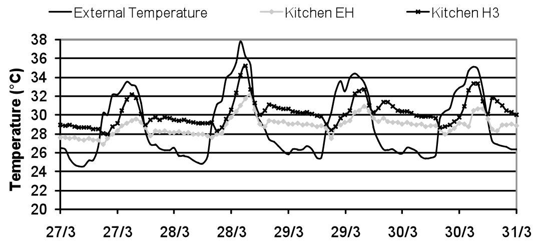


Fig 12. Internal temperatures in West oriented rooms including external temperature over the period 27/03 to 31/03/2007

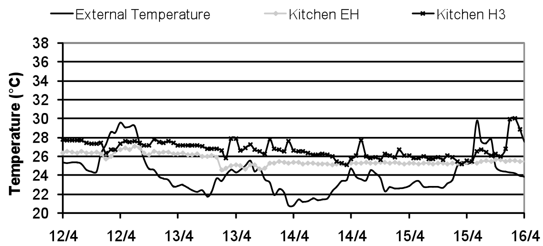


Fig 13. Internal temperatures in West oriented rooms including external temperature over the period 12/04 to 16/04/2007

6.3 Amplitude

Maximum, average and minimum amplitudes as well as the standard deviation were calculated for each room over the period 17/02 to 30/04/2007. Table 2 shows the results for each solar orientation. The average amplitude is lower for the rooms in the Efficient House for every solar orientation. This is due to its higher inertia. However, for North and South orientations the standard deviation of temperatures are higher in the Efficient House which means that amplitudes are more variable and confirm the weakness of those two orientations.

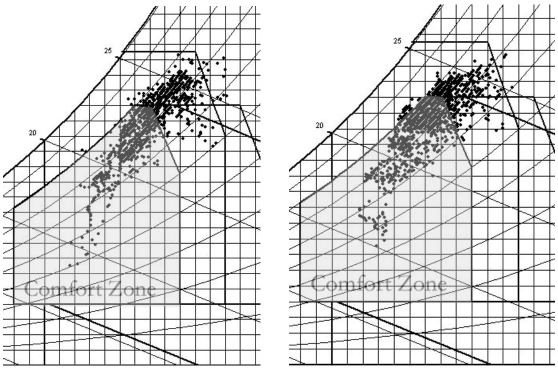
Table 2: Amplitude and standard deviation for all rooms over the period 17/02 to 30/04/2007.

Amplitude	South		North		Southeast	
(°C)	EH	H1	EH	H2	EH	H3
Maximum	4.9	4.6	5.1	3.6	4.1	4.2
Average	1.8	2.4	1.9	2.1	1.5	2.3
Minimum	0.3	0.8	0.3	0.4	0.3	0.7
SD	1.1	0.9	1.1	0.7	0.8	0.8
Amplitude	Northeast		West		Northwest	
(°C)	EH	H1	EH	H3	EH	H2
Maximum	4.0	5.7	4.8	7.2	4.2	4.8
Average	1.4	3.6	1.8	3.8	1.7	3.0
Minimum	0.3	1.3	0.3	0.4	0.3	0.8
SD	0.8	1.2	1.0	1.4	1.0	1.0

Note: EH stands for Efficient House; H1, H2 and H3 stand for houses 1, 2 and 3; SD stands for standard deviation.

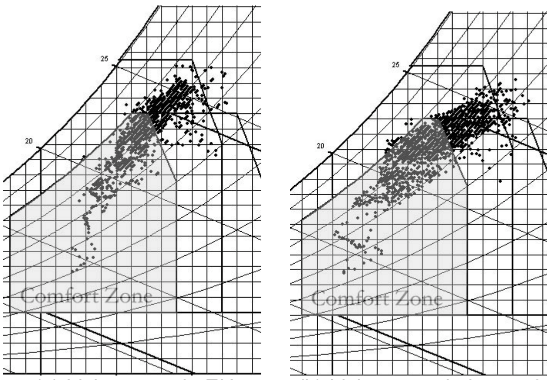
6.4 Bioclimatic charts

Figs. 14 to 19 show the internal data plotted on bioclimatic charts for each room according to their solar orientation. In general, it can be seen that there is no great difference between the results for each solar orientation. However, air temperature in houses 1, 2 and 3 is higher, which is shown by dots outside the comfort zone.



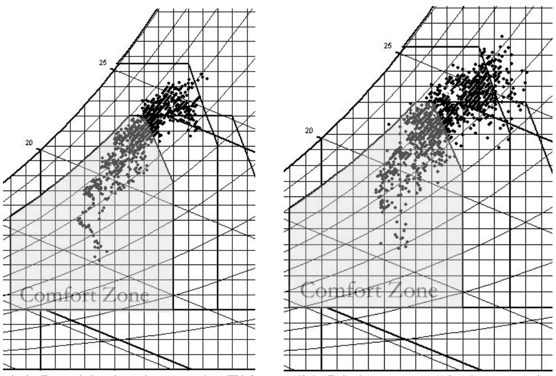
(a) Dining room in EH (b) Living room in house 1

Fig 14. Bioclimatic chart with internal data for South oriented rooms



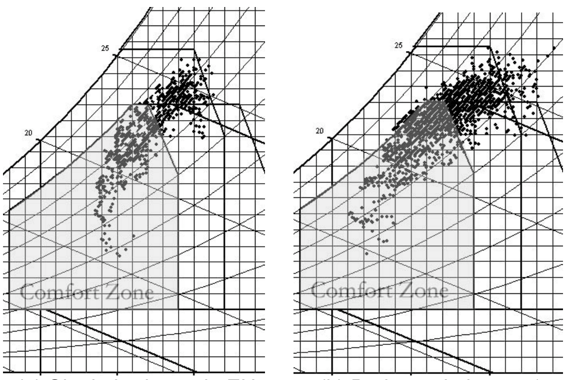
(a) Living room in EH (b) Living room in house 2

Fig 15. Bioclimatic chart with internal data for North oriented rooms



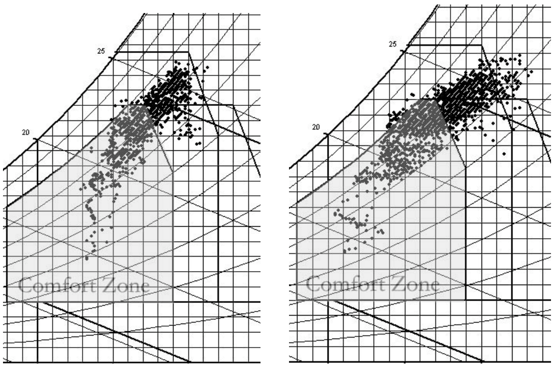
(a) Double bedroom in EH (b) Dining room in house 3

Fig 16. Bioclimatic chart with internal data for Southeast oriented rooms



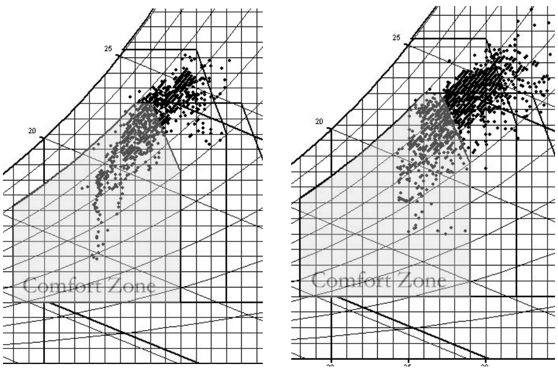
(a) Single bedroom in EH (b) Bedroom in house 1

Fig 17. Bioclimatic chart with internal data for Northeast oriented rooms



(a) Bathroom in EH (b) Bedroom in house 2

Fig 18. Bioclimatic chart with internal data for Northwest oriented rooms



(a) Kitchen in EH (b) Kitchen in house 3

Fig 19. Bioclimatic chart with internal data for West oriented rooms

Table 3 shows the percentage of time in which there is comfort and discomfort in each room. In general, rooms in the Efficient House present a higher percentage of time for comfort, ranging from 50.3% to 57.7% amongst all solar orientations. In the other houses, it ranges from 31.7% to 65.7%. Table 4 shows the bioclimatic design strategies recommended to meet comfort over the period considered in the analysis.

Discomfort is caused by hot weather conditions. Natural ventilation, thermal mass and evaporative cooling are the bioclimatic strategies recommended to meet thermal comfort. Natural ventilation is the strategy recommended to improve comfort conditions from 42.0% to 49.4% of the time in which there is discomfort in the Efficient House. Thermal mass and evaporative cooling are recommended to improve comfort about 9-13% of the time in which there is discomfort.

In all the other houses, natural ventilation, thermal mass and evaporative cooling are also the strategies to improve comfort. In house 1, for example, the living room is considered uncomfortable over 34.3% of the time. Natural ventilation would improve comfort over 34.0% of the time; thermal mass, about 8.2% of the time; and evaporative cooling, about 8.1% of the time in which there is discomfort.

The same trend can be observed in houses 2 and 3.

As for air conditioning, which is recommended for when there is no bioclimatic design strategy to meet thermal comfort conditions, it can be observed in Table 4 that it is necessary from 4.0% to 7.7% of the time in rooms oriented to Northeast, West and Northwest in houses 1, 2 and 3. In the Efficient House it lies between 0.2% and 1.0%, which indicates better thermal performance for this house.

Table 3: Percentage of time in which the measured data lie inside or outside the comfort zone over the period 17/02 to 30/04/2007 as obtained from Analysis Bio.

Result	South		North		Southeast	
(%)	EH	H1	EH	H2	EH	H3
In CZ	53.3	65.7	53.7	49.4	57.7	55.6
Out CZ	46.7	34.3	46.3	50.6	42.3	44.4
Result	Northeast		West		Northwest	
(%)	EH	H1	EH	H3	EH	H2
In CZ	56.2	48.1	51.1	31.7	50.3	50.7
Out CZ	43.8	51.9	48.9	68.3	49.7	49.3

Note: In CZ stands for inside comfort zone; Out CZ stands for ouside comfort zone; EH stands for Efficient House; H1, H2 and H3 stand for houses 1, 2 and 3.

Table 4: Bioclimatic design strategies recommended for each room over the period 17/02 to 30/04/2007 as obtained from Analysis Bio.

Bioclimatic	South		North		Southeast	
strategy (%)	EH	H1	EH	H2	EH	H3
[1]	45.8	34.0	45.4	49.6	42.0	43.6
[2]	10.7	8.2	9.7	15.3	12.9	8.1
[3]	10.2	8.1	9.3	13.7	11.5	7.7
[4]	0.9	0.3	1.0	1.0	0.3	0.8
Bioclimatic	Northeast		West		Northwest	
strategy (%)	EH	H1	EH	H3	EH	H2
[1]	43.4	46.9	48.2	59.8	49.4	45.1
[2]	13.4	16.3	13.2	32.2	13.0	17.6
[3]	12.2	13.8	12.5	27.6	12.4	15.2
[4]	0.4	4.6	0.7	7.7	0.2	4.0

Note: [1] Natural ventilation; [2] High thermal mass; [3] Evaporative cooling; [4] Air conditioning.

7. Conclusions

In general, average temperatures in the rooms in the Efficient House are lower than those in the other houses. Its high thermal mass contributes to avoid high temperatures over the day and high amplitudes. Bedrooms present good results with low amplitudes and no overheating. This result is caused by high thermal mass of walls, green roof and thermal insulation of walls and roof.

Although the Efficient House took bioclimatic design strategies into account at design stage, its thermal comfort conditions are not significantly higher than the other houses over the ten-week period. Some conclusions and considerations can be made to account for that: (a) as the Efficient House was designed to consider natural ventilation as a bioclimatic strategy and such a strategy is still recommended, it is likely that there was little or no wind over the ten-week period; (b) measurements took place over a short summer period, but in winter there is a 50% discomfort caused by cold weather conditions; (c) although the solar orientation of the rooms allows for their comparison, their occupation pattern is not the same.

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