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Comfort temperature and humidity evaluation of a bioclimatic design building

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Abstract.

An evaluation of the hygrothermal comfort levels on a bioclimatic experimental building prototype located in Galician coast is presented. Its design was performed following strict bioconstruction criteria and it is called *"A Vieira"* (scallop in Spanish) after its shape. The construction was carried out as part of the international formative activity "*Ecological Building with Straw Bales in Vocational Training*" and the innovation project in vocational training *"Didactical Resources for Bioclimatic Construction"* during the 2011/12 academic year. The building is currently used for educational, training and experimental purposes. As constructive materials, regional wood, straw bales, clay, lime and grave were used. Floor was constructed with an experimental mortar consisting of a mixture of recycled mussel shell and hydraulic lime. The building was fitted with an insulating green roof and photovoltaic solar panels. Given its experimental character, the building has its climatic parameters continuously monitored to evaluate its response in terms of comfort. The results after the experimental data analysis show a positive behaviour in terms of comfort compared to conventional constructions.

Key words

Bioclimatic building, Bioconstruction, Straw bale construction, thermal comfort

1. Introduction

Bioclimatic strategies involve the set of techniques designed to achieve proper thermal conditions inside buildings using local natural resources like sun, wind, rain, snow, soil or vegetation. This technique implies a deep understanding of the climatological characteristics and available resources on the construction location [1][2]. The ultimate goal is to design obtaining the best possible energy efficiency by using solutions that involve minimal environmental impact throughout its lifecycle.

Overall, the basic foundations of the bioclimatic construction are simple: leverage, isolate and regulate. Thus, the solar collection is optimized through guidance and constructive elements while the isolation levels are improved by using appropriate materials. The result is an comfort conditions improvement through the temperature and humidity regulation [3].

Currently, there are bioclimatic construction guideline sets [4] introducing new materials and/or traditional techniques upgrade. One of these techniques is the straw construction [5].

This paper presents an experimental prototype based on straw bale bioconstruction bioclimatic principles known as *"A Vieira"* ("The Scallop" due to its shell shape). Local and regional constructive materials were used on the building. For the edification, the technique known as *"posts and beams"* or *"in-fill method"* [6] was used, employing wood as container material. As innovation, a floor specific mortar made from crushed mussel shell and hydraulic lime was used. The aim of using this experimental mixture is to study its thermal response and thus, be able to assess the potential of shellfish derived waste recovery.

Although this prototype was built with the aim of achieve an important educational resource for visitors (mainly teachers and construction-related students), it provides also an interesting experimental device for scientific purposes.

In this paper this capability is exploited, particularly when considering the validity of the used solutions in terms of comfort for this bioclimatic construction. For this matter, the *"A Vieira"* building has been equipped with a monitoring system based on the analysis of the two fundamental parameters in the thermal comfort study: temperature and humidity. This long-term monitoring expects to verify the adequacy of the proposed solutions to the building location and confirm their suitableness.

2. Experimental set-up: Bioclimatic module *“A Vieira”*

A. Module design and construction

The considered experimental set-up bioclimatic module has been constructed under bioclimatic and bioconstruction criteria. This project arises from the international formative activity *“Ecological Building with Straw Bales in Vocational Training”* and the innovation project in vocational training *“Didactical Resources for Bioclimatic Construction”*, developed in the Someso CIFP (A Coruña, Spain) during the 2011/12 academic year. The selected design comes after cultural issues related to the module’s geographic location. The constructive materials selection, fully based on bioconstruction criteria, can be consulted in Table 1.

Table 1: Module’s construction employed materials

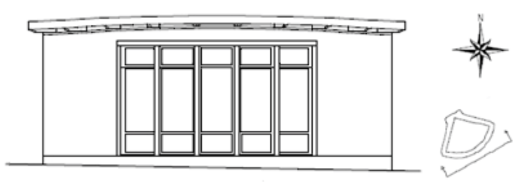
Structure:	**Material:** Pinus Silvestris pinewood **Source:** Castilla-León (Spain) **Management:** Sustainable
Enclosures:	**Material:** Straw bales **Source:** Castilla-León (Spain) **System:** Posts and beams **Inner cover:** Clay mortar (three layers) **Outer cover:** Clay mortar (two layers) plus hydraulic lime mortar (third layer) **Outer paint:** Silicate paint
Roof:	**Beams:** Solid Pinus Silvestris pinewood **Source:** Castilla-León (Spain) **Management**: Sustainable **Voids:** Pine wooden frieze (gaps under 1 m) **Insulation:** Granulated cork (20 cm) and oriented strand board (OSB) **Green cover:** Protective films and waterproof layer under a 10 cm substrate
Floor:	**Foundation:** 80 mm pitching gravel (20 cm) **Regularization surface:** Lime mortar **Insulation:** Cork ply (4 cm) **Bedding:** Mussel shell loose arid (10 cm) **Flooring:** Experimental mussel shell and hydraulic lime mortar (10 cm)

The module dimensions (Table 2) are conditioned upon the limited available space on the educational complex with the appropriate sunlight and orientation. The building drawings (Figure 1) and pictures (Figure 2) are displayed as reference of the module under analysis.

Table 2: Bioclimatic module dimensions

Shape:	Quarter circumference of 6 m radius
Useful surface:	28 m^2
Height:	2.65 to 3.05 m (roof slope)
Roof slope:	4º

(a)



(b)

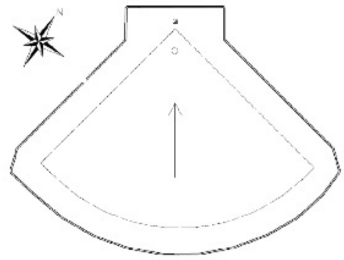


Figure 1. Module elevation (a) and plan (b) drawings

Figure 2. Bioclimatic module *“A Vieira”* design and construction process: a) Model design, b) Foundations, c) Walls construction, d) Module without enclosures, e) Green roof, f) Module finished look

B. Data source

For the temperature and humidity monitoring, two Omega OM-EL-USB-2 data logger are used (see Table 3 for device characteristics). Internal temperature and humidity data logger is installed 1 m far to the inner wall and protected against sunlight and air currents. External temperature and humidity are measured 0.5 m far to the outer wall, protected from the rain as the data logger is located under the building's eaves. Figure 3 displays the data logger's location.

Table 3: Data logger characteristics

	Temperature	Humidity
Measurement range:	-35 to +80 ºC	0 to 100 %
Accuracy (overall error):	±0.5 ºC	±3 %
Internal resolution:	0.5 ºC	0.5 %

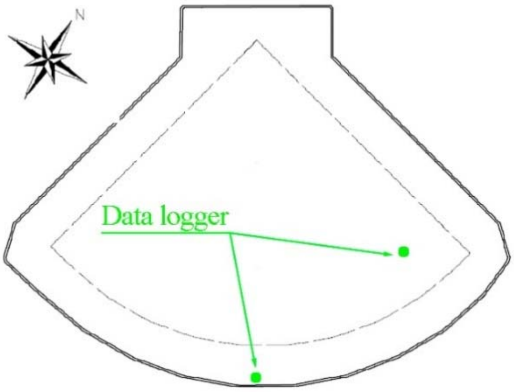


Figure 3. Data logger devices location

C. Data acquisition

For the temperature and relative humidity measures, a 10-minutes interval is considered for both internal (T_{int}, RH_{int}) and external (T_{ext}, RH_{ext}) data.

The hygrothermal data analysis is performed over a 9-consecutive month period. The first 7 days each considered month are selected as representative sample.

3. Methodology

Data evaluation method is based on measure the time percentage that the module interior is within the world accepted hygrothermal comfort limits [7][8]. For the temperature, a comfort interval between 18ºC and 25ºC is considered. For humidity, relative humidity values among 40-70% are accepted [9].

Considered variables for the analysis are the interior temperature and relative humidity (T_{int}, RH_{int}) and exterior (T_{ext}, RH_{ext}). This measurement is not absolutely precise and comparison with a conventional house would be desirable. Besides, gathered data are almost no affected by human use as there is a sporadic visiting schedule. It also must be noticed that from June 1 to September 30 the module's upper windows are opened to allow air renovation. It is also necessary to emphasize the fact that the module has no other active or passive heating or cooling systems.

In order to have unbiased gain values, the pool will be considered as the percentage of variation between two comparable variables. For this analysis, temperature pool (1) and relative humidity pool (2) will be used:

$$T_{pool} = \frac{T_{int} - T_{ext}}{T_{int}} \cdot 100\ (\%) \qquad (1)$$

$$RH_{pool} = \frac{RH_{ext} - RH_{int}}{RH_{int}} \cdot 100\ (\%) \qquad (2)$$

The achieved results are not universally valid as they are related to a well-defined climatic zone. A 9-year available climatic data historic (Table 4) identifies the location to a Cfb climate [10] (warm temperate climate, fully humid with warm summer) according to Köppen classification [11]. Figure 4 shows the characteristic climate distributions for *"A Vieira"* location.

Table 4. Climate reference values for Köppen classification (Data source: A Coruña-Dique meteorological station (43.37º N, -8.37º O) located 3.1 km far [12])

Average minimum temperature:	6.95 ºC
Precipitation of driest month:	0.01 mm/day
Precipitation of wettest month:	7.72 mm/day
Average temperature of hottest month:	19.1 ºC

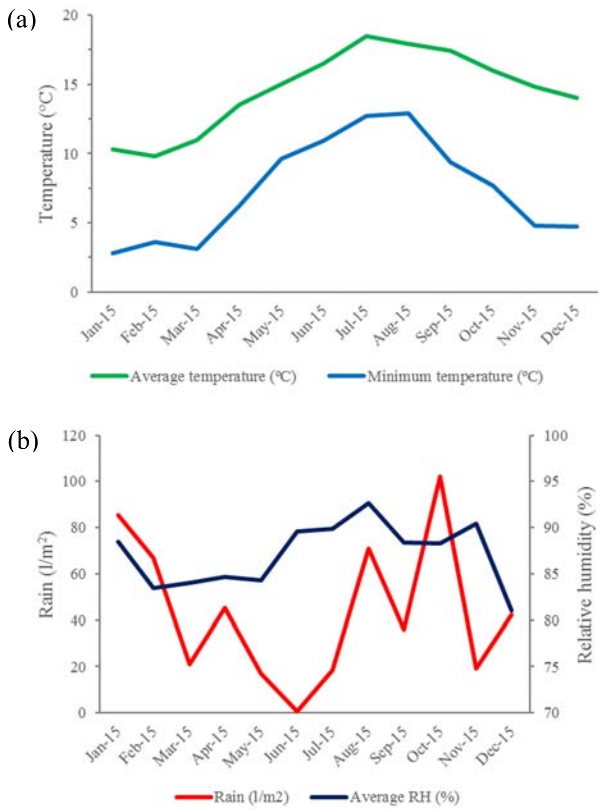


Figure 4. Location's monthly meteorological data [12] for year 2015: a) Average and minimum temperature, b) Rain and relative humidity

4. Results and discussion

Data analysis has been carried out on a 9-consecutive month data sample. For each case, 7 successive days were considered for each month as a representative data behaviour sample. This analysis aims to evaluate the prototype response in different seasons. For this, December, May and July were selected for winter, spring and summer respectively. Once these months are chosen, the previously defined hygrothermal comfort parameter limits evaluation for the considered week is performed.

A. *Thermal response*

Figure 5 shows the module's thermal response for the different considered seasons with its corresponding exterior temperature. Each plot includes a grey strip to identify the defined temperature comfort interval. It can be seen that interior temperature, T_{int}, shows high comfortability levels even in extreme weather intervals (winter), remaining within the defined thermal comfort intervals.

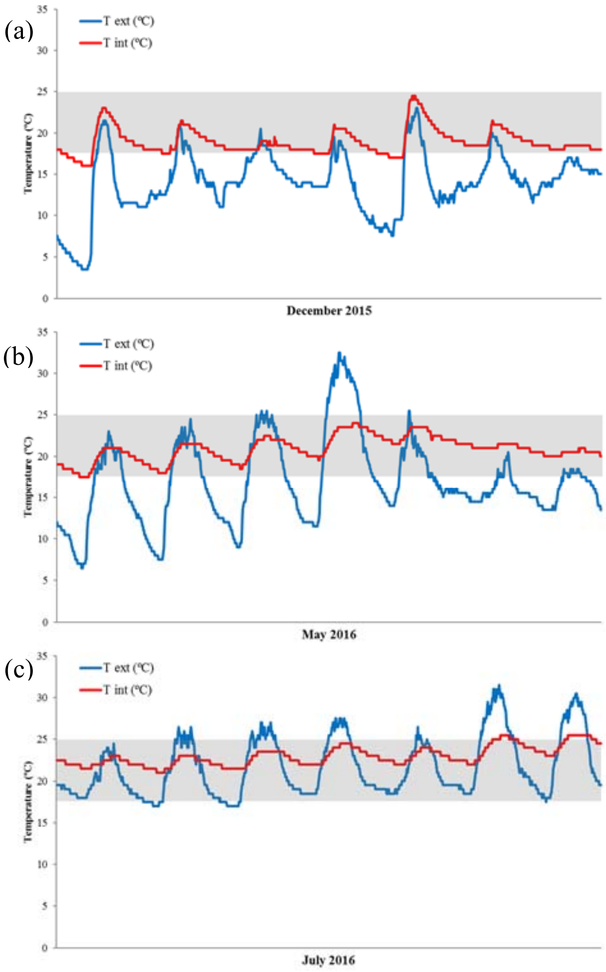


Figure 5. Interior and exterior temperature for the considered months: a) December, b) May, c) July

Table 5 displays the accurate comfort percentages. It is remarkable the fact that only in 15% of the winter (December) interval the internal comfort levels are not reached even if there is no any kind of additional heating system. Besides, just 6% of the summer time (July) shows a slight thermal discomfort. This time percentage values must be compared with the exterior discomfort of 84% for the winter and 27% for the summer considered period.

Table 5. Time percentage in comfort interval for temperature

	Dec. 2015	May 2016	Jul. 2016
18ºC<T_{int}<25ºC	85%	98%	94%
18ºC<T_{ext}<25ºC	16%	31%	73%

The temperature pool distribution allows to see prototype's thermal response along the year. Figure 6 shows its distribution and it can be observed how as the external temperature increases, the interior temperature gain relative to the exterior decreases. This is an expected result, although it seems there are some observed saturation levels on its response that that may require further studies.

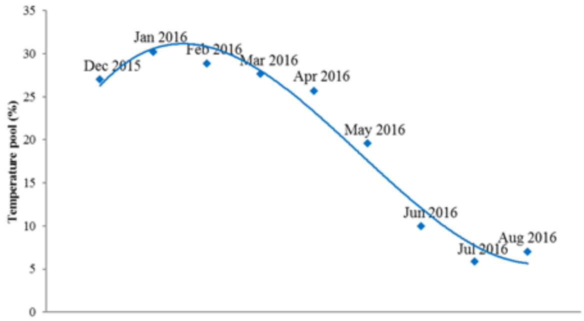


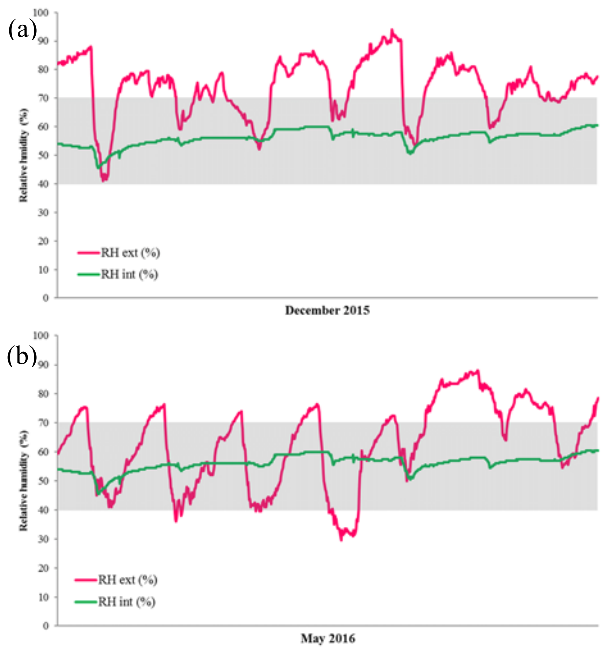
Figure 6. Monthly average temperature pool evolution along the considered data interval

In brief, the thermal response inside the module is optimal throughout the entire year with almost no dependence on exterior temperature. Also, it must be noticed that the prototype has no additional heating system. Comparison with a conventional house response would be desirable.

B. *Humidity response*

Figure 7 shows the building's interior and exterior hygrometric behaviour for the different considered seasons. Each graph, as in previous case, includes a grey strip to identify the considered internal humidity comfort interval. For this variable, RH_{int}, the prototype shows absolute comfort levels response with no dependence on external conditions. Interior and exterior humidity for the considered months: a) December, b) May, c) July

Table 6 displays the numeric results in percentages. The winter season (December) values are particularly remarkable as the exterior humidity comfort levels represent only the 31% of the considered time with 100% internal relative humidity levels.



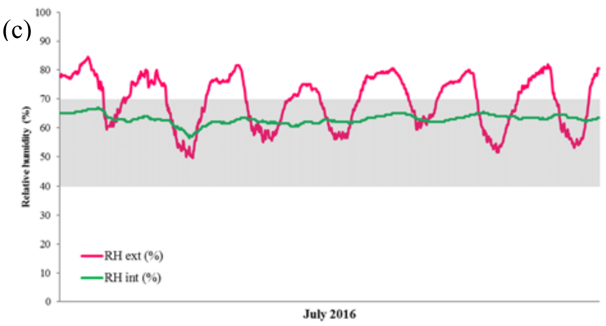


Figure 7. Interior and exterior humidity for the considered months: a) December, b) May, c) July

Table 6. Time percentage in comfort interval for humidity

	Dec. 2015	May 2016	Jul. 2016
Interior	100%	100%	100%
Exterior	31%	63%	74%

Relative humidity pool response along the year shows a linear behaviour (Figure 8). Furthermore, it can be seen that interior relative humidity is always below 70% (higher humidity values favours the fungi and other germs development) and over 40% on the considered period.

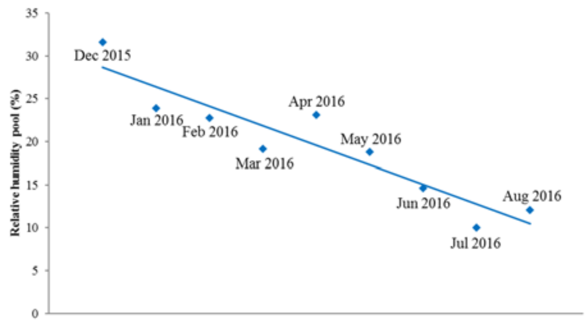


Figure 8. Relative humidity pool along the considered data interval

Interior relative humidity is optimal along the year with no dependence on the exterior humidity levels. Taking into account the rainy weather on the location, it can be stated that the selected construction criteria is optimal in terms of relative humidity.

5. Conclusions

Temperature and humidity monitoring was performed on an experimental housing built following the bioclimatic architecture criteria. The building, known as *"A Vieira"*, was constructed as part of an international formative activity ad was erected in September 2011 in A Coruña (Spain) in a Cfb climate zone (warm temperate, fully humid, warm summer). The house has no additional heating or cooling systems and is used in a demonstrative level only.

Aiming to assess the proposed bioclimatic solutions in terms of temperature and humidity, the system was monitored inside and outside A 10-minute interval of 9-month data record is considered.

Achieved results in terms of temperature were comfort levels over 85% for the considered interval, reaching almost 100% in intermediate seasons. There is a linear tendency along the year showing certain saturation effects in extreme levels.

The relative humidity was always in comfort levels on the inside for all the studied intervals. Meanwhile, the outer relative humidity was out of comfort levels between 69% of the time for winter and 53% for summer season. For this case, the tendency is completely linear.

With these results, it can be concluded that the considered constructive solution is optimal in terms of interior relative humidity and shows a very good response in terms of interior temperature. A response comparative study with a conventional house would be of particular interest.

References

[1] J. A. Turegano, M. C. Velasco, and A. Martinez, *Arquitectura bioclimatica y urbanismo sostenible (Volumen I) (Spanish Edition)*. Universidad de Zaragoza, 2009.

[2] J. A. Turegano, M. C. Velasco, and A. Martinez, *Arquitectura bioclimatica y urbanismo sostenible (Volumen II) (Spanish Edition)*. Universidad de Zaragoza, 2012.

[3] F.J. Neira Gonzalez, *Arquitectura Bioclimática en un entorno sostenibe*. Munillaleria, 2004.

[4] R. Nitzkin and M. Termens, *Casas de paja. Una guía para autoconstructores*. Editorial Ecohabitar, 2016.

[5] M. Myhrman and S. O. MacDonald, *Build it with Bales*. Out on Bale, 1997.

[6] G. Minke and F. Mahike, *Manual de Construcción con Fardos de Paja*. Fin de Siglo, 2006.

[7] B. Givoni, *Man, Climate and Architecture*. Elsevier Science Ltd, 1976.

[8] F. Nicol, "The limits of thermal comfort : avoiding overheating in European buildings," *CIBSE Tm52*, pp. 1–25, 2013.

[9] BOE, "Real Decreto 1826/2009, de 27 de noviembre, por el que se modifica el Reglamento de instalaciones térmicas en los edificios, aprobado por Real Decreto 1027/2007, de 20 de julio.," vol. 298, no. I, p. 104924 a 104927, 2009.

[10] M. Kottek, J. Grieser, C. Beck, B. Rudolf, and F. Rubel, "World map of the Köppen-Geiger climate classification updated," *Meteorol. Zeitschrift*, vol. 15, no. 3, pp. 259–263, 2006.

[11] F. Rubel and M. Kottek, "Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification," *Meteorol. Zeitschrift*, vol. 19, no. 2, pp. 135–141, 2010.

[12] "Meteogalicia - Estacións Meteorolóxicas: Coruña-Dique." [Online]. Available: http://www2.meteogalicia.es/galego/observacion/estacions/estacionsActual.asp?Nest=14000&x=88&y=40&red=102&idprov=0. [Accessed: 11-Oct-2016].