RESEARCH ARTICLE (Open Access)

Impact of surface temperatures variation of window elements versus thermal performance of traditional wooden window

FIRDUS HAVERAJ[1]

[1]Department of Physics and Applied Sciences, Faculty of Forestry Sciences, Agricultural University of Tirana, Kodër Kamëz, Str. "Paisi Vodica", 1029 Tirana, ALBANIA

*Corresponding author; E-mail: fhaveraj@ubt.edu.al

Abstract

Windows play an important role in building performance associated with thermal comfort. This study evaluated the influence of window temperatures variation versus thermal performance of traditional windows with a 4 mm glass and wooden frame of ***Pinus nigra Arn***. under the climate conditions of Tirana. The study focused on the distribution of air temperatures and surfaces temperatures of glazing and wooden frame, in assessing the thermal comfort according to the Olgyay's diagram, in the variance assessment between the temperature groups according to the ANOVA test, and in the differentiation of the sub-populations of different temperature meanings according to Tukey-Kramer tests. It was noted that the temperature distribution field resulted within the thermal comfort zone for the summer season, but near the upper boundary; and generally, outside for the winter season. Population groups of temperatures of glazing and wooden frame surfaces resulted in the same mathematical tendency and there was no significance between the glass temperatures and wooden frame temperatures of window for both seasons: summer: ($F (3; 52) = 0.4754$; $p=0.7008$) and winter: ($F (3; 52) = 2.516$; $p=0.0623$). A significant minimum difference (MSDs) of 1.533 and 1.806 resulted respectively during summer and winter in the Tukey-Kramer test. It was concluded that the traditional window met the conditions of thermal comfort during the summer, but not during the winter; and that the surface temperatures of window elements were influenced by indoor and outdoor air parameters; and also, that groups of temperature populations did not have significant differences between them for the level of trust received.

Keywords: window, wooden frame, Olgyay's diagram, Tukey-Kramer.

1. Introduction

Windows play an important role in building performance associated with thermal comfort. At the present time it is aimed toward larger surfaces of windows and rooms as naturally illuminated, but the windows are at the same time the weakest points in the overall thermal insulation of the building. The large change in heat transfer coefficients and thermal capacity between the window glass and the building wall causes differences in their surfaces temperatures and relative humidity of air associated with disturbing air currents. Assessment of the performance of windows materials is raised as a priority task in order to provide a thermal comfort, acoustic comfort and lighting convenience that must meet the requirements for energy efficiency in buildings in accordance with Law no. 116/2016 "The energy performance of buildings " (FZ no.226, 2016). The objectives of this study were to study the variation of surface temperature of window elements and outdoor and indoor air parameters, for the purpose of evaluating:

- how the surface temperature of the window element components (glass and frame) is influenced by the ambient temperature and/or the outside air temperatures, and
- whether the differences between them had an impact on the thermal comfort of persons in the building.
- the impact of indoor air parameters on the thermal comfort of people in the building for the summer and winter seasons by determining the temperature range according to the diagram provided by Olgyay regarding the effects on thermal comfort (Jokl, 2002).

These hypotheses were raised for the area location of the average temperatures of the window glass surfaces and wooden frame surfaces in the center and in the corner of the windows in the thermal comfort diagram:

1. H_0: The chosen window meets the conditions of thermal comfort during the summer and winter season climate,
2. H_0: The surfaces temperatures of wooden frame of window are higher than temperatures of window glass because the wooden frame absorbs more heat, both during the summer and winter,
3. H_0: Temperatures at the center of the window glass are higher than the temperatures in its corners (as a result of thermal bridges) (during winter),
4. H_0: Population groups of surface temperatures of window glass and frame have the same mathematical tendency.

The data from (Papadopoulos *et al*., 2001) on temperature changes of window glass surfaces in function of the number of glass sheets in the respective window package are shown below in tabular diagram form (Figure 1), versus outdoor and interior design temperatures for the Tirana area (Voshtina *et al*., 2004):

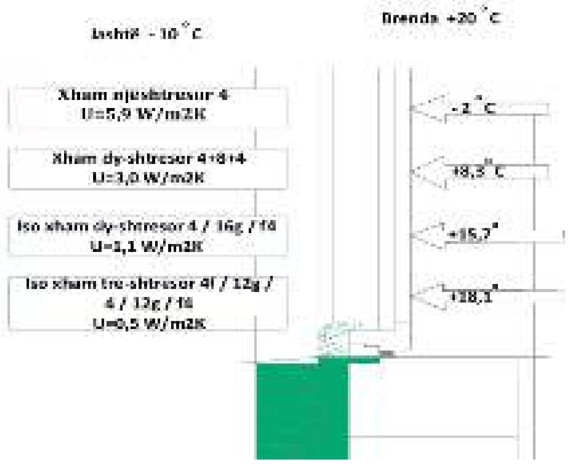


Figure 1. Interior window interior temperature differences depending on indoor and outdoor design temperature of the building and type of window, (Papadopoulos *et al*., 2001)

2. Material and Methods

In order to evaluate the thermal comfort under working conditions (wall-mounted, non- insulated) a window unit (size: l = 132 cm x h = 155 cm) with a white clear single glass of 4 mm, with frame thickness of 5 cm, and from massive wood material of black pine, *Pinus nigra* Arn.; and mounted on the west side of a residential building situated in the suburban area of Tirana, was chosen to study the variation of the surface temperatures of the window elements and the parameters of the indoor and outdoor air.

2.1. Measuring Apparatus

Window surface temperature measurements were carried out directly at selected time intervals by means of Profi Scale Energy PS 7420 temperature measuring apparatus, which performs measurements on various surfaces without contact with them through infrared rays over the measurement area to run with the help of the laser beam (Figure 3). The device is built in accordance with the European standard EN 60825 - 1/1994 + A1; 2002 + A2; 2001. The accuracy for the temperature from 0 °C to 180 °C is 2 % or ± 2 °C. Two meteorological apparatus 1.mp man FA - SW9 and 2.WO - 119 were used simultaneously to measure air temperature TA (°C) and relative humidity φ_{Air} (%) (Figure 2).

Figure 2. Apparatus for measuring the temperature and relative humidity of the air

2.2. Method of measuring

The measurement period included an one-week period for both main seasons of the year: summer and winter, respectively from 24.05. until 30.05. for summer and from 02.01. until 09.01. for the winter.
Measurements were conducted in the corners and in the center of the window glazing, and in the corners and in the middle of the window frame, respectively 5 (five) measurement's points on glazing (center point no.5 and corners points: no.1, 2, 3 and 4) and 10 (ten) measurement's points on wooden frame elements (middle points: no.5, 6, 7, 8, 9 and 10, and corner points: no.1, 2, 3 and 4) (Figure 3). Measurements were conducted directly by the thermometer Profi Scale Energy PS 7420 for every 4 hours (8^{00}; 12^{00}; 16^{00}; 20^{00}) during the summer, and for every 6 hours (6^{00}, 14^{00}, 22^{00}) during the winter, on a window mounted within the wall of the building, and avoiding the currents of indoor and outdoor air. Measurements were carried out at height 1.5 m from the floor and at least 1.5 m away from the window by Asaeda, Ca & Wake (1996) (Guan, 2011), (Jokl, 2002). Relative humidity φ_{Air} of air and temperatures of indoor (TIA) and outdoor (TOA) air were also measured.
To evaluate better the summer season were treated especially measurements of midday (12^{00} and 16^{00}) by (Guan, 2011), and during the winter season are used measurements during 24 hours of the day.

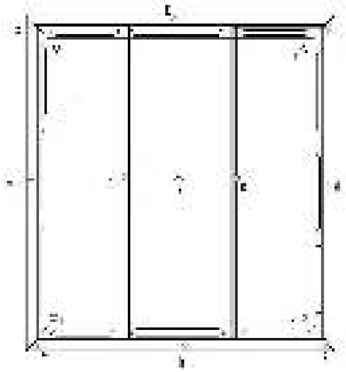


Figure 3. Measurement points of surface temperature of window elements. Window glass: in the center: item no.5; in the corner: item no. 1, 2, 3 and 4. Wooden frame: in the middle: item no. 5, 6, 7, 8, 9 and 10; in the corner: item no. 1, 2, 3 and 4

The evaluation method of thermal comfort of windows was based on the study of the variation of surface temperatures on the window elements (glass and frame) and the variation of the thermal parameters of the external and internal air by means of:

- Olgyay bioclimatic diagram for determining the field of temperatures for the assessment of thermal comfort offered by the window in the context of a moderate European climate (Jokl, 2002). The area of seasonal comfort zones: summer and winter, defined by Olgyay, includes the conditions under which everybody feels the achievement of "the point at which with minimal energy consumption adjusts themselves to the surrounding environment" (Rellihan, 2003).
- Microsoft Excel program for the drafting of comparative diagrams of internal and external temperatures of air, temperatures of surface of window glazing and frame,
- Microsoft Excel XLStat 2016 program for the drafting of *box-plot and whisker* diagrams.
- Statistical test - ANOVA One Way (ANOVA linear model, or otherwise model with specified sub-populations).
- Tukey-Kramer test that aims to distinguish different averages from each other by comparing them two by two, based on the usual Student or Gosset test.

3. Results and Discussion

The variation of temperatures of surfaces of window elements and the variation of parameters of the external and internal air

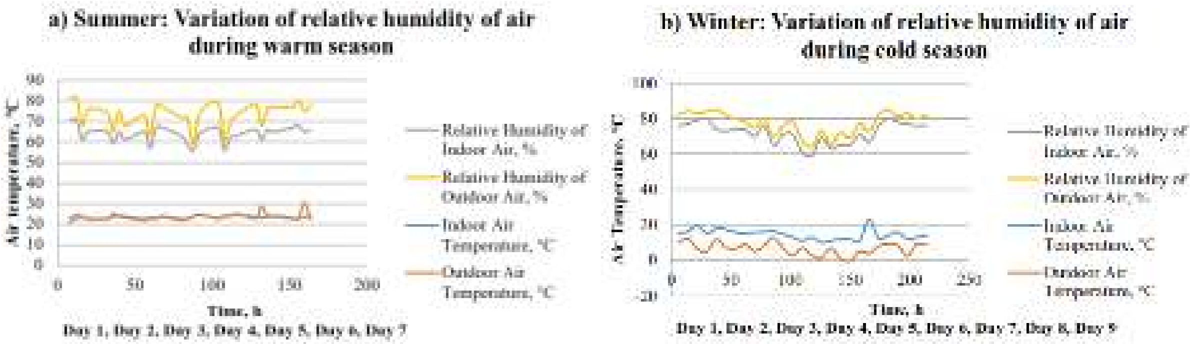
3.1. Climate characteristics, Olgyay diagram and thermal comfort of windows

a) Summer

The distribution of relative humidity φ_{Air} of the external and internal air to the summer season resulted in each case with $\varphi_{\text{Internal Air}} < \varphi_{\text{External Air}}$ to the maximum and minimum values respectively outside (82 % and 59 %) and inside (71 % and 56 %) of the window. Indoor TIA (and outdoor TOA) air temperatures ranged from 22.2 °C to 24.7 °C (from 20.4 °C to 30.4 °C).

b) Winter

The distribution of relative humidity φ_{Air} of the external and internal air to the winter season resulted in each case with $\varphi_{\text{Indoor Air}} < \varphi_{\text{Outdoor Air}}$ to the maximum and minimum values respectively outside (84 % and 64 %) and inside (80 % and 59 %) of the window. Indoor TIA (and outdoor TOA) air temperatures ranged from 10 °C to 23 °C (from – 0.5 °C to 13°C).



a) b)

Figure 4. Variation of relative humidity of air φ_{Air} and air temperatures (TIA and TOA) during a) summer and b) winter

Olgyay diagrams for summer and winter season were built by setting the values of thermal comfort of window under real climate conditions. To evaluate the thermal performance of the window, the inside or outside location of points of window performance is compared to the boundaries of the respective areas of seasonal thermal comfort.

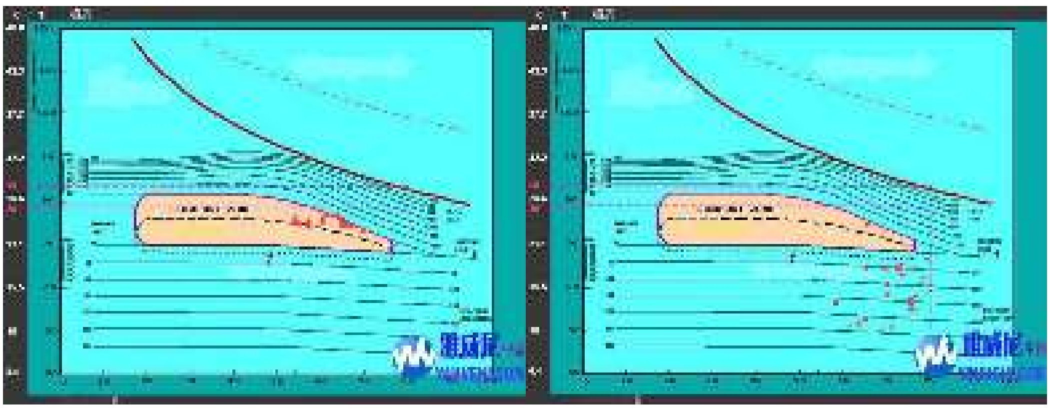


Figure 5. Variation of values (φ_{IA}, TIA) in the Olgyay diagram for the season: a) summer and b) winter

3.2. Analysis of changes of the temperatures between the interior surfaces of glass and frame, as well as between the center (middle point) and corners of window

Average temperatures measured on interior surfaces of window ranged from 24.94 °C to 25.55 °C in the summer; and from 10.99 °C to 12.52 °C in winter, resulting in very similar values. Center of window glass resulted warmer (25.55 °C) in summer and colder (10.99 °C) in winter, but the corners of the window frame resulted in the lowest/ higher average temperature (Summer/Winter : 24.94/12.63 °C). This was due to the change of direction of the heat flow according to the season. This temperature difference was 0.6 °C in summer and 2.64 °C in winter. Average temperatures of the glass surface between the center and its corners showed a small temperature difference of 0.05 °C in summer and a significant temperature difference of 1.66 °C in winter. This temperature difference in summer/winter: 0,5/0,11°C was more significant/less significant for the surface temperatures of the frame, where corners belonging to the perimetral edges of thermal bridges. On this occasion, during the summer noon, when the heat comes from the outside to inside, there was the impact of higher thermal capacity of the wooden frame against the window glass. During the summer the building of *box plot and whisker* diagrams clearly displayed a range of extremes temperatures of surface of frame corners narrower than in other cases, as well as the maximum temperature in this case was the lowest (26.25 °C), occurring due to the impact of thermal bridges. Only ATGCo - value of 30.075 °C was outside the range as maximum outlier, respectively above the upper *wisker* value. ATGCe - value appeared at a narrower range during winter, but the ATFM - value displayed a more regular distribution of values against the average. The highest minimum value of the average temperatures was ATFM =7.625 °C in winter and the highest maximum value was ATFCo =16.233 °C. Only two of minimal ATGCe - values and one of minimal ATGCo – values, respectively 4 °C and 5 °C, fell outside the range as minimum outliers, i.e. below the lower *wisker*.

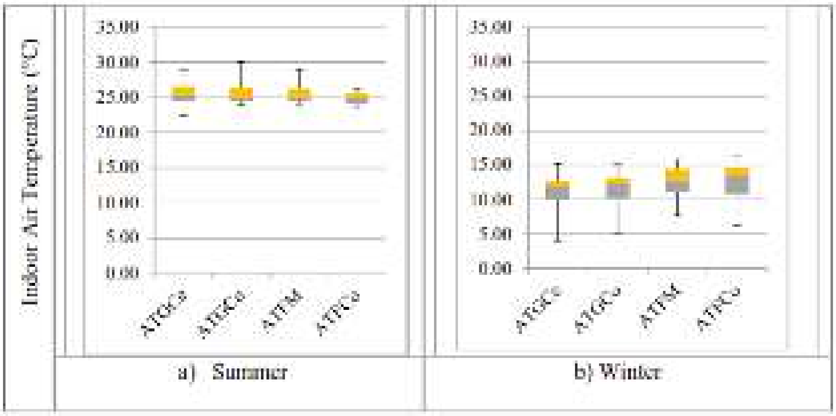
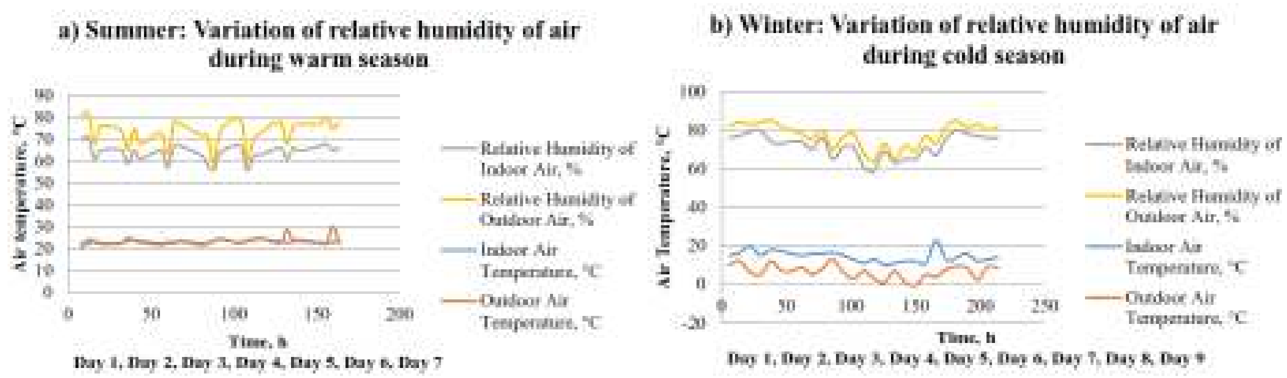


Figure 6. Box plot and whiskers for the indoor temperature of the window glass and wooden frame: a) summer, b) winter

3.3. Analysis of the effect of the temperature of the surface to air temperatures

It was observed that changing the TIA during the summer had the greater impact in changing of ATGCe, and this impact on ATFCo was smaller. Two linear graphs of ATGCo (y=1.5206·x - 10.045) and of ATFM (y=1.5004·x - 9.6569) resulted almost matched, featuring almost the same impact on the TAB. During the winter it was observed that ATGCe (y=0.3753·x + 6.1706) and ATFM (y=0.4677·x + 5.6945) graphs were nearly parallel, and that changing the TIA resulted in greater impact on ATFCo, and less on ATGCo. In all cases that were studied was shown a generally strong and positive correlation between the indoor air temperature and the surface temperature of window glass and wooden frame (on the center and on the corners of glass, on the middle and on the corners of frame).



a) b)

Figure 7. Surface temperature versus indoor air temperature TIA: a. Summer, b. Winter

By One-Way ANOVA test (linear model) showed:

- failure of the rejection of the null hypothesis H0, i.e. all sub- populations of the population of the surface temperatures of glass and frame on the middle points and on the corners of the window had the same mathematical expectation, and
- rejection of the alternative hypothesis H1, under which were at least two sub- populations with different mathematical expectation, because the value of probability of psummer=0.7008 was greater than the significance level of $\alpha = 0.05$; likewise it resulted from comparison of Fisher's criterion: Fsummer=0.4754 < Fcrit =2.7826; it resulted for winter likewise but closely, respectively pwinter=0.0623 > $\alpha = 0.05$; Fwinter=2.516 <Fcrit=2.692.
- Evaluation of variance by One-Way Anova test showed that:
- The variance between the groups of temperatures resulted lower (≤ 0) that the variance within the group with a probability of Summer/Winter : 0.7008/0.0623 greater than level of significance of $\alpha=0.05$; i.e. failed rejection of zero hypothesis H0. The null hypothesis H0 also failed to be rejected by comparison of other variances were taken into consideration in the Anova test, because:
- Difference of variance within the group, compared with the variance between groups, resulted = 0 with a probability of Summer/Winter: 0.5984/0.1247; greater than the significance level $\alpha = 0.05$;
- Difference variance within the group, compared with the variance between groups, resulted ≥ 0 with probability Summer/Winter: 0.2992/0.9377; greater than the significance level of $\alpha=0.05$. Through ANOVA One - Way test resulted that there was no significance between the surface temperatures of window glass and frame during both seasons: a) Summer ($F(3.52)=0.4754$; $p=0.7008$) and b) Winter ($F(3.52)=2.516$; $p=0.0623$).

p - and $\mathbf{R_2}$ - values were determined during Anova t-test two tail, comparing the population of TIA with each population of surface temperatures of window components (glass and frame) in the center (middle points) and corners. During the summer the maximum **p**-value of 0.043711 (R_2=0.297112) resulted to the corner of window glass, and the minimum **p**-value of 0.002512 (R_2=0.546643) resulted to the glass center. **p**-values of window frame fell between these extremes values. During the winter, the maximum **p**-value of 0.015564 (R_2=0.212339) resulted to corner of window glass, and the minimum **p**-value of 0.000142 (R_2=0.445625) resulted to the frame corner. **p**-values at the center of the constituent elements of window fell between these extremes values.

Table 1. p- values and R_2: a) Summer b) Winter

		Glass Center	Glass Corner	Frame Middle	Frame Corner
a)	R^2	0,546643	0,297112	0,436738	0,456627
	p-value	0,002512	0,043711	0,010147	0,007994

		Glass Center	Glass Corner	Frame Middle	Frame Corner
b)	R^2	0,228168	0,212339	0,409734	0,445625
	p-value	0,011743	0,015564	0,000323	0,000142

By Tukey-Kramer test resulted minimal significant differences (MSDs) of 1.533 and 1.806; respectively for summer and winter. Also absolute values of averages difference between each pair of temperatures populations resulted smaller than the minimum significant difference MSD. Finally, the Tukey-Kramer test resulted that all averages of temperatures populations were not any difference between them for the accepted level of trust, namely the groups of temperatures populations of surfaces of window glass and of wooden frame had the same mathematical trend.

4. Conclusions

- **Thermal comfort**

Field of results fell within the zone of thermal comfort by Olgyay model, respectively at its limit (only 2 (two) performance's points fell outside the limits of comfort zone of window), confirming the hypothesis **1-H$_0$** for the summer. This **1-H$_0$** hypothesis was not confirmed for the winter season, because with the exception of one, all values fell outside the limits of comfort zone of the window. Using window with single glass of 4 mm resulted in boundary state of thermal comfort for indoor environment. Considering the location of the building, its position against winds, and weather conditions of the area (during measurement), it was concluded that the window with the single glass of 4 mm, which was taken into consideration, met the conditions of thermal comfort during the summer but not during the winter

- **Differences between the temperatures of the internal surfaces of glass and window frame**

It was concluded that different values of surface temperatures of different materials of window influenced by relative air humidity φ_{Air} and internal TIA and external TOA air temperatures to them. It was concluded that the colors of surfaces affected the temperature of surfaces, because dark surfaces (wooden frame) absorb more solar radiation and there is a lower solar reflection, while areas of light colors (window glass) reflect more light and higher solar reflection, according to Sailor (1995) (Guan, 2011). The results obtained to temperatures on the window glass and the wooden frame confirmed the 2-H$_0$ hypothesis and conclusions according to (Guan, 2011), which stated:

- than the window glass surface is more smooth, it is the more cold; while tougher surfaces (wood frame in this case) are warmer due to exposure to the sun during the day, according to (Doulos *et al.,* 2004),
- than the window materials (the glass and the wooden frame) absorb heat during the day and radiate it back later by heating the indoor air according to (Svensson & Eliasson, 2002).

It was also concluded from the results of temperature changes on the surface between different materials of the window (glass and wood frame), that during the winter the temperature in the center of glass were higher than the temperatures in his corners (as a result of thermal bridges) confirming 3-H$_0$ hypothesis. It was also concluded, through the statistical tests (Anova and Tukey - Kramer) of temperature data on the indoor surface of glass and wooden frame in the center (center) and in the corner, that the population groups of average temperatures of surfaces of window glass and wooden frame had the same mathematical tendency, proving the hypothesis 4-H$_0$, but it was not possible to determine the effect of heat absorbed by the material at the temperature of the indoor air.

5. Recommendations

It is recommended:

- replacing the window with a single glass through the window with double or triple glazing because the location of the temperature range is also shifted within limits of comfort zone, creating improved thermal performance of the window,
- the assessment of impact of thermal bridges on the energy performance of windows, even through simple tools and methods of measuring,
- that the thermal measures be taken to have a difference as small as possible between the temperature of the internal surfaces of materials that compose the window: glazing (in the center and in the corner) and wooden frame (in the middle and in the corner), especially during the season winter.

6. References

1. Doulos LM, Santamouris and Livada I: **Passive cooling of outdoor urban spaces. The role of materials**. Solar Energy. 2004.Vol.77. 231-249,
2. Guan KK: **Surface and ambient air temperatures associated with different ground material: a case study at the University of California**. Berkeley, Spring, 2011, 1-14,
3. Jokl MV: **Thermal comfortand optimum humidity. Part I;** Acta Polytechnica, **42**, 1/2002, 12-24,
4. Papadopoulos AM, Theodosiou ThG, Karatzas KD**: Masat rinovuese për realizueshmërinë e kursimeve të energjisë në ndërtesat urbanistike. Impakti i çmimeve të energjisë dhe**

kriteri i pranueshëm për kohën e vetëshlyerjes. 1-14,

5. Rellihan SS: Design with climate: **A retreat for vieques**, Puerto Rico, 2003, 1-75,
6. Svensson, M. K. & Eliasson, I. **Diurnal air temperatures in built-up areas – an urban planning perspective**, Landscape & Urban Planning, No.61/2002, pp.37–54.
7. Voshtina L, Simaku Gj: **Ngrohja, ventilimi dhe klimatizimi i ndërtesave**, 2004, Tiranë, ISBN 99943- 638-4-0, 5-30.