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THERMAL COMFORT IN LIBYA - FIELD STUDY

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Abstract

As part of the thermal comfort investigation in Libya a thermal comfort field survey was carried to set local thermal comfort temperature. This paper will present a field study results of thermal comfort in Libya. A thermal comfort survey has been held out in 39 domestic building across the three cities from three climatic zones, The criteria of selection only limited in free running domestic houses (naturally ventilated houses). Nearly 160 persons were included in this survey, they have been interviewed in their houses under their normal living conditions during the hottest (Summer), the coldest (Winter) and the moderate (Spring) periods of the year. The study investigates and assigns the thermal comfort temperature in three climatic zones in Libya, and three equations were concluded from the study, using the running mean outdoor temperature as predictor of the thermal comfort, that can indicate the limits of the comfort zones for the three cities. The paper also presents the researcher study on thermal insulation values for traditional Libyan clothing. The most common ensemble clothing for women and men were tested using thermal manikin.

Keywords: *Thermal comfort, Adaptive thermal comfort, Thermal insulation values for traditional Libyan clothing.*

1. Introduction

This paper reviews three thermal comfort studies that have been conducted in the three cities Tripoli, Ghadames and Gheryan. From the three cities nearly 160 individuals have been interviewed in their own houses, 16 houses in Tripoli, 12 houses in Ghadames and 11 houses in Gheryan, during the hot period of the year. The buildings were selected from naturally ventilated buildings ranging from vernacular traditional houses to new houses in the three climatic zones. However, In Ghadames and Gheryan most of the data was collected from new houses, since most of the traditional vernacular houses were deserted.

The subjects were asked to complete a questionnaire, which was divided into two parts Personal questions (Gender and Age) and thermal comfort questions; which referred to their thermal sensation, the air movement, humidity and their preferences. In addition they have been asked about their clothing and activities during the last hour. The subject marks their thermal sensation in seven steps according to the ASHRAE scale, and the environmental variables air temperature and RH, air flow and Air quality were measured. The subjects concerned in the survey were from both genders; the gender distribution was 43% percentage of the votes for female and 57% male, and their age ranging from 18 to over 80 years old. The study covered three seasons summer 2010 and winter 2010 and spring 2012.

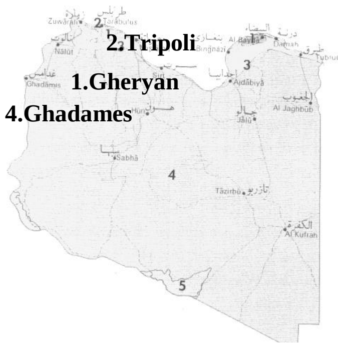


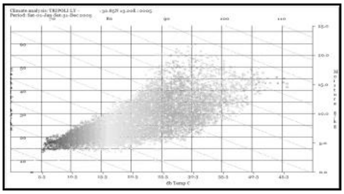
Figure. 1, the general classification of Libya's climate, after Buxtehude, 1981

2. Climate of Libya

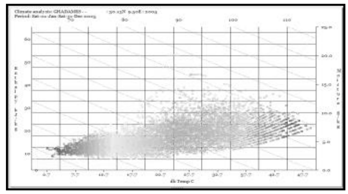
The Libyan population is mainly distributed in three climatic zones: Semi-Mediterranean on the coastal area (2-hot-humid), Mediterranean climate on the mountains (1-cold zone) and Steppe (4-semi-arid). In this study three cities were selected each featuring these main climatic zones, respectively Tripoli, Gheryan and Ghadames.

3. Clothing

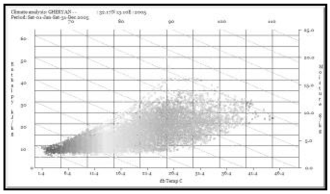
Clothing is one of the main parameters that effect the thermal sensation of the people; therefore evaluating the clothing thermal insulation of subject's clothing is important. In Libya cultural factors have a great influence on clothing type, the clothing preferences of the Libyan people have been categorise into two categories western clothing and traditional clothing.



Tripol



Ghadames



Gheryan

Figure. 2, Annual Psychometric charts.

In order to estimate the clothing insulation for the western clothing the study uses ASHRAE tables, (ASHRAE, 1992; ISO, 1994, 1995). These have been developed from clothing insulation studies conducted in laboratory studies, mainly for western clothing. However, the data from the field survey shows that a number of subjects included in the survey were wearing traditional Libyan clothing, therefore finding the thermal insulation value for the traditional Libyan clothing is important to study the thermal sensation and comfort temperature in Libya.

Recently, ASHRAE extended the western clothing table to include the non-western clothing, in the 1504-TRP, “Extension of the Clothing Insulation Database for Standard 55 and ISO 7730.” The data also include the effect of posture on air movement. Unfortunately Libyan traditional clothing is not included in the tables. This led the researcher to conduct a test to evaluate the thermal insulation of the traditional Libyan clothing in the climate chamber. With the help of Dr. Simon Hodder, a Technical Tutor (Ergonomics) at the Environmental Ergonomics Research Centre (University of Loughborough), the thermal insulation properties of the Libyan traditional was tested using thermal manikin.

3.1 THE DESCRIPTION OF LIBYAN TRADITIONAL CLOTHING

The traditional libyan clothes are unique in their components and ensemble, as they are products of the mediterranean civilizations influence on the libyan tradition. the libyan traditional male clothes changes according to seasons (figure 3). it consists of two parts the internal and external clothing, the internal clothing include (1) the serwal a loose light trousers made of cotton, (2) Suriya is a short loosely fitting gown that covers the body to the knees, and (3) Farmela, a cotton vest is worn in summer; however in winter a long sleeve Farmela (4) replaces the vest or worn over the vest.

Figure. 3, Libyan traditional clothing for male and female

The external clothing part (Al Ja'red)(6) a garment that is similar to the Ancient Roman toga. A white cloth of 4-meter long and 1meter width is wrapped around the body in special way. It is worn over the internal clothing. The male clothing ensemble changes according to seasons. In summer, a man usually wears the Serwal and Suriya only without the vest inside the house. However wearing Al Jared in winter is most common in older generation.

There are two sorts of female traditional clothing: the internal clothing and external clothing. The internal clothing includes; (7) Serwal, light loose trousers made of cotton, (8) Eqmeja a short loosely fitting long sleeve dress, usually made of light material in summer and heavy material in winter. (8)Al Re'da is the external part worn by female in everyday. It is a coloured cloth of 4-meter long and 1 meter width, usually made of cotton and sometimes wool and silk, but cotton is the most common material for everyday wear. It is wrapped around the body over the dress and trousers. The material of the Re'da changes according to seasons, in summer, they are made of cotton material while in winter they are made of wool (figure 3). Wearing a headscarf is part of the Libyan female traditional clothing; usually it is made of the same material of the Re'da. These days female wear Re'da over their western clothing mainly over a dress. However cu\lturally, the external part of the clothing cannot be worn by it self the Re'da have to worn all the time.

3.2 EVALUATING THE THERMAL INSULATION OF THE TRADITIONAL LIBYAN CLOTHING

The Libyan traditional clothing for women and men were tested using the most common ensemble, and the everyday clothing.

Figure. 4, the traditional Libyan clothing for female and male worn on the thermal manikin (Newton)

The test of the thermal insulation for winter and summer traditional Libyan clothing for male and female are listed in the following table.

Male summer clothing	Clo	m2.oC/W	Female-summer clothing	CLO	m2.oC/ W
(1) Shirt (Suriya)	0.22	0.034	(8) Long sleeve light shirt-Eqmeja	0.22	0.034
(2) Trousers (Serwal)	0.26	0.040	(7) Trousers (Serwal)	0.26	0.04
(3) Vest (Farmela)	0.15	0.023	(9) External material (Ra’ da)	0.69	0.107
Total for Summer	0.63	0.098	Total for summer	1.176	0.182
Hat (Al Shana)- wool hat	0.17	0.026	Head scarf	0.062	0.01

Table 1 Thermal insulation value for the female and male traditional Libyan clothing in summer

Male – winter clothing	CLO	m2.oC/W	Female – winter clothing	Clo	m2.oC/W
(1) Shirt (Suriya)	0.22	0.034	Long-sleeve shirt (Eqmeja)	0.29	0.045
(5) Trousers (Serwal)	0.26	0.04	Heavy long-sleeve sweater	0.37	0.058
(4) Heavy jacket– (Farmela)	0.49	0.076	Trousers (Serwal)	0.26	0.045
(6) External material (Al-Jared)	0.98	0.155	External material (Ra' da)	0.69	0.107
Total for winter	1.95	0.35	Total for winter	1.61	0.25
Hat (Al Shana)- wool hat	0.17	0.026	Head scarf	0.06	0.01

Table 29 Thermal insulation value for male and female traditional Libyan clothing in winter

In winter season the traditional Libyan clothes for women are usually heavier than summer as they wear a heavy Cardigan. On the other hand the men traditional clothing for winter are even heavier as they wear (Al Jared), wrapping it around the body over the internal clothing (long sleeve shirt and trousers and heavy vest or jacket) as illustrated in figure (3).

The above tables show that the thermal insulation for the women traditional Libyan clothing are heavier then men in summer and lighter in winter. This can be related to cultural factors, as wearing Re'da is obligatory for women in many families especially in extended families houses and in most of the older generation. Men's clothing varies from light clothing with low insulation value 0.63 clo to higher thermal insulation value in winter with 1.952 clo by wearing a heavy jacket, 0.49clo, and Al Jared with 0.982 clo.

From investigating the thermal insulation of Libyan clothing; where in the summer, females in Libya usually wear heavier clothes than the male clothing, while in winter men were recorded to wear heavier clothes than women. The research shows that, older generations tend to wear heavier clothing than the younger generation, and wearing traditional Libyan clothes is more common in the older generation.

The variation of clothing is subject to climate and culture, in terms of climatic aspect; from the survey the subject were found to wear less than 0.5clo if the operative temperature is higher than 25°C and they wear heavier cloths when temperature is low. The clothing as an indicator of behavioural adaptation to the climate is illustrated in figure (5).

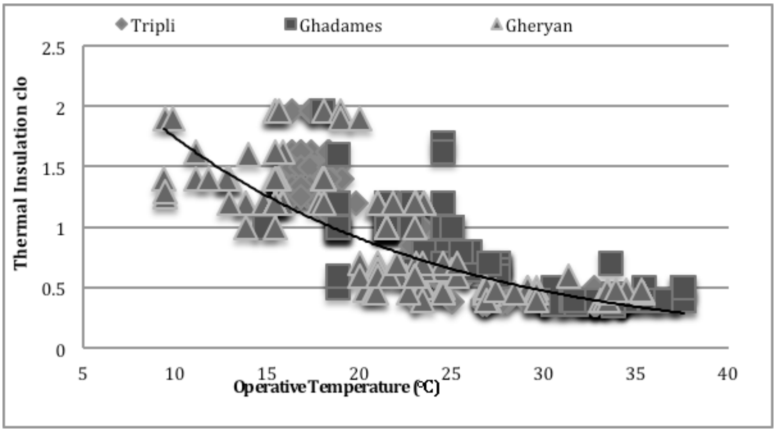


Figure. 5, the average clothing insulation worn in the three cities

The subjects were asked about their activity over the last two hours before the interview, and this information is used to develop a met estimate for each participant. Using the Metabolic Rate table, ANSI/ASHRAE Standard 55-1992R (Activity levels – Metabolic Rates for Typical Tasks). According to ANSI/ASHRAE Standard 55-1992R (Activity levels – Metabolic Rates for Typical Tasks) most of the activities are ranged between standing or sedentary work with 1.2 met (70W/m^2), to medium light work with 2 met (116 W/m^2). This shows that women tend to record more activity than men; this is mainly as a cultural factor in the country where only women are responsible for housework.

However, the standard table has been calculated based on the western life style, there is many factors determined the metabolic rate such as the meaning of the activity description can be vary according to culture, using 2.0 met as an estimate for housekeeping in the ANSI/ASHRAE Standard 55-1992R cannot be applied on the Libyan women were housecleaning includes heavy work such as cleaning carpet or courtyards.

4. Comfort Vote Data Analysis

The result obtained from the survey, are used to indicate the comfort temperature for Tripoli, Ghadames and Gheryan. First Linear regression analysis using the least square method have calculated between the thermal sensation as dependent variable and the indoor operative temperature, from the results the thermal comfort temperature was calculated using Griffiths method (Griffiths, 1990). Finally, the linear regression analysis was used to predict the thermal comfort temperature using the running mean outdoor temperature as predictor.

The response of the subjects to the thermal environment (Actual Mean Vote) is plotted against the indoor operative temperature. The linear regression of the relation between the thermal sensation and the operative temperature in the three cities in summer, winter and spring shows that the respondents were thermally comfortable in a wide range of indoor operative temperature. The air movement below 0.5m/s and with average relative humidity 50%, the operative temperature is sufficient thermal index to define the neutral temperature.

Location	Values for a	Values for b	Correlation coefficient r2
Tripoli	0.1684	-0.4368	0.69
Ghadames	0.1005	1.2014	0.4
Gheryan	0.1599	-0.0664	0.63

Table 310 the result of the linear regression

The relationship between the AMV and the operative indoor temperature for the three cities are shown in Figures (6). According to the polynomial trend line illustrated in the graphs, in the three cities people voted comfort in wide range of operative temperature; in the city of Tripoli the people voted comfort in operative temperature ranges from 20°C to 32°C, and in Ghadames they vote comfort in operative temperature ranges from 20°C to 35°C, while in Gheryan people vote comfort when the operative temperature in between 20°C and 30°C. This shows that in Libya people tend to adapt to wide range of temperature.

Moreover a linear regression analysis shows that the desert (Ghadames) is higher than the coastal zone (Tripoli) and the mountain zone (Gheryan), indicate that people in Ghadames tolerate higher temperature than Tripoli and Gheryan. The neutral temperature found from the linear regression equations illustrated in Figure (6) Shows the results of linear regression in the form: C = aTi + b. In other word to calculate the comfort temperature (Tn) for the summer and winter, in Tripoli subjects voted neutral (C=4) when the temperature is 26.3°C, In Ghadames the subjects voted neutral in a higher temperature 27.8°C. In Gheryan the subjects voted neutral in a lower temperature 25.4°C. Statically, the correlation coefficients for comfort temperature in the three cities are low; there are two reasons for this result; first this is expected for any field studies that attempt to predict human psychology and respond toward thermal comfort. Secondly, the low number of subjects in the survey for each city (nearly 50 per season) and measurement error can result this low regression.

Taking the comfort temperature value from the people who voted neutral reduces the data by neglecting the other votes and therefore an unreliable comfort temperature. As noted by Nicol "If, for any block of data, the mean operative temperature and the mean thermal sensation are known it is simple to calculate the thermal comfort temperature" this also known as Griffiths method, (Nicol, Humphreys, and Roaf 2012 -P16). Therefore, for a small group of subjects using the Griffiths method is more reliable for evaluating the mean comfort, by assuming the increase in temperature for each thermal sensation scale point using the Griffiths slope G (K-1), this is equivalent to the regression coefficient between the comfort vote and operative temperature.

In this study the regression coefficient between the comfort vote and operative temperature was found from the scatter chart illustrated in figures (6). The study used Griffiths method and adopted Humphrey's assumption for the G value where the increase in temperature for each thermal sensation scale point is 2K. And the correlation between the comfort vote and operative temperature was found from the chart illustrated in figure (6), the comfort temperature was calculated for each vote using the following equation

$$T_{comf} = T_{op} - {}^{TS}/_{G} \qquad (1)$$

Where T_{comf} is the comfort temperature, T_{op} is the mean operative temperature, and TS is the mean thermal sensation. The Top and Ts was found from the field survey for each city and during each season, the comfort equation for the three cities was as follows

$$T_{comf} = a\,T_{op} + b \qquad (2)$$

According to research questionnaire for example at operative temperature 30 ℃ a person voted (5 slightly warm) on the thermal sensation scale, therefore to feel comfort (4) we need to reduce the operative temperature 2K which is equivalent to one thermal sensation, and his comfort temperature will be 30-2K= 28℃. According to chart figure (6) the thermal comfort temperature equations for the three cities have been calculated as follows

$$T_{comf} = 0.6631T_{op} + 8.8735 \quad (3) \qquad R^2 = 0.90 \text{(Tripoli)}$$

$$T_{comf} = 0.799\, T_{op} + 5.5972 \quad (4) \qquad R^2 = 0.91$$
(Ghadames)

$$T_{comf} = 0.6803\, T_{op} + 8.1283 \quad (5) \qquad R^2 = 0.89 \text{(Gheryan)}$$

From the above equations (3,4 and5) it is clear that subjects in Ghadames tolerate higher temperature than Tripoli and Gheryan. For example for the indoor operative temperature 30℃, Ghadames comfort temperature is nearly 29.5℃, while in Tripoli and Gheryan it is 28.5℃.

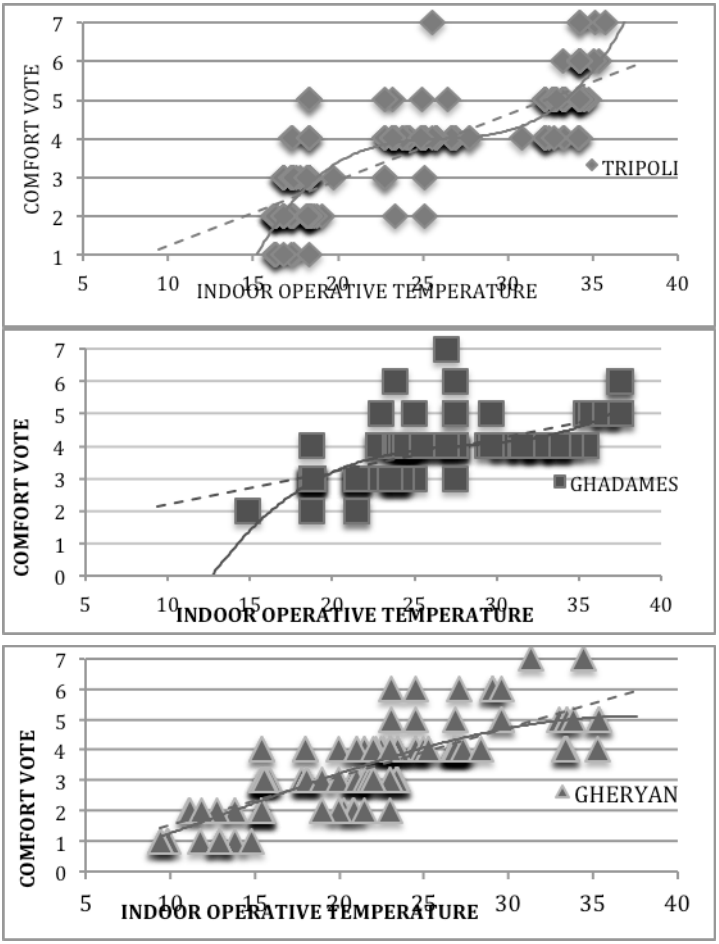


Figure. 6, Poly. and linear regressions of AMV on indoor Temperature for objects in three cities during the three seasons

3.3 THE COMFORT TEMPERATURE VERSUS RUNNING MEAN OUTDOOR TEMPERATURE

According to Adaptive theory, predicting thermal comfort temperature is dependent on indoor environment and out door temperature. Therefore calculating comfort temperature using the running mean outdoor temperature is crucial. In this study the running mean outdoor temperature was selected as predictor of the comfort temperature with $\propto = 0.8$ using the following equation (Humphrey, 2010);

$$\mathrm{T}_{\mathrm{rm(tomorrw)}} = \propto \times \mathrm{T}_{\mathrm{rm(yesterday)}} + (1-\propto) \times \mathrm{T}_{\mathrm{m(today)}}$$

The running mean outdoor temperature was taken from the data collected from the three cities using a long term-temperature reading computer chip (iButtom) installed outside the houses for 10 days during summer, spring and winter seasons, using the courtyard temperature data in Tripoli and Gheryan, and the roof temperature in Ghadames. However, for missing data, it has been estimated with respect to the weather data collected from meteorological stations. Chart illustrated in figure (7) shows the correlation between the running mean outdoor temperature and the comfort temperature for the three cities. Comfort temperature for the three cities can be found from the above chart as follows:

$$T_{comf} = 0.51T_{rm} + 14.12 \qquad R^2=0.85 \qquad (6)$$

$$T_{comf} = 0.46T_{rm} + 16.72 \qquad R^2=0.7 \qquad (7)$$

$$T_{comf} = 0.47T_{rm} + 14.26 \qquad R^2=0.7 \qquad (8)$$

To indicate the limits of the comfort zones for the three cities it can be assumed that subjects can be comfortable in a range from 3 to 5 on the thermal sensation scale, 3 for slightly cool and 5 for slightly warm.

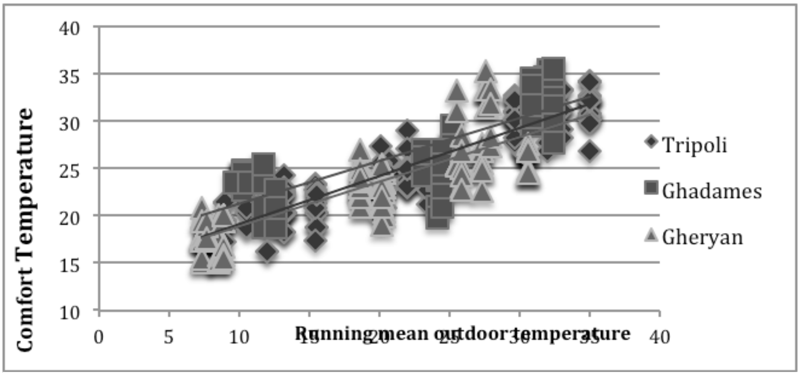


Figure. 7, Comfort temperature versus running mean outdoor temperature

5. Conclusion

The Paper analysis the outcome of two studies, first, is the finding from investigating the thermal insulation of Libyan clothing; where in the summer, females in Libya usually wear heavier clothes than the male clothing, while in winter men were recorded to wear heavier clothes than women. Thermal insulation of the traditional Libyan clothing was tested in a climatic chamber and the results show that male traditional clothing is 0.63clo in summer and 1.95clo in winter. While female traditional clothing is 1.17clo in summer and 1.6clo in winter. The research shows that, older generations tend to wear heavier clothing than younger generation, and wearing traditional Libyan clothes is more common in older generation.

Secondly, a thermal comfort investigation in the three cities is conducted to calculate comfort temperature in Libya; Occupants' adaptive adjustments have a great influence in setting the thermal comfort temperature in the three cities. The study correlates the comfort temperature with the indoor operative temperature and the running mean outdoor temperature to define comfort temperature. The study investigates and assigns the thermal comfort temperature in three climatic zones in Libya, and three equations were concluded from the study, using the running mean outdoor temperature as predictor of the thermal comfort, that can indicate the limits of the comfort zones for the three cities.

It is important to highlight the critical use of Griffiths method and the Humphrey's assumption for the G value where the increase in temperature for each thermal sensation scale point is only 2K, and according to the field study people seems to adapt and feel comfort at high temperature, therefor more studies in the field are required.

There is limited thermal comfort research in Libya conducted by just a few studies (Ealiwa et al. 2001; Alzubaidi, 2002; Akair and Bánhidi 2007)(Akair and Bánhidi, 2007; Alzubaidi, 2002; Ealiwa et al., 2001), thus, thermal comfort standards are not defined in Libyan Codes yet. The small numbers of respondents in most of the thermal comfort investigations in Libya do not give a good estimation for population responses. Therefore more studies in the field are required. The data in this research can be part of a broader study to set a thermal standard for the North African Countries 'Al-Maghreb Al-Arabie' includes (Libya, Tunisia, Algeria, Mauritania and Morocco).

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References

Al-ajmi F F, Loveday, D.L Bedwell, K.H., Havenith, G., 2008. *Thermal insulation and clothing area factors of typical Arabian Gulf clothing ensembles for males and females: measurements using thermal manikins*. Appl Ergon 39, 407–414.

Brager, G.S., Dear, R.J. de. 1998. *Thermal adaptation in the built environment: A literature review*. Energy and Buildings 27, 83–96.

De Dear, R., Brager, G.S., 1998. *Developing an Adaptive Model of Thermal Comfort and Preference.* http://www.cbe.berkeley.edu/research/other-papers/de Dear - Brager 1998 Developing an adaptive model of thermal comfort and preference.pdf

Engineers, A.S. of H.R. and A.-C: 2009. *ASHRAE Handbook - Fundamentals (I-P).* American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Fanger, P.O: 1973. *Thermal Comfort.* New York: McGraw-Hill Inc.,US.

Griffiths, I: 1990. *Thermal comfort studies in building with passive solar features*: Field studies Report to the Commission of the European Community, ENS35 090 UK.

Humphreys. M., Rijal H. B., Nicol J. F: 2010. *Examining and developing the adaptive relation between climate and thermal comfort indoors*. Windsor 2010. http://nceub.commoncense.info/uploads/22-01-05-Humphreys.pdf. (Accessed 26 July 2011).

J. Fergus Nicol & Mike Wilson: 2011: *A critique of European standard EN 15251: strengths, weaknesses and lessons for future standards,* Building Research & Information,39:2, 183-193. http://nceub.commoncense.info/uploads/16-01-02-Nicol.pdf

Nicol, F: 2004. *Adaptive thermal comfort standards in the hot-humid tropics* [An article from: Energy & Buildings]. Elsevier.

Nicol, F., Humphreys, M., Roaf, S: 2012. *Adaptive Thermal Comfort: Principles and Practice*. Routledge, Abingdon u.a.

Olesen, B.W., Brager, G.S: 2004. *A better way to predict comfort*: the new ASHRAE standard 55-2004.

Parsons, K.C: 2002. *The effects of gender, acclimation state, the opportunity to adjust clothing and physical disability on requirements for thermal comfort*. Energy and Buildings 34, 593–599.

Nicol, F: 1995. *Standards for Thermal Comfort: Indoor Air Temperature Standards for the 21st Century*. Taylor & Francis.

Zhang, H., Huizenga, C., Arens, E., Yu, T: 2001, *Considering Individual Physiological Differences in a Human Thermal Model*. Center for the Built Environment. http://escholarship.org/uc/item/9451r851. (Accessed 20June 2011).