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CLOTHING INSULATION AND THERMAL COMFORT IN AFRICA: CURRENT STANDARDS AND APPLICABILITY.

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Abstract

Background: *The adoption of air conditioning (AC) is growing rapidly in developing countries across the world which puts a high burden on electricity distribution systems. This development is mostly driven by income growth and building design, but also due to increasing outdoor temperatures and to provide indoor thermal comfort. Current indoor thermal comfort standards are based on western clothing (in terms of the ASHRAE Standard 55 and ISO 7730). However, due to different clothing practices in regions such as Africa, providing comfortable indoor environments may differ significantly. For optimal design and achieving energy savings of AC systems, accounting for different clothing practices is fundamental.*
Methods: *The research presented is based on a project aimed at the extension of the ASHRAE Standard 55 database to include non-western clothing. The paper focuses on the African clothing tested on thermal manikins. Three sets of female clothing and five sets of male clothing were measured. The ISO7730:2004 standard which uses the PMV/PPD indices was used to assess the optimal indoor temperature (assessed between 20-30 °C). The occupant was considered acclimatized with low activity (120 W), with an air velocity of 0.2 m/s, no additional heat radiation and a relative humidity of 50 %.*
Results and Conclusion: *The optimal indoor temperature for both women (PMV: -0.09, PPD: 5 %) and men (PMV: 0.1, PPD: 5 %) was found to be 24 °C. Considering better ventilation and evaporation in African clothing the comfort temperatures could be even higher. In conclusion, sub-optimal indoor thermal conditions are being adopted in Africa resulting in lower indoor air temperatures than required, causing an unnecessary waste of energy from AC systems and affecting the thermal comfort of the occupants.*

Keywords: *Thermal Comfort, Developing Countries, Air Conditioning, Standardization, Clothing*

1 Introduction

Almost 60 % of the world's electricity is consumed in residential and commercial buildings, most for space heating and cooling, making more efficient energy use and sustainable energy supply in buildings, critical [1]. Global climate change will increase outdoor temperatures, and may harm health and productivity for millions of people, the African continent being specifically vulnerable [2-5]. Air conditioning (AC) is a common technical solution to provide a comfortable indoor environment and includes both temperature and humidity control of the indoor air [6]. However, growing AC use increases electricity consumption and therefore climate change, if the energy source is not renewable. It also contributes to the urban heat island effect due to heat rejection outdoors from the AC unit [7]. It is well known that cooling demand increases as the climate warms and the temperature gradient between the indoor and outdoor temperature greatly affects the electricity consumption of the AC unit [1].

Currently, it is estimated that the world consumes about 1 trillion kilowatt hours (kWh) of electricity for AC annually; more than twice the total energy consumption of Africa. It is also estimated that the energy for cooling could increase tenfold by 2050 [8]. Most of the projected growth in air conditioning is expected to occur in Asia, while the use in Africa will grow more slowly [9]. Significant growth is forecasted in the upcoming decades in North Africa. On the other hand, growth will remain low in Sub-Saharan Africa, as income in these countries is not expected to exceed the threshold of affordability [10]. The growth in AC use is mostly driven by income growth and perceived need, but also due to increasing temperatures due to climate change [3] and to provide thermal comfort. In addition, new housing developments in Africa are dominated by modern building characteristics with an influence of western architecture, such as glass-dominant structures, predominant use of concrete, and incorporation of large windows and flat concrete roofs which leads to large cooling loads. Without electricity, the modern building designed for AC becomes a heat trap. The faith in modern scientific solutions to achieving thermal comfort has side-stepped local knowledge. AC has therefore become the most common option for cooling comfort [11]. The growing use of electricity increases risk for blackouts during summer peak demand and during heat waves, with associated high health risks [12].

The negative impacts of increased energy costs for cooling are projected to be concentrated in the tropics and subtropics. The Global Energy Assessment (2012) identifies that the social choices about cooling technology will prove increasingly important in the future [1]. In contrast, energy demand for heating is projected to increase until 2030 and then stabilize. While heating is commonly done with natural gas, biomass and fossil fuels, AC depends on electricity. These trends create additional inequity between low and high income countries as tropical and subtropical countries will increase the electricity and primary energy demand, while there may be a beneficial effect (less heating needed) in more temperate high income countries [1].

The objective of this paper is to explore thermal comfort and energy reduction potential of AC systems on the basis of the traditional clothing worn in Africa. African nations often have different clothing behaviour from the west and knowledge of the insulation parameter is essential in optimizing the AC systems for these countries. The research is based on an ASHRAE project aimed at expanding the clothing databases to include traditional non-western clothing. Comprehensive data on clothing insulation values are available however; the vast majority of these data are for western-style clothing ensembles. Therefore, an extension of the ASHRAE database was called for as clothing insulation is a crucial parameter in the assessment of thermal comfort [13-18]. This study focuses on the African clothing tested for insulation, evaporative resistance and ventilation on thermal manikins at laboratories in Sweden, UK and Hong Kong [19]. Different clothing materials, body postures and ventilation ability affect the insulation value of clothing ensembles. Three sets of female clothing and five sets of male clothing were tested in the project and thermal comfort was evaluated using the thermal comfort standard ISO7730:2004 which uses the PMV/PPD indices [20].

2 Materials and Methods

Clothing

The traditional African work clothing was tested on thermal manikins at Lund University, Sweden, Loughborough University, UK and Hong Kong Polytechnic University as part of the ASHRAE project [19]. Three sets of female clothing and five sets of male clothing were investigated, all made mainly of cotton fabric. All ensembles were considered traditional and commonly worn clothing, mainly from Nigeria and Ghana. The clothing insulation was measured on thermal manikins in three laboratories and evaporative resistance was measured in one laboratory [19]. The average clothing insulation and the maximum and minimum for women and men was used for the thermal comfort evaluation.

The influence of postures and motion (ventilation) were tested at Lund University. A walking thermal manikin Tore was used. Tore is made of plastic with a metal frame inside to support the body parts and to simulate joints. The walking movement is created by pneumatic cylinders fixed to wrists and ankles. The manikin is divided into 17 individually controlled zones. In the climate chamber, the air temperature was set at 22.2±0.1 °C. The mean radiant temperature was considered to be equal to the air temperature and the air velocity was 0.21±0.07 m/s. The walking tests followed the recommendation by ISO 15831 (2004) [21]. The step length of 0.65 m at 45 double steps per minute gave an estimated walking velocity of 0.98 m/s. The surface temperature of the manikin was maintained at 34 °C. The temperatures and heat losses were recorded at 10 second intervals. Data from the last 10 minutes of the stable state was used for insulation calculation [21]. Each clothing ensemble was measured independently at least twice, i.e. the manikin was undressed and redressed between the measurements. If the difference of the measurements was above 4 % an additional test was carried out.

The Thermal Comfort Index: PMV/PPD (ISO7730:2004)

In the standard, human thermal sensation is related to the thermal balance of the body as a whole (extremities not included). This balance is influenced by physical activity and clothing, as well as the environmental parameters such as air temperature and humidity. When these factors have been estimated or measured, the thermal sensation for the body can be predicted by calculating the Predicted Mean Vote (PMV) index and the Predicted Percentage of Dissatisfied (PPD) index [20]. The index provides information on thermal discomfort or thermal dissatisfaction by predicting the quantity of people likely to feel too hot or too cold in a given environment. The PMV is an index that predicts the mean value of the thermal votes of a large group of persons following a 7-point thermal sensation scale. However, individual votes are scattered around this mean value and it is therefore useful to predict the number of people likely to feel uncomfortably warm or cool. The PPD index establishes a quantitative prediction of the percentage of thermally dissatisfied people [20]. The PMV/PPD indices were used to assess optimal indoor comfort in this study.

For the comfort analysis, the occupant was considered acclimatized with low activity (120 W), with an air velocity of 0.2 m/s, no additional heat radiation and a relative humidity of 50 %. The anthropometric data input consisted of an acclimatized person with a weight of 70kg and a height of 170cm. Temperature input varied between 20-30 °C for the comfort evaluation using the ISO 7730 Standard [20].

3 Results

The mean thermal insulation with standard deviation, mean evaporative resistance and motion data is presented in Table 1. Overall, all clothing evaluated had appropriate insulation values in relation to the expected outdoor heat exposures, apart from the African robe (boubou) which had relatively high insulation values. In hot conditions the clothing should allow for evaporation and enhanced ventilation. Overall, these traditional clothes are effective from this aspect.

Table 1 Clothing description, measured average insulation, evaporative resistance and effects of motion [19]

Ensemble (Women/Men)	**Permeability Index (i_m) mean of 3 laboratories**	**Mean Clothing Basic Insulation (I_{cl}) clo (s.d of 3 laboratories)**	**Results from walking measurements (I_{cl}) clo (correction factor)**
African dress with headband (F)	0.33	0.65 (s.d: 2.88 %)	0.36 (0.55)
African long short and trousers (F)	0.33	0.79 (s.d 1.15%)	0.47 (0.6)
African shirt with long sleeves and trousers (F)	0.40	0.78 (s.d 6.88%)	0.47 (0.6)
African shirt with long sleeves and trousers (M)	0.29	0.64 (s.d 1.96%)	0.44 (0.68)
African shirt with short sleeves and trousers (M)	0.32	0.61 (s.d 3.42%)	0.39 (0.64)
African shirt with long sleeves and trousers + boubou (African robe), matching hat (M)	0.44	1.40 (s.d 9.82%)	0.73 (0.52)
African shirt with long sleeves and shorts (M)	0.56	0.45 (s.d 11.05%)	0.27 (0.61)
African shirt with long sleeves and trousers + hat (M)	0.40	0.84 (s.d 12.83%)	0.53 (0.63)

The average value from the insulation results was used as input for the PMV/PPD index calculation; 0.74 clo for women and 0.79 for men respectively together with the maximal and minimal insulation values. Table 2 shows the results from the comfort evaluation using the ISO 7730 Standard [20] where the temperature input varied between 20-30°C. Optimal indoor temperature based on the clothing for both men and women in this case resulted in around 24°C, somewhat higher than usually seen as the norm of 21-23°C.

Table 2 Results of PMV/PPD calculation from the thermal comfort ISO 7730 Standard [20]

Temperature	**Average PMV (max / min)**		**Average PPD (max / min)**	
	Female	*Male*	*Female*	*Male*
20°C	-1.24 (-1.11/-1.49)	-1.11 (-0.06/-2.19)	37% (31/50)	31% (5/84)
21°C	-0.96 (-0.84/-1.19)	-0.84 (0.14/-1.84)	24% (20/35)	20% (5/69)
22°C	-0.67 (-0.56/-0.89)	-0.56 (0.34/-1.49)	14% (12/22)	12% (7/50)
23°C	-0.38 (0.28/-0.58)	-0.28 (0.54/-1.13)	8% (7/12)	7% (11/32)
24°C	**-0.09 (0.01/-0.27)**	**0.01 (0.77/-0.78)**	**5% (5/7)**	**5% (18/18)**
25°C	0.2 (0.29/0.04)	0.29 (0.98/-0.42)	6% (7/5)	7% (25/9)
26°C	0.49 (0.58/0.35)	0.58 (1.19/-0.05)	10% (12/8)	12% (35/5)
27°C	0.78 (0.86/0.66)	0.86 (1.4/0.32)	18% (21/14)	21% (45/7)
28°C	1.08 (1.15/0.98)	1.15 (1.61/0.68)	30% (33/25)	33% (57/15)
29°C	1.38 (1.44/1.29)	1.44 (1.82/1.05)	44% (48/40)	48% (68/28)
30°C	1.68 (1.73/1.61)	1.73 (2.03/1.42)	61% (63/57)	63% (78/47)

4 Discussion

From the results of the clothing and thermal comfort analysis, it is clear that sub-optimal indoor thermal conditions are being adopted in Africa if traditional clothing is being worn at the workplace. Current comfort standards result in lower indoor air temperatures than required in this setting, causing an unnecessary waste of energy. Optimal indoor temperature is usually set at 21-23°C, which is based on wearing the standard business suit. However, in this case, the indoor temperature can be raised by about 1-3°C (total of 24°C), reducing the temperature gradient between the indoor and outdoor temperature and saving a substantial amount of energy for cooling. This analysis shows that by adopting the non-western clothing in comfort standards, energy wastage of AC systems can be improved; whilst at the same time improve thermal comfort of the occupants. Considering the better ventilation of the African clothes (see Table 1) [19] than in the western ones and allowing somewhat higher sweat rates for evaporative cooling the recommended temperatures in the offices and homes could easily stay even higher of 25-28 °C resulting in even higher energy savings. Also, such temperatures would allow people to stay acclimated to heat reducing the thermal strain when being exposed to outdoor urban spaces such as unshaded streets.

Furthermore, international standards are largely based on theoretical analyses of the human heat-exchange with the environment based on experiments and field investigations, conducted in climate chambers and/or offices in the western world. They are further based on the hypothesis that regardless of race, age and sex, human beings are thought to feel comfortable in a narrow, well-defined range of thermal conditions. However, satisfaction with the thermal environment is a complex subjective response to several interacting factors. Discrepancies include the acceptable thermal-comfort range, the metabolic and clothing-insulation rate values, as well as other less tangible factors, including cognition, expectations and acclimatization. In other words, due to this complexity, there is really no absolute standard for thermal comfort and additional local thermal comfort studies are therefore needed in the African context.

5 Conclusion

The African clothing, mainly made of cotton, had low insulation values and loose fit which promoted ventilation. The thermal comfort standard ISO7730:2004 (PMV/PPD index) was used to assess the optimal indoor temperature. Environmental conditions were constant apart from the temperature and clothing, which was tested between 20-30 °C for the female and male clothing. The occupant was considered acclimatized with low activity (120 W), an air velocity of 0.2 m/s, no additional heat radiation and a relative humidity of 50 %. The optimal indoor temperature for both women (PMV: -0.09, PPD: 5 %) and men (PMV: 0.1, PPD: 5 %) was found to be 24 °C. In conclusion, it is well known that the temperature gradient between the indoor and outdoor temperature greatly affects the electricity consumption of the AC unit. Sub-optimal indoor thermal conditions are being adopted in Africa resulting in lower indoor air temperatures than required, causing an unnecessary waste of energy. By adopting the non-western clothing in the comfort standards, energy wastage of AC systems can be improved, whilst at the same time improve thermal comfort. Considering better ventilation and evaporation in African clothing the comfort temperatures could be even higher (25-28 °C), helping to reduce energy use even more.

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