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What is the relationship between humidity and comfort at high temperatures? In search of new ways of looking at the issue

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Abstract

This draft paper was developed as a stalking horse for the Windsor 2014 Conference workshop on Statistics, It presents the results of summer time field work undertaken by Abdulrahman Alsheikh in the region of Damman, Saudi Arabia and the data collected shows that middle class homes families there occasionally report thermal neutrality at very high temperatures and humidities. The issues surrounding the collection, analysis and understanding of the complex issues around the relationship between humidity and comfort at high temperatures has long been a difficult one and the paper sets out some general back ground, presents the preliminary findings from the Dammam field work and then raises some questions that we hope the expert statisticians running the workshop can help us make sense of, with a view to publishing a full paper subsequently including the results of the workshop deliberations.

Keywords: PMV, Thermal Comfort, High Temperatures, Humidity

1. Introduction

Where the temperature and humidity are both high, humidity came to be seen historically as a potent force for discomfort. Many of the early developments in heating and cooling systems that were devised to reduce humidity were instigated to improve the efficiency of manufacturing processes in hot climates and also in response to the very poor standard of building construction, particularly in cold climates. On cold damp days in buildings with thin walls that were almost the same temperature on the inside as the outside, large families gathered in wood gas or coal heated rooms resulted in damp walls and mould the health and well-being of building occupants.

John Gorrie, a pre-eminent pioneer of air-conditioning who lived and worked in Florida focussed on temperature rather than humidity in his work in his designs for cooling systems using 'mechanical condensation' that began as early as 1854 [i]. Many subsequent buildings were cooled with ice placed in the air supply ducts but by 1918 Alfred Woolff, Stuart Cramer and Willis Carrier, doyens of the US heating, ventilating and air-conditioning (HVAC) industry had all built mechanical ventilation systems that incorporated humidity control to improve indoor comfort. By this stage US designers had identified humidity as a primary cause of summer discomfort and air-conditioning systems were increasingly designed not only to cool the air but to manage its humidity. Wolff concluded that 55% RH was the optimal level to strive for but such conclusions were based on little evidence. The consequence of this assumption was to push systems to use a two phase cooling systems, first chilling down the air to remove humidity by condensation and then to heat it up so further reducing its relative humidity – but only at the cost of significant energy inefficiency to get air to the required temperature.

Tradition held that cold damp weather chilled one to the bone while hot humid days made people feel sickly and uncomfortable. Today the average US worker takes one day a month off due to Sick Building Syndrome but this is a condition, that research leads us to believe, is affected by humidity but results from inadequate ventilation, chemical contaminants from indoor or outdoor sources, and/or biological contaminants.

However a key symptom of the use of air-conditioning systems is the drying of indoor air that can typically be as low as 10%-35% RH causing a range of SBS symptoms and discomfort. However it has been found that increasing humidity in such dry buildings to above 40% has no measurable impacts on occupant heath [ii]. But if the core concern is occupant comfort, the subsequent century of research has often contributed to the confusion of the actual role and impact of humidity on the experience of comfort at high temperatures [iii].

A wide range of 20th Century tropical comfort indices were developed based the results of field studies and laboratory studies [iv] linking humidity to comfort in a single measure such as those developed by Webb [v], Sharma [vi] and others. In 1973 Nicol and Humphreys presented the results of field studies in the UK, India, Iraq and Singapore [vii] with result showing that mean comfort vote changes little with the mean temperature experienced[viii]. A number of meta-analyses of the role of humidity in comfort in tropical regions have been undertaken including that by de Dear et al [ix]. Numerous recent field studies have often shown that comfort in tropical regions is experience with high humidity and temperatures when compared with Western standards for comfort [x].

In order to clarify the issues involved in our own minds we are bringing the following recent Dammam region case study to the Windsor 2014 conference for a discussion of how we might use statistics better to unravel the complex relationship between humidity and comfort at higher temperatures. Data collection and results were produced by Abdulrahman Alsheikh and the whole underlying data set was supplied to Rex and Jane Galbraith prior to the W14 Conference. They were asked to review the approach, limitations and opportunities presented by this study, during discussion at the Windsor Workshop on Statistics.

2. The Damman Case Study methodology

The Dammam field surveys were undertaken using a standard longitudinal thermal sampling in air-conditioned houses in the city of Dammam, Saudi Arabia. The survey involved 17 homes distributed in the eastern region of Saudi Arabia and was carried out from 10^{th} to 31^{st} of August 2013 during the hot season. Subjective data were collected through parallel questionnaires, which were completed during almost two weeks for each house over the day when the subjects were at home. The survey was completed with about 480 votes, the total subject group was 35 people and the gender split was eighteen to seventeen, males and females respectively. The ages of the subjects ranged from 21 to 60 years with a mean age of 34 years old. All subjects were in good health.

This study used air temperature as its principal physical variable. Air temperatures were obtained using small data loggers that collected and stored results automatically in an optional strain choice. The data loggers were fitted in two different places in each house, in the living rooms and bedrooms, and automatically measured indoor temperature and relative humidity. The positions of the data loggers were located to minimize heat from direct radiation, either from mechanical or human sources. Measurements of the environmental data were taken every five minutes and each volunteer was asked to vote at least twice a day. The survey was designed by the researcher to be operable in all smartphones platforms, making it easier, and more enjoyable, for subjects to vote during day/night time and in any situation.

The questionnaires contained four main sections and also requested personal information from subjects. The sections involved: thermal sensation, using a seven-point ASHRAE scale (cold, cool, slightly cool, neutral, slightly warm, warm, hot); metabolic rate, clothing and individual's adaptation in a specific time and occupied room. The thermal scale and other sections of the questionnaire were translated into Arabic. As the culture and religion is taken into account, Values of clothing insulation were mainly derived from Al-ajmi et al. (2008) as well as from clothing values used by Nicol et al. (2012). The metabolic rates given in ISO 7730 cited in (Nicol et al., 2012) were used in this study.

3. Results and Discussions

During the fieldwork in August the indoor air temperatures ranged from a low of 19.9°C to 35.3°C with an average of around 27°C [Figure 1]. A single high report of 39.3°C was recorded in a unique event of one of the cases.

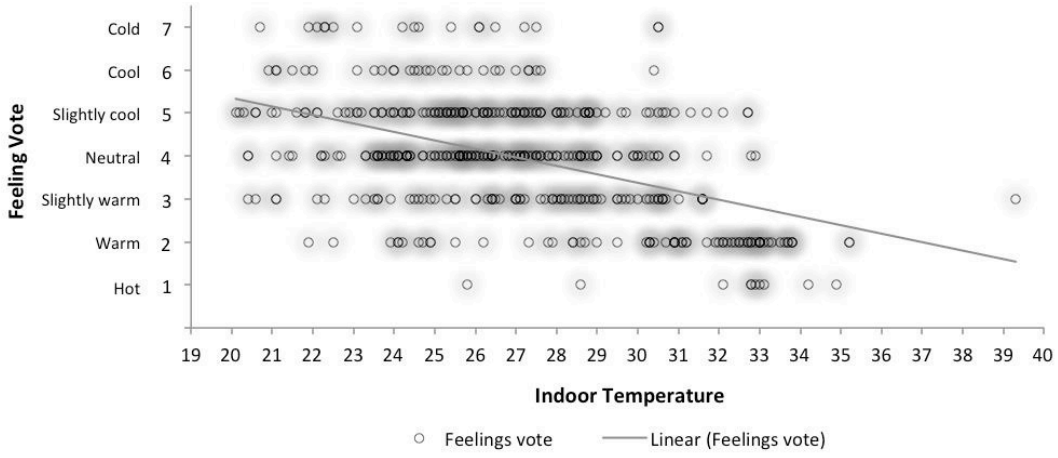

Figure 1: Distribution of indoor temperature from longitudinal survey in Dammam Region during Summer 2013.

The recorded humidity fluctuated from a low of 29% to a high of 84% with an average of around 60% relative humidity [Figure 2]. The mean clothing values were 0.42*clo* with minimum of 0.05*clo* and maximum of 0.97*clo.* About 60% of subject's clothing values were in the scope of 0.05*clo* and 0.41*clo*. The mean metabolic rate was 0.67*met* during the hot season.

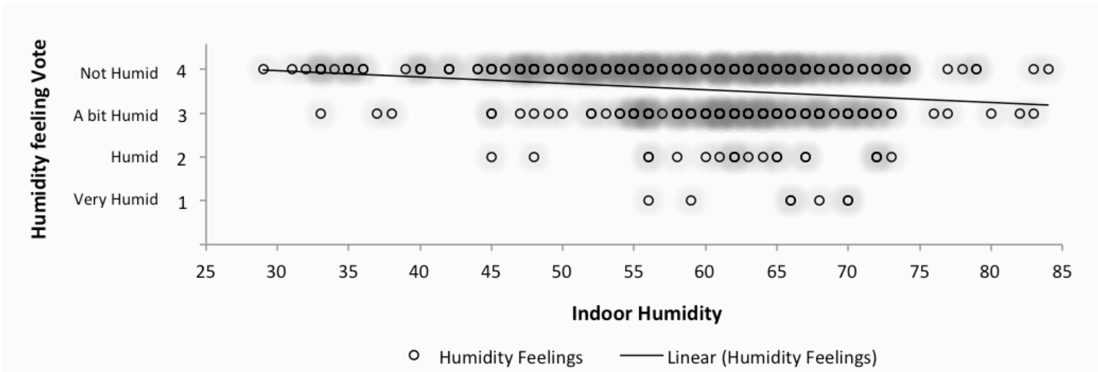

Figure 2: Distribution of indoor relative humidity from longitudinal survey in Dammam Region during Summer 2013

The analysis of the sensation votes show that about 65% of subject votes in indoor conditions indicate one of the four top categories, between Hot and Neutral, and the mean sensation votes for all subjects on the ASHRAE scale were 3.32 (Slightly warm). Furthermore, almost the same portion of subject's votes indicated they wanted more cooling to be more comfortable which shows that people are not very satisfied with their environment conditions [Figure 3].

It is obvious to ask why, if these people did not feel comfortable, don't turn on or up the AC to be more comfortable. One question in the survey been asked of all subjects that in comparison to the monthly income, do you think that the electricity bill is expensive? About 65% of the subjects responses were the price is expensive compared to their incomes.

In exploring the subject's preferences data in [Figure 3] the data shows that it is fairly robust. However, the next step will be to investigate what are the boundary conditions around these outliers votes. There were in certain circumstances some votes in warm conditions asking to be a bit warmer. A preliminary analysis shows that people who prefer to be in warmer conditions, even in the range of 29-35°C, quite feel cool and are less active. Also a couple of subjects were underweight. Subjects aged between 15-20 years old voted at these temperatures for warmer conditions.

Other outlier votes showed that people in a pretty cool conditions desire to be in cooler state. Data showed that this cohort were all in the bedroom and about 90% of them were overweight. Moreover, one specific house showed a substantial portion of these outliers, so more investigation in this case is needed. In this specific outlier home it appears that those who voted to be 'a bit' or 'much' cooler, occupied indoor humidity levels above 55% and below 80%. Thus, further statistical analysis is required to understand the relationship between humidity and temperature and comfort in these studies.

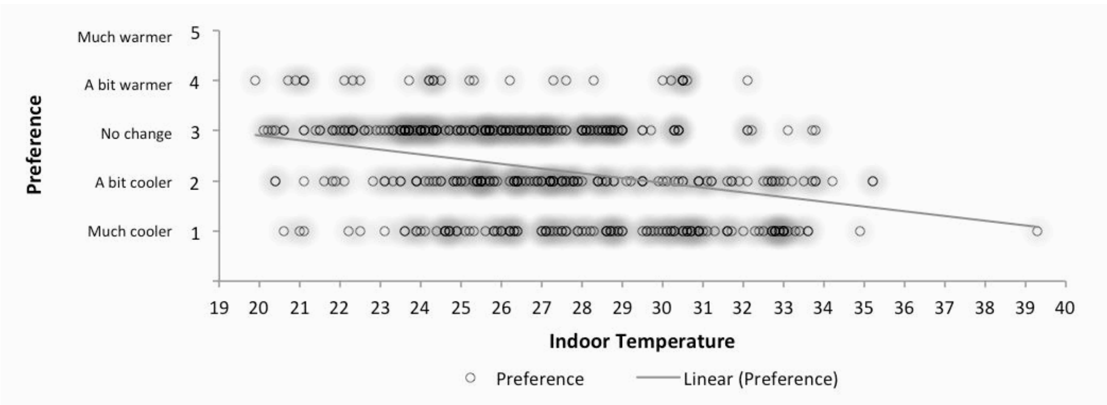

Figure 3: Regression of indoor temperature on people preferences

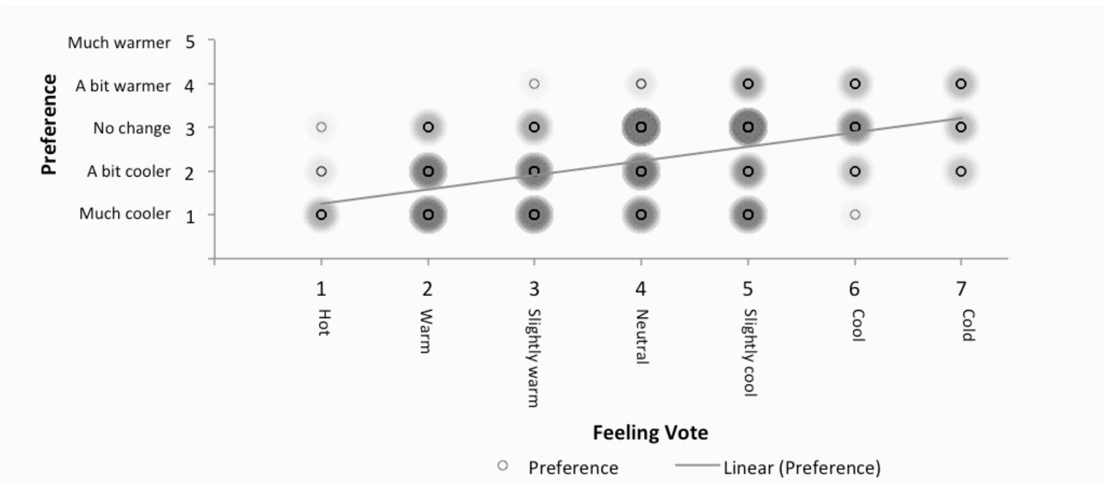

Figure 4: Regression of subject's sensation votes on their preferences

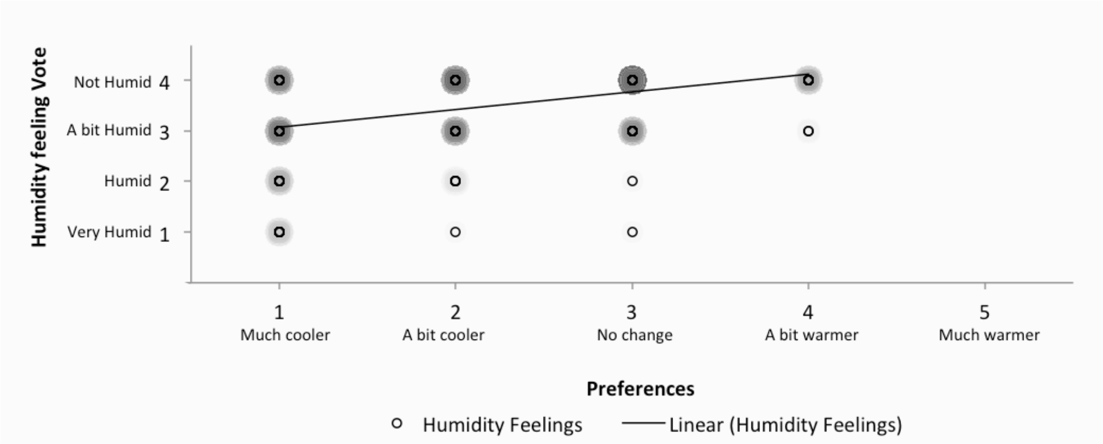

Figure 5: Regression of the subject's humidity feeling votes on their preferences

A number of questions are raised about the ability of a standard longitudinal study of comfort in extreme conditions where multiple adaptive strategies are employed to ensure occupants remain comfortable over the day. These include:

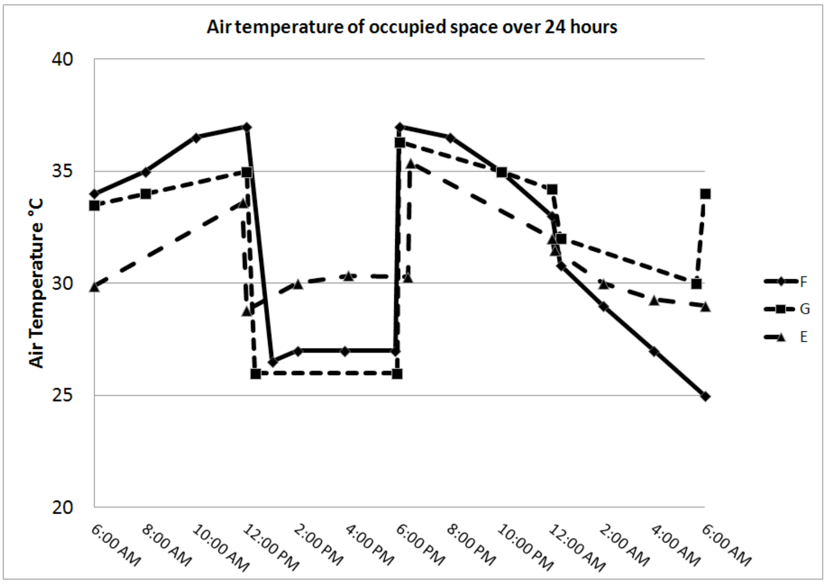

Figure 6: Temperatures occupied by housewives in the houses in the hot dry desert city of Yazd in Iran showing the wide range of thermal environments occupied over a single typical day (S.Roaf 1989[xi]).

How best can we deal with the outlier data points when they show people being comfortable at extremely high temperatures? Lifestyle observations and person centred thermal records are necessary to understand the adaptive behaviours that are used to mitigate the impacts of high temperatures experienced at different times of the day and year with building occupants:

a) getting on with their usual lifestyles as ambient temperatures ramp up or down over a day, until a certain temperature level is reached at which point they occupants change their clothing, activities, location, turn on/off a machine or open/close a window. This ramping effect and the transition temperatures (and humidities ?) are recorded by observation, not analysis of data sets.

b) moving from one location people can go from one state – eg. cool in a basement in Yazd (Figure 6) into a hot environment, cruising physiologically on stored coolth for a subliminally calculated safe period of time. This scavenging and storing of heat or cold, to enable people to occupy uncomfortable and/or unsafe thermal environments for intermittent periods within the well-trodden thermal pathway of a habitual lifestyle in extreme climates is common practice. The diverse thermal environments habitually occupied over a day, or over more extended periods, are not typically collected in longitudinal field studies but are key to understanding how comfort is thus achieved.

In trying to understand the complex interaction between humidity and comfort at high temperatures we are looking for help in the Statistics Workshop in exploring how we can systematise the recording of data to enable us to understand and compare the different behaviours associated with achieving comfort in such conditions and also in analysing the data in such a way that we can extrapolate from that data the key characteristics of the relationship between humidity and comfort at high temperatures.

4) Conclusions

We very much welcome the opportunity to share this data with the experts at Windsor to learn from the discussions more about this complex and yet extremely important issue.

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