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Identifying a suitable method for studying thermal comfort in people's homes

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Abstract

Within the context of increasing energy prices and resulting fuel poverty as well as the energy efficiency refurbishment of existing dwellings and associated comfort take-back, the need to study thermal comfort in domestic environments is becoming increasingly important.

In order to fulfil the aims of this study to measure domestic thermal comfort, two methods were chosen for comparison. A less-intrusive method, referred to as the 'Silver standard', was compared against the ASHRAE/ISO recommended method (termed as the 'Gold standard'. Using the Silver Standard method, the experimenter measured air temperature and humidity at a central location of the living room and at only one height, and assumed that air temperature was equal to mean radiant temperature, air velocity was equal to the default value of 0.1m/s. Data on clothing and activity were self reported by the participants. Using the Gold Standard method, the experimenter measured all required environmental variables at three heights close to where the participant was seated and recorded clothing and activity levels. The study was conducted in 16 owner occupied homes during the summer. Predicted Mean Vote (PMV) was computed from data collected using both methods. A strong correlation was observed between PMV values obtained using the Silver Standard method and those obtained using the Gold Standard method. The findings suggest that overall, the less-intrusive method (the Silver Standard) devised and tested in this trial has the potential to provide reliable data for the study of thermal comfort in homes. This method has the potential of contributing towards large scale studies of domestic thermal comfort. One of the key issues that need to be improved is the clothing ensemble list provided to the occupants. The findings suggest that further work is necessary, particularly in winter conditions to comprehensively validate this non-intrusive method.

1.0 Introduction

The existing UK domestic building stock accounts for nearly one third of the total energy consumption of the UK (Figure 1) and as shown in Figure 2, space heating alone is responsible for over 50% of the domestic energy consumption. Therefore, in order to reduce domestic energy consumption, the energy efficiency of the domestic stock needs to be improved. However, improving the overall energy efficiency of the domestic stock and reducing space heating energy requirements alone will not be sufficient to reduce overall domestic energy consumption. Since space heating is directly related to the human needs of thermal comfort, a better understanding of people's thermal comfort in their homes will also be required, in order to ensure that whilst space heating energy requirements are reduced, acceptable thermal comfort is achieved and expected energy savings are not lost due to thermal take-back. The majority of thermal comfort studies across the globe, and particularly in the UK, have been conducted in offices and other non domestic buildings, with very few thermal comfort studies conducted in domestic buildings (Pimbert and Fishman (1981), Hunt and Gidman (1982), Oseland (1994), Summerfield et.al. (2007), Hong et.al. (2009), Shipworth et.al. (2010)). In order to develop a better understanding of domestic thermal comfort, large scale studies would be helpful. However, there are challenges in conducting thermal comfort studies in domestic environments. The biggest challenge whilst conducting thermal comfort studies in people's homes is to maintain an optimum balance between the scientific rigor of an experiment and the practicality of conducting experiments in privately occupied houses. Field experiments with participants often have constraints that limit the extent of control that an experimenter can have on the environment as well as the participants. Furthermore, the use of measuring equipments, including data loggers, can often cause disruption to the daily life of the participants as well as other occupants of the house who may not be participating in the experiment. In addition to this, it may not be appropriate for the experimenter to be present at the house for the entire duration of the experiment, as it could be considered intrusive by the householder. Hence the question that needs to be answered is, what is the most optimum method for conducting thermal comfort studies in peoples' homes, particularly while conducting large sample surveys. Based on this research question, the overall aim of this study was to propose and validate a less-intrusive method for conducting thermal comfort studies in homes in the UK.

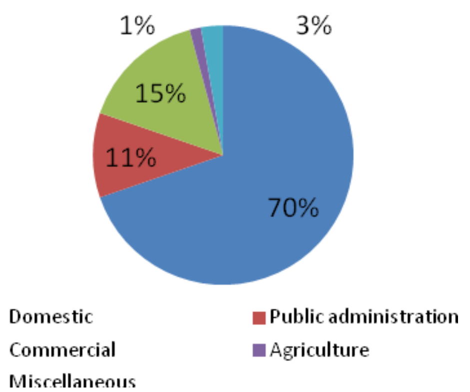

Figure 1: UK Domestic energy consumption in 2008 (DECC 2010)

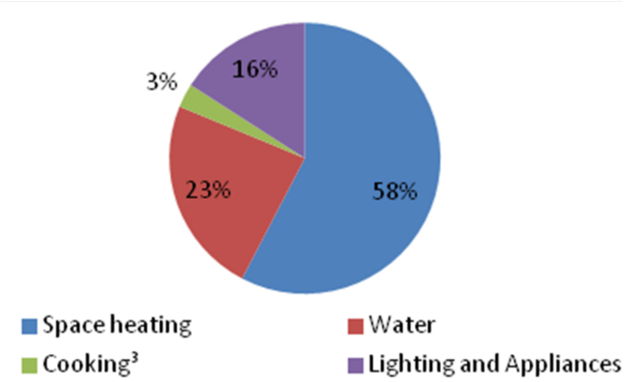

Figure 2: Domestic energy consumption by end use and fuel in 2008 (DECC 2010)

2.0 Methods

The most common method used to objectively evaluate thermal comfort is Fanger's PMV-PPD method (Fanger, 1970). The PMV-PPD method is based on a steady state model. Developed in the 1970s, Fanger's PMV-PPD model is, to date, the most influential work in thermal comfort theory and practice. ASHRAE Standard 55 (ASHRAE, 2010) and ISO 7730 (BSI, 2005) present methods for determining and interpreting thermal comfort based on this model and also outline environmental conditions that are considered acceptable for general thermal comfort. By using this method, PMV (Predicted Mean Vote) and PPD (Percentage of People Dissatisfied) values can be calculated. The PMV values indicate the average thermal sensation of a large group of people when exposed to a given thermal environment.

In order to compute PMV, six factors that influence a person's thermal comfort are required to be measured. These are the four environmental factors which consist of air temperature, radiant temperature, air velocity and humidity and two personal factors which consist of the occupants' clothing insulation (CLO value) and metabolic rate. While it has been relatively easier to measure these factors and conduct thermal comfort studies in offices and other non domestic buildings, it is more challenging to the do the same in people's homes. Within the private context of people's homes, conducting such studies would usually be considered intrusive and inconvenient. Hence, one of the main aims of this study was to field test and validate a non-intrusive technique that could get quality thermal comfort data from a dwelling.

The non-intrusive method, referred to as 'the Silver Standard method' in this study, consisted of collecting a limited amount of information and relying on certain assumptions. Air temperature and humidity data were recorded through small sized HOBO data loggers (Figure 3 and Table 2) placed in the room close to the where the participant was seated. Air velocity was assumed to be less than or equal to 0.1m/s and mean radiant temperature was assumed to be the same as air temperature. Metabolic rate and clothing insulation values were self reported by participants who were seated on their living room sofa/chair. The participants were asked not to take any adaptive actions, remain seated throughout the duration of the experiment and watch television or read a book, thereby engaging in sedentary activity. Participants used the clothing ensembles list (Table 3) to calculate their CLO values and reported them to the experimenter. In order to validate and test the accuracy of the Silver Standard method, results obtained from this method were compared with those obtained using the method specified by ASHRAE (ASHRAE, 20010) and ISO Standards (BSI, 2005). This ASHRAE/ISO method, referred to as 'the Gold Standard method' in this study, consisted of measuring air temperature, air velocity and humidity at three heights (0.1m, 0.3m, 0.6m as shown in Figure 4), using laboratory grade instruments that complied with specifications prescribed by ASHRAE (ASHRAE, 2010). Mean radiant temperature was measured at the height of 0.6m with a 150mm diameter globe. Clothing insulation and metabolic activities were recorded by the experimenter using a clothing ensemble list (Shown in table 3).

A sample of 17 owner occupied houses located in the Loughborough area was selected for the purpose of this study. Whilst indentifying the sample, the following considerations were made:

- To get an even mix of males and females

- Ensure an even spread of age whilst selecting participants (age range from 18 to 60)
- Ensure an even mix of gender
- Ensure that the participants had acclimatized to the climate (lived in the UK for at least 5 years)
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Details of the sample are give in Table 1.

Table 1 : Details of building and occupants surveyed

Build no	Building type	Participants' gender	Age of participants
1	Terraced	Male	30-35
2	Detached	Female	20-25
3	Semi-detached	Male	50-55
4	End of terrace	Male	20-25
5	Detached	Male	25-30
6	Semi detached	Male	25-30
7	Detached	Female	20-25
8	Detached	Male	30-35
9	Detached	Female	40-45
10	Detached	Female	25-30
11	Detached	Male	45-50
12	Terraced	Female	50-55
13	Detached	Male	55-60
14	Semi-detached	Female	30-35
15	Semi-detached	Male	25-30
16	Detached	Male	20-25
17	Terraced	Female	45-50

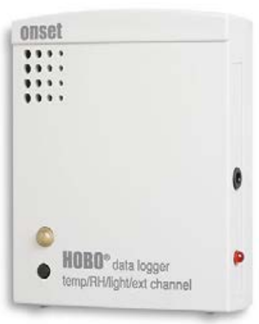

Figure 3: HOBO U-12 Temperature and relative humidity data logger used as a part of the Silver

Table 2: Specification of the HOBO temperature sensors used for the Silver Standard method

Parameters	**Specifications**
Make	HOBO U12 Temp/RH/ logger
Measurement range	-20° to 70°C (-4° to 158°F)
Accuracy	± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F)
Resolution	0.03°C at 25°C (0.05°F at 77°F)
Drift	0.1°C/year (0.2°F/year)
Response time in airflow of 1m/s	6 minutes, typical to 90%
Time accuracy	± 1 minute per month at 25°C (77°F)
Launch/readout:	0° to 50°C (32° to 122°F), per USB specification
Battery life	1 year typical use
Memory	64K bytes (43,000 12-bit measurements)
Weight	46 g (1.6 oz)
Dimensions	58 x 74 x 22 mm (2.3 x 2.9 x 0.9 inches)

Table 3: Clothing Ensemble List used for the Gold and Silver Standard methods

Clothing	**Clo Value**
T-shirt, shorts, light socks, sandals	0.3
petticoat, stockings, light dress with sleeves, sandals	0.45
shirt with short sleeves, light trousers, light socks, shoes	0.5
stockings, shirt with short sleeves, skirt, sandals	0.55
shirt, light-weight trousers, socks, shoes	0.6
petticoat, stockings, dress, shoes	0.7
shirt, trousers, socks, shoes	0.7
track suit (sweater and trousers), long socks, runners	0.75
petticoat, shirt, skirt, thick knee, socks, shoes	0.8
shirt, skirt, round neck sweater, thick knee socks, shoes	0.9
singlet with short sleeves, shirt, trousers, V-neck sweater, socks, shoes	0.95
shirt, trousers, jacket, socks, shoes	1
stockings, shirt, skirt, vest, jacket	1
stockings, blouse, long skirt, jacket, shoes	1.1
singlet with short sleeves, shirt, trousers, socks, shoes	1.1
singlet with short sleeves, shirt, trouser, vest, jacket, socks, shoes	1.15
shirt, trousers, V-neck sweater, jacket, socks, shoes	1.3
Underwear with short sleeves and legs, shirt, trousers, vest, jacket, coat, socks, shoes	1.5

3.0 Experimental plan

The experimental plan adopted for this study was as follows:

1. Before commencing the experiments, the experimenter visited the home of the participants and explained to them the nature of the experiment and obtained consent to participate using a consent form. This was done in accordance with the guidance set out by Loughborough University's Ethical Advisory Committee.
2. After obtaining consent, a HOBO temperature and humidity data logger was placed in the living room of the house, such that it did not interfere with their day-to-day activities of the household.
3. The participants were asked to carry out sedentary activities, like watching the usual TV programme or reading a book, for about 60 minutes and fill in the questionnaire towards the end of the experimental session.
4. By means of this questionnaire, the participants were asked to report on the following:

    a. Their comfort on a scale of -3 ('Too Cold') to +3 ('Too Hot'), 0 being the comfortable/thermally neutral.
    b. How they rated their environement on a scale of 0 ('Comfortable') to 4 ('Very Uncomfortable')
    c. Thermal preference: How they would prefer to be on a scale of -3 ('Much Cooler'), to +3 ('Much Warmer'), 0 being no change.
    d. Thermal acceptability: How they judge their personal environment from 'Clearly Acceptable' to 'Clearly Unacceptable'.
    e. Whether they got up from their seat during the 60 minutes and how long for.
    f. The clothing insulation and metabolic rate value at the time of the experiment.
5. Once the 60 minutes were over, the experimenter returned to the property and asked the participants to complete the same questionnaire for the second time.
6. While the participants were completing the questionnaire for the second time, the experimenter took detailed measurements of air velocity, mean radiant temperature, humidity and air temperature, in order to obtain data in accordance with the Gold Standard method, as described earlier. The experimenter also noted the items of clothing that the participants were wearing and also made a note of their activity levels.

Overall, each experimental session lasted for approximately 75 minutes. Figure 4 below show examples of both Silver Standard and Gold Standard methods being used at the participant's living room and Figure 5 shows the detail of the temperature and humidity measuring equipment.

Figure 4: Set up of equipment in the Silver and Gold Standards

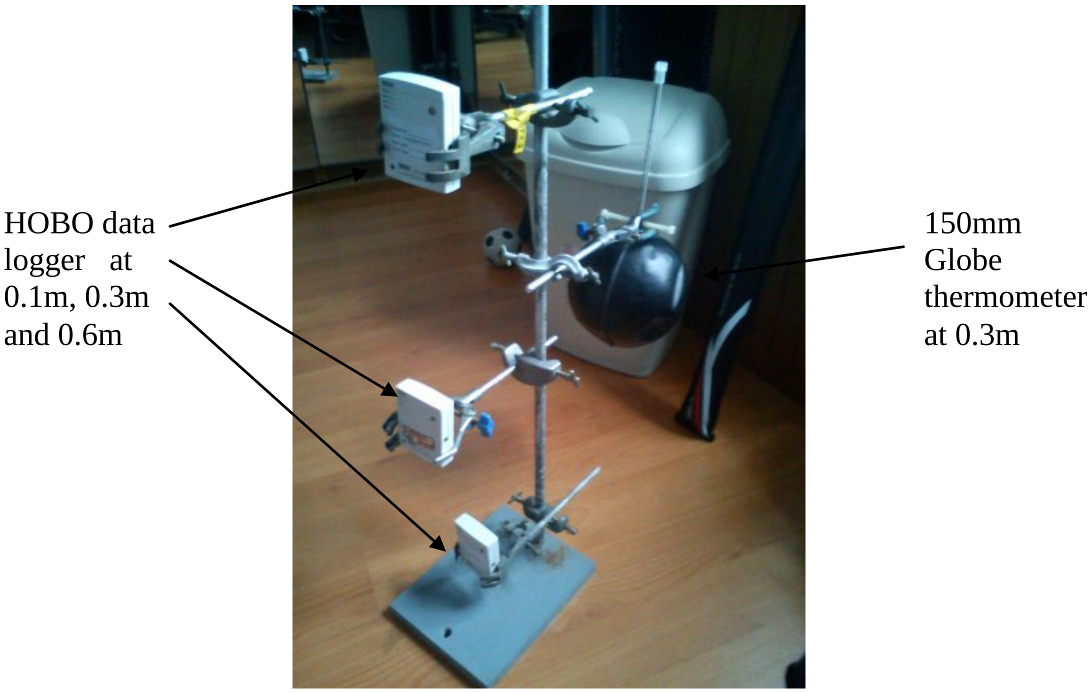

Figure 5: Detail of the Gold Standard Temperature and Relative Humidity measuring equipment

The following values, taken from Oseland (1994), were added to each participant's clothing insulation value in order to account for the insulation of their seating:

1. Side/ Table = 0.13 clo
2. Typist/VDU = 0.12clo
3. Executive = 0.17 clo
4. Arm/Sofa = 0.18 clo

4. Findings

The data collected were analysed with the objective of validating the Silver Standard method against the Gold Standard method. Although the study was conducted in 17 households, the results are based on an analysis of data collected from 16 households. This is because one of the data loggers being used for the Silver Standard method developed a technical fault whilst recording. This shows a limitation of the Silver Standard that depends on the reliability of the single data logger used. If this develops a technical fault whilst recording, then there will be no data available to use for that particular sample, whereas the Gold Standard method, with its three data loggers, minimises the risk of data loss.

4.1 Air Temperature

The first assumption that was made in the Silver Standard method was that air temperature measured in a central location in the room will be the same as air temperature measured at the locations recommended by ASHRAE/ISO. Overall the results shown in Figure 6 show that the Silver Standard method overestimated air temperature by about 1°C as compared to the Gold Standard method.

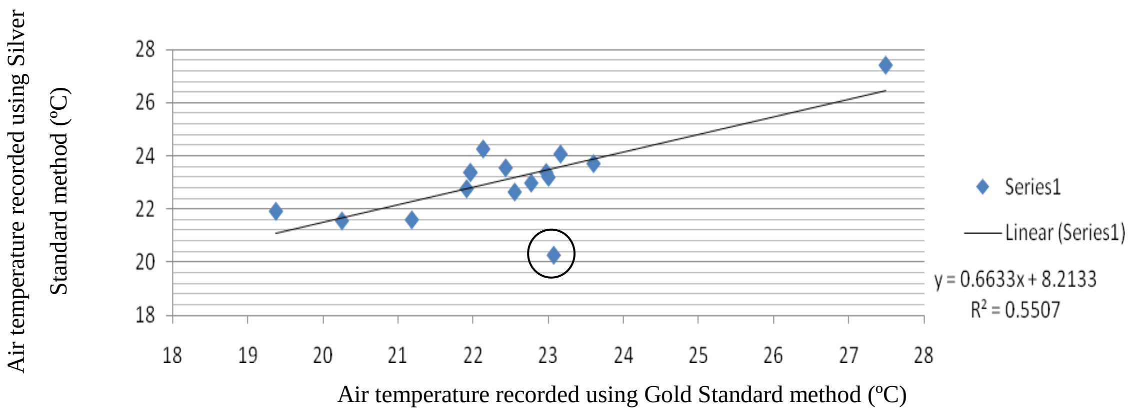

Figure 6: A regression of indoor air temperature measured using the Silver Standard method vs. indoor air temperature measured using the Gold Standard method (includes data from all houses).

Furthermore, a weak correlation (R^2= 0.55) was observed between air temperature recorded by both methods. However, an anomaly was observed in the data collected from house number 6 (circled in Figure 6). The room in house number 6 had a layout which consisted of a sofa being in front of the window with the radiator on the wall below the window and behind the sofa. As a result of this configuration, the local environment around the sofa was completely different from the rest of the room. By taking this anomaly out of the results (Figure 7), the R^2 value between both methods increased to 0.82 making the assumption a lot more accurate and leading to the overall conclusion that the air temperature could be accurately obtained from the Silver Standard method as long as the layout of the room does not leave the environment around the occupant seated being completely different to any other point in the room.

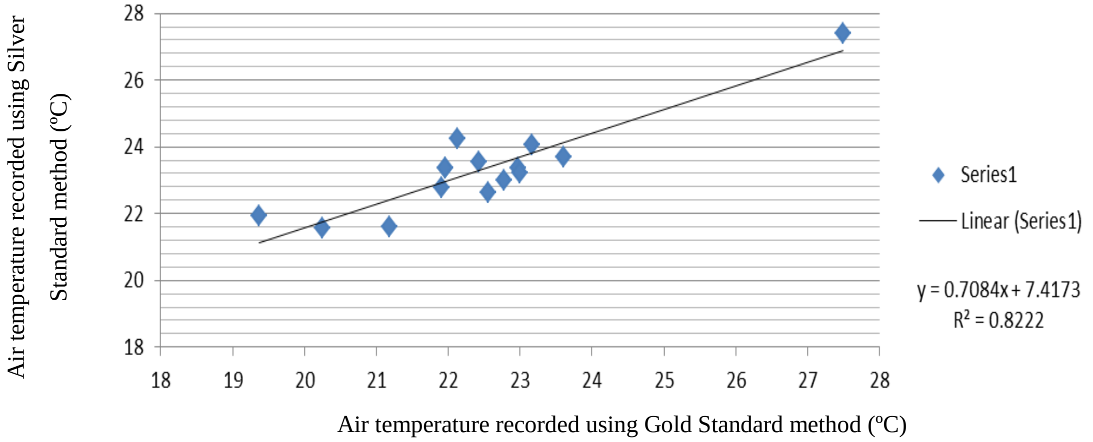

Figure 7: A regression of indoor air temperature measured using the Silver Standard method vs. indoor air temperature measured using the Gold Standard method (house no.6 data excluded).

4.2 Humidity

The second assumption made in the Silver Standard method was that humidity measured at a single point in the room will be the same as that measured using the Gold Standard method. When comparing both standards (Figure 8), 75% of the data had a difference of 0-3% RH and 25% of the data had a difference of 3-6%RH between both standards of measurement. Although the correlation (R^2) value between both methods was 0.74, analysis of PMV results (reported later in the paper) indicate that these differences in relative humidity had no effect on the overall PMV, thereby suggesting that the Silver Standard method gave reasonably reliable data for PMV-PPD analysis.

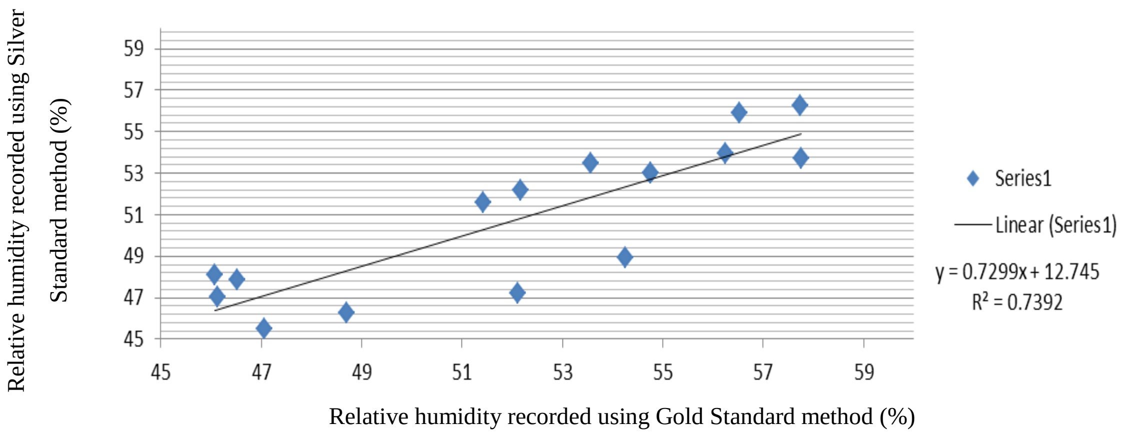

Figure 8: A regression of relative humidity measured using the Silver Standard method vs. indoor air temperature measured using the Gold Standard method.

4.3 Air Speed

Whilst using the Silver Standard method, it was assumed that the air speed would be equal to 0.1m/sec, which is the default minimum value that is used in PMV calculations and hence it would not be necessary to measure air velocity whilst conducting surveys in people's homes.

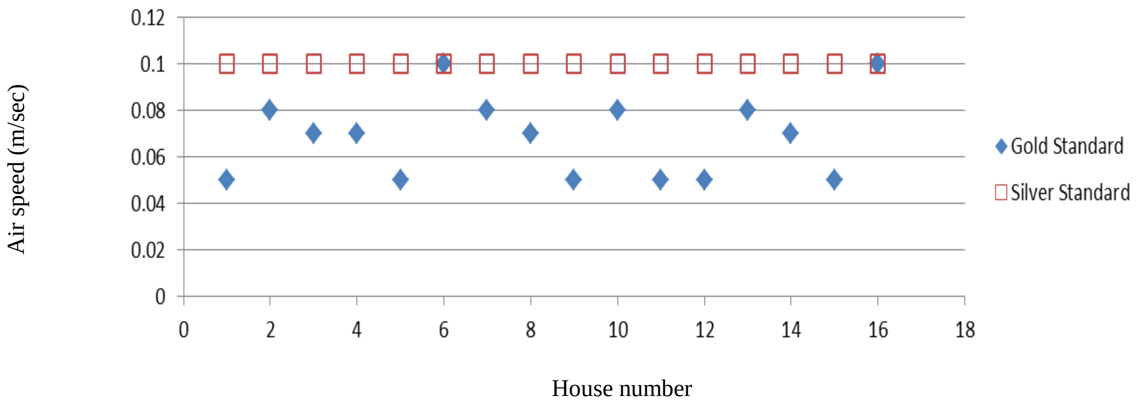

Figure 9: Air speed measurement using the Gold Standard method, compared with assumed air speed in the Silver Standard method.

Figure 9 shows that air velocity measured in all of the 16 houses, using the Gold Standard method, was equal to or lower than 0.1m/sec. Whilst using the ASHRAE thermal comfort software to calculate PMV-PPD values, 0.1m/sec is the minimum value for air velocity that can be used. Therefore, the assumption made in Silver Standard method, that air velocity is equal to 0.1m/sec would be accurate enough in these types of houses in the UK.

4.4 Mean Radiant Temperature

The Silver Standard method assumes that the mean radiant temperature is the same as air temperature. A comparison of mean radiant temperature measured using the Gold Standard method with air temperature measured using the Silver Standard method indicates that in 75% of the cases there was a difference of 0-1°C and in 19% of the cases there was a difference of 1-2°C.

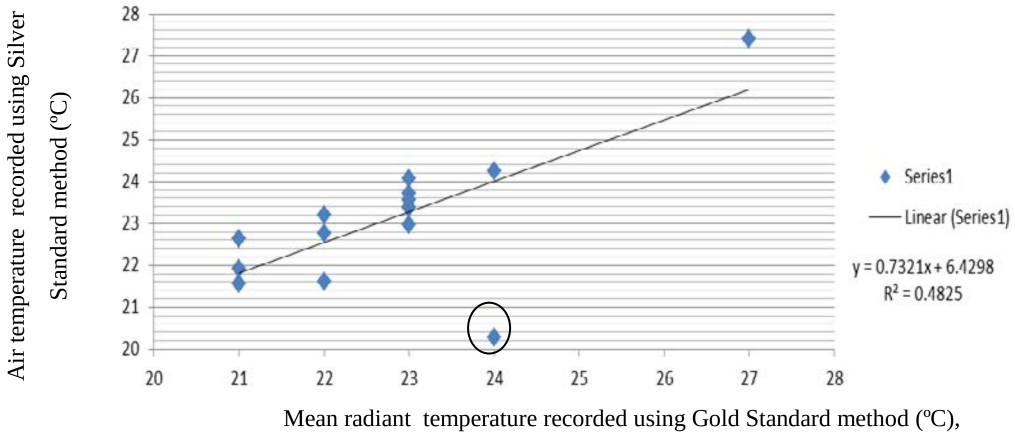

Figure 10: A regression of air temperature measured using the Silver Standard method vs. mean radiant temperature measured using the Gold Standard method (includes data from all houses).

The biggest difference of 3.7°C was found in house number 6 (circled). Once again the anomaly that was found in house number 6 was as a result of the layout of the room, as discussed earlier in the analysis of air temperature. As a result of this anomaly, the comparison gave an R^2 value of 0.48. However, when house no.6 was removed from the analysis, the R^2 value increased to 0.88 (Figure 11), suggesting that it was reasonable to assume that mean radiant temperature was equal to air temperature in rooms. However, in rooms with layouts that caused an environment to be different around the occupant as compared to any other point in the room, the Silver Standard method might not be able to provide reliable/accurate data.

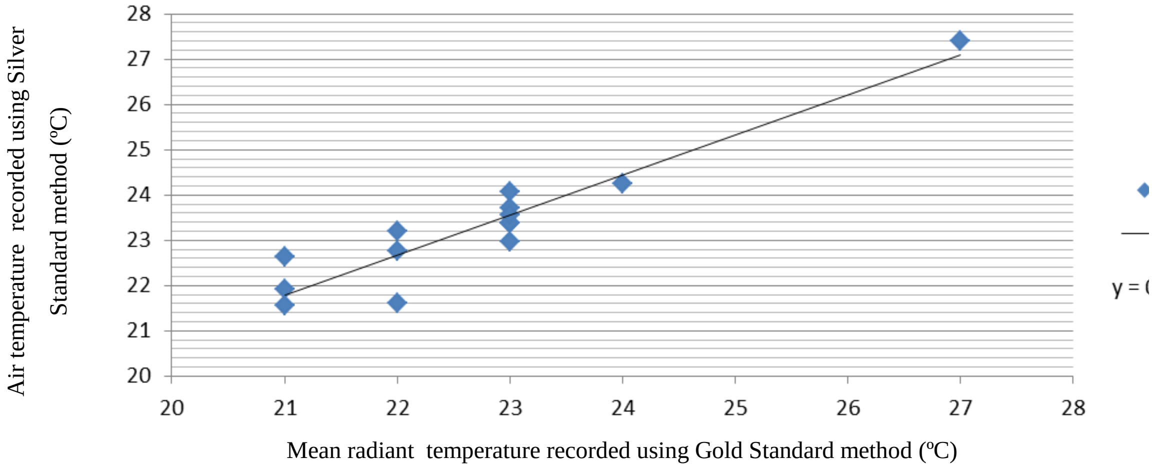

Figure 11: A regression of air temperature measured using the Silver Standard method vs. mean radiant temperature measured using the Gold Standard method (house no.6 data excluded).

4.5 CLO Value

When it came to gathering information about the CLO value it was assumed that the Silver Standard method consisted of collecting self reported data from the participants were accurate enough as compared to the data collected by the experimenter using the Gold Standard method.

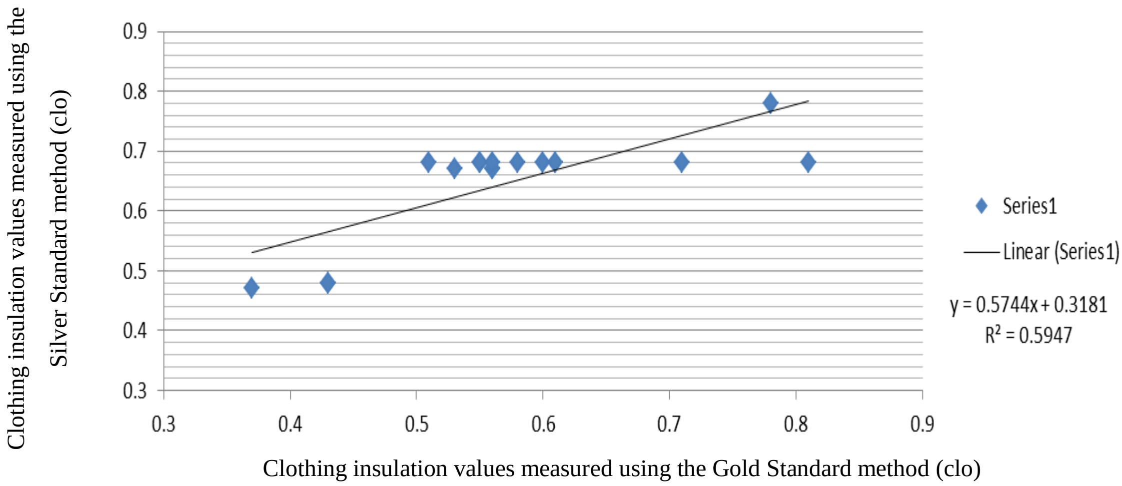

Figure 12: A regression of clothing insulation levels measured using the Silver Standard method vs. clothing insulation levels measured using the Gold Standard method.

The results show that in comparison to the Gold Standard method, the Silver Standard method overestimated the CLO values. One of the reasons assumed for the overestimation of the silver standard was that in the ensemble clothing list provided in the silver standard shoes were included in all of the scenarios and it was noticed that people wearing shoes while they are relaxing in their living room was rare. The second reason for the overestimation occurred due to the simplicity of the clothing ensemble list, The reason for this assumption is that when taking detailed CLO values in the gold standard the smallest difference e.g ankle socks or thick socks would make a difference on the overall CLO value of the occupant. Based on this, the conclusion was that in order to get more accurate results the clothing ensemble list provided needed to be improved by having for example, ensembles with or without shoes. Additionally, in one house the occupant was wearing traditional Indian clothing for which the CLO value was not found in ASHRAE or ISO Standards; therefore the CLO value in this case was obtained from a study done by Indraganti (2010).

4.6 Predicted Mean Vote (PMV)

PMV values calculated from data obtained by both methods were compared and are shown in Figure 13. The comparison suggests that the Silver Standard method overestimated PMV values as compared to the Gold Standard method. Furthermore, a weak correlation of 0.5 was observed between the PMV values obtained from both methods.

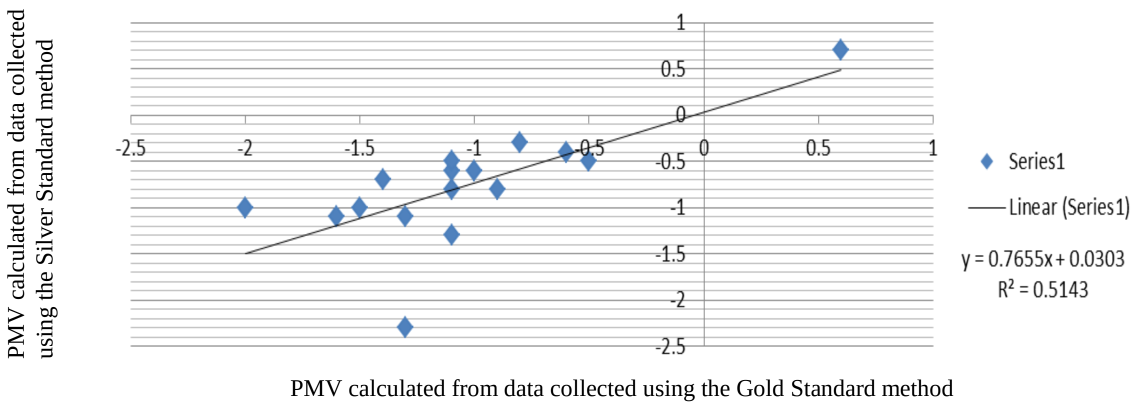

Figure 13: A regression of PMV values calculated from data collected using the Silver Standard method vs. PMV values calculated from data collected using the Gold Standard method.

In order to investigate the extent to which the six PMV variables gathered using the Silver Standard method were responsible for these differences, further analysis was carried out. For this analysis, the eight cases (samples) which had a difference of greater than 0.5 between both methods were used. PMV values were recalculated by replacing the data collected by using the Silver Standard method with the data collected by using the Gold Standard method. Table 1 below gives result of this analysis.

Table 4: Results of analysis on PMV.

Scenario	PMV
Average difference in PMV values calculated using Gold Standard method and Silver Standard method for the 8 cases.	0.66
Average difference for the 8 cases, values of air temperature measured using the Silver Standard method are replaced with values of air temperature measured using the Gold Standard method.	0.4
Average difference for 8 cases, values of relative humidity measured using the Silver Standard method are replaced with values of relative humidity measured using the Gold Standard method.	0.66
Average difference for 8 cases, 0.1m/sec values of air speed assumed in the Silver Standard method are replaced with actual values of air speed measured using the Gold Standard method.	0.66
Average difference for 8 cases, mean radiant temperature values (assumed to be the same as air temperature) in the Silver Standard method are replaced with actual values of mean radiant temperature measured using the Gold Standard method.	0.46
Average difference for 8 cases, values of clothing insulation measured using the Silver Standard method are replaced with values of clothing insulation measured using the Gold Standard method.	0.34

The results show that replacing relative humidity and air velocity had no difference on the PMV results, thereby suggesting that the assumption made in the Silver Standard method regarding air velocity and relative humidity were reliable enough. The replacement of mean radiant temperature and air temperature took the average difference down to 0.46 and 0.4 respectively. Furthermore, the replacement of CLO values reduced the difference down to 0.34, thereby suggesting that data on CLO values should be collected using the Gold Standard method. Further analysis reveal that when Gold Standard CLO values were used, the R^2 value between both PMVs of both methods increased from 0.51 (Figure 13) to 0.81 as shown in Figure 14. The R^2 value further increased to 0.91 when data from house no.6 were removed from this analysis. This suggests that the Silver Standard method is unable to provide very reliable data on CLO values and therefore the Gold Standard method should be adopted for collecting data on clothing insulation.

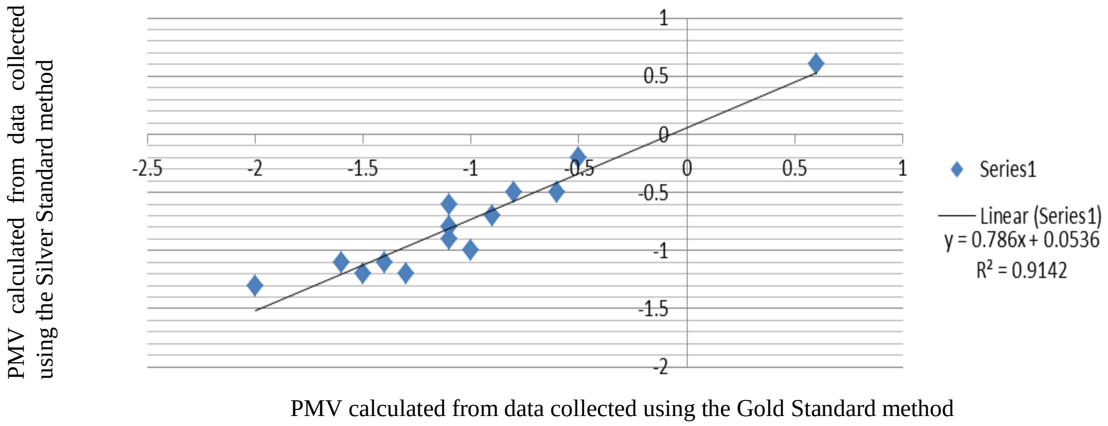

Figure 14: A regression of PMV values calculated from data collected using the Silver Standard method vs. PMV values calculated from data collected using the Gold Standard method (values of clothing insulation measured using the Silver Standard method are replaced with values of clothing insulation measured using the Gold Standard method + data of house number 6 excluded)

5. Conclusion

A comparative analysis of the data collected using both methods has been presented in this paper. The overall aim of the study was to devise a non-intrusive method to conduct thermal comfort studies in domestic environments and test its accuracy and reliability. The non-intrusive method (Silver Standard method) was based on five assumptions that were made to simplify the data collection process, minimise disruption to householders and to avoid any intrusions to the privacy of the householders. From the analysis, the following conclusions are made:

1. If the indoor environment within the room is fairly uniform then the air temperature data gathered using the Silver Standard method is accurate and reliable enough for the studies of thermal comfort.
2. Relative humidity has little impact on PMV as compared to other variables and therefore the Silver Standard method can be used to record data on relative humidity.
3. The assumption that air velocity is less than or equal to 0.1m/second, made in the Silver Standard method, is appropriate for thermal comfort studies of domestic buildings in the UK.
4. Mean radiant temperature can be assumed to be the same as air temperature as long as the layout in the room does not leave the environment around the sofa completely different to any other point in the room and sensors are located adequately.
5. The CLO value from the ensemble list that was used was not accurate enough to get the data that were required, therefore further studies should be done in order to develop a list which can get more accurate CLO value and also include traditional Indian clothing.
6. A good correlation (R^2 = 0.9) has been observed between PMVs obtained from the Silver Standard method and the Gold Standard method, suggesting that the Silver Standard method can provide reliable data for the study of thermal comfort. This method would particularly be useful in conducting large scale studies of domestic environments.

6.0 Future work

The study was conducted during the summer of 2011. Conducted as part of the MSc research project at Loughborough University, the study was limited to a sample size of 16 houses located in Loughborough. In order to further validate and refine the proposed Silver Standard method, further work is required. Firstly, it would be useful to conduct a similar study covering a larger sample in order to see whether the same results are achieved. Secondly, the Silver Standard method should also be trialled during the winter period, particularly to assess the differences between air temperature and mean radiant temperature during the heating period. And finally, further work is also required to improve the clothing ensemble list to ensure that all types of clothing are included.

References

ASHRAE, (2010). ANSI/ASHRAE Standard 55-2010 *Thermal environmental conditions for human occupancy.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, USA.

BSI, (2005). BS EN ISO 7730:2005 - Ergonomics of the thermal environment. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. British Standard Institute, London, UK

DECC, 2010. *Digest of United Kingdom Energy Statistics 2010*, TSO, London, UK.

Fanger P.O., (1970). Thermal comfort: Analysis and Applications in Environmental Engineering, Danish Technical Press: Copenhagen.

Hong .S.H, Gilbertson .J, Oreszczyn. T, Green .G, Ridley .I, (2009). The Warm Front Study Group, A Field study of thermal comfort in low-income dwellings in England before and after energy efficient refurbishment, *Building and Environment* 44(2009) 1228-1236.

Hunt, D.R.G. & Gidman, M.I., (1982). A National Field Survey of House Temperatures. *Building and Environment*, 17(2), pp.107-124.

Indraganti .M, Using the adaptive model of thermal comfort for obtaining indoor neutral temperature: Finding from a field study in Hyderabad, India, *Building and environment* 45 (2010) 519-536.

Oseland, N.A., (1994). A comparison of the predicted and reported thermal sensation vote in homes during winter and summer, *Energy and Buildings* 21(1994) 45-54.

Pimbert, S.L. & Fishman, D.S., (1981). Some recent research into home heating. *Journal of Consumer Studies & Home Economics*, 5(1), pp.1-12.

Shipworth, M. ,Firth.S., Gentry. M.I.,Wright.A.j., Shipworth.D.T., Lomas.K.J.,(2010). Central heating thermostat settings and timing: building demographics. *Building Research & Information*, 38(1), pp.50-69.

Summerfield, A, Lowe.R.J., Bruhns.H.R., Caeiro.J.A.,Steadman.J.P., Oreszczyn.T. (2007). Milton Keynes Energy Park revisited: Changes in internal temperatures and energy usage. *Energy and Buildings*, 39(7), pp.783-791.