Proceedings Paper:

Shahzad, S. orcid.org/0000-0003-2425-776X, Arias-Franco, S. and Rijal, H. (2021) Visual thermal landscaping: a novel method in personalising thermal comfort. In: Roaf, S., Nichol, F. and Finlayson, W., (eds.) Windsor 2020 Resilient Comfort Proceedings. 11th Windsor Conference on Thermal Comfort, 16-19 Apr 2020, Windsor, United KIngdom. , pp. 949-967. ISBN 9781916187634

Visual Thermal Landscaping: a Novel Method in Personalising Thermal Comfort

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Abstract:
Do the occupants adapt to a predictable thermal environment, which is always the same? In this work, Visual Thermal Landscaping (VTL) model was applied, which is a novel method in analysing thermal comfort through a human centric approach in regard to individual differences and spatial context. This is a qualitative architectural analysis method, in which data is mapped on the building layout. It allows intuitive interpretation of collected data through field studies of thermal comfort according to the meaning, individual information (e.g. comfort survey), connections between individuals, their environment and other individuals within the context. Simulation and statistical analysis were also applied on the field data. The simulation accurately predicted the temperature and energy use in the building. The PMV and the statistical analysis suggested that a slight change in the temperature will improve thermal comfort conditions. However, the VTL model revealed the complexity of satisfying everyone with a predictable uniform and steady indoor temperature, due to individual differences and the dynamic aspect of thermal comfort. This study suggests the application of personalised thermal comfort systems to enhance user comfort and satisfaction.

Keywords: Visual Thermal Landscaping, thermal comfort, personalised, individual differences, method

1. Introduction

Do the occupants adapt to a predictable thermal environment, which is always the same? This work investigated user comfort regarding a uniform and steady thermal environment in a fully air conditioned office building in Stockholm, Sweden. It also examined the application of a novel Visual Thermal Landscaping in assessing thermal comfort. This is a qualitative visual analysis method using colour coding for a personalised analysis of thermal comfort according to the spatial context and meaning.

Air conditioned buildings aim to provide a steady thermal environment. Energy is used to regulate the indoor temperature of such buildings. Many studies examine thermal comfort under steady state conditions, such as Blythe (2008), Schellen et al. (2010) and Dai et al. (2017). For uniform and steady thermal environments, PMV model is widely used (Zhang and Zhao, 2008). The ASHRAE Standard 55 (2004) aims to satisfy 80% to 90% of the occupants through the application of the standard comfort zone. Many studies focus on the optimum temperature, such as the work of van Hoof and Hensen (2006), Cui et al. (2013), and Jiang et al. (2018). However, research shows that no particular temperature is acceptable to all (Humphreys, 1972, Baker and Standeven, 1995, Nicol, 1995, Humphreys, 1996, Baker and Standeven, 1997, Humphreys, 1995, Shahzad, 2014). Humphreys and Nancock (2007) state that ‘people differ in the room temperatures they desire’. Meir et al. (2009) explain that the ASHRAE has a contradiction in presenting the comfort zone and defining thermal comfort.

The latter is a state of mind and satisfaction, but ASHRAE leaves this open to interpretation (ASHRAE, 2009). However, the comfort zone is very precise with clear boundaries. He suggests that comfort is not so 'clear cut'. Individual differences in perceiving the thermal environment have been recognised (Anderson, 2012, Shahzad et al., 2019). However, this is not reflected in the main stream of thermal comfort research, such as modelling thermal comfort and human behaviour (Schweiker et al., 2016). Some studies recognise individual differences related to age, gender, and body mass, as discussed in a review by Wang et al., (2018), rather than simply differences between individuals. This work examines individual differences in perceiving and preferring the thermal environment within the spatial context using a novel Visual Thermal Landscaping model. It investigates how different individuals respond to a uniform and steady thermal environment throughout the day.

2. Methodologies

Statistical analysis is the most common method in assessing thermal comfort (Shahzad, 2014). Although very useful, human interpretation of the current statistical analysis is not easy. Also, individual differences in perceiving the thermal environment are acknowledged, but overlooked. Visual Thermal Landscaping was developed (Shahzad, 2014) through architectural analysis techniques using colour coding. The VTL model allows an intuitive interpretation of collected data through field studies of thermal comfort according to the meaning, individual information (e.g. comfort survey), connections between individuals, their environment and other individuals within the context. In this work, the application of the VTL model is compared against PMV and statistical analysis.

Field studies of thermal comfort were applied in this work in an office building in Stockholm, Sweden in the summer of 2012. The building was a fully air conditioned sealed box with no openable windows. The only means of thermal control was the use of internal blinds to avoid direct solar gain. Environmental measurements were applied both constantly using tinytag data loggers and at the workstation level, while a thermal comfort survey was recorded by the participant. Because of the qualitative analysis, a relatively small sample size was preferable in this work. Forty one datasets were collected from eighteen occupants with a good balance of age and gender. All respondents were asked to respond to the survey three times a day, including morning (09.00am to 12.00pm), noon (12.00pm to 14.00pm) and afternoon (14.00pm to 17.00pm). Based on the availability, not every respondent could fill in the survey three times a day. Mainly sedentary activities were observed. A mixture of summer clothing (0.5 clo) and warmer clothing (up to 0.7 clo) was observed. Occupants only wore trousers and no skirts or a dresses were observed. The follow up interviews revealed that several ladies considered the office uncomfortably cool; hence, not suited to wear a skirt. Two female occupants mentioned the need for extra clothing layers in the office during the summer, because of the indoor cool conditions. They both explained that upon exiting the office, they remove the extra layers. As all occupants were wearing trousers in this study, only the thickness and sleeves of the shirt as well as additional scarf and warm clothing layers have been considered for clothing.

Visual Thermal Landscaping was the key analysis method and the focus of this study. Shahzad (2014) introduced and explained this visual analysis method. It provides a platform for a qualitative analysis of thermal comfort data per respondent according to meaning, spatial context and in relation to other occupants (Shahzad et al., 2019). This method was developed through architectural knowledge and expertise. A colour coding system was applied to reflect the thermal comfort survey data on the plan of the building (as demonstrated in Figure 1) according to the respondent's workstation and situation in the office. Further information was reflected on the plan regarding the architectural, spatial, contextual, and work related information. For example, the workstation arrangements, neighbouring occupants, teams, windows, blinds, open plan, personal offices, and other information were reflected as part of the VTL model, as illustrated in Figure 18.

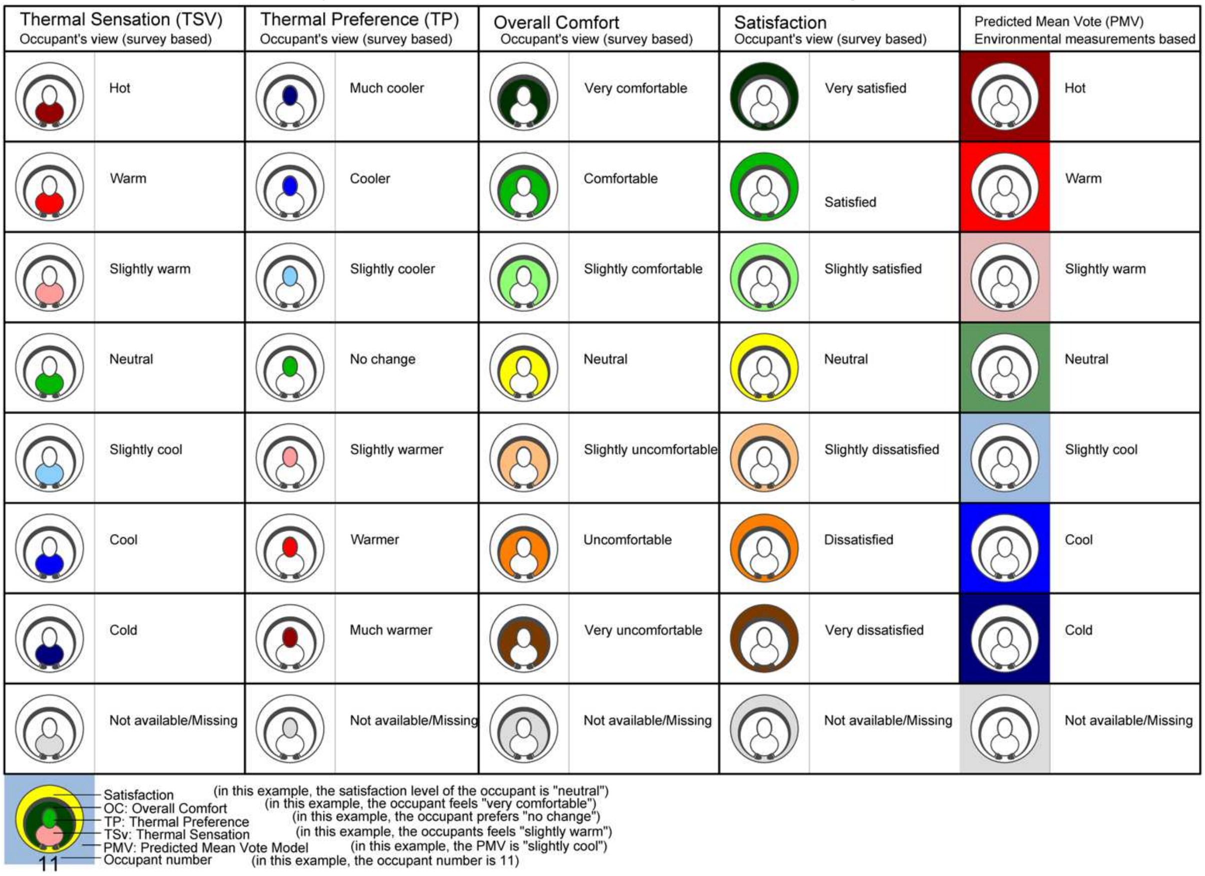

Figure 1. The legend to read the colour coding of the VTL model (Shahzad et al., 2019)

In order to analyse the data using VTL, interpretation and qualitative analysis is required, as demonstrated in Shahzad et al. (2019). The VTL method allows drawing fresh and unexpected conclusions. Hence, in order to get the most out of this method, a more flexible approach is required. Thus, grounded theory was applied as the main methodology in this study. In this approach, instead of starting the research with a pre-judged hypothesis (Glaser and Strauss, 1967), rather several hypotheses exist (Groat and Wang, 2002) and the researcher allows the theory to emerge from the data and analysis (Groat and Wang, 2002, Hunter and John, 2008). It relates to real life conditions and people (Star, 2007), which is suited to the field studies of thermal comfort. This approach leaves the door open for unexpected results, which is arguably a valuable contribution.

3. Analysis

In this section, the building performance is assessed using the actual recorded data as well as simulation analysis. Also, the common statistical analysis of thermal comfort is applied on the surveyed data to assess occupants' response. Finally, Visual Thermal Landscaping is applied on the data and a detailed interpretation is discussed. The contrast between the three analysis methods will be further examined in the discussion section.

3.1. Simulation and Thermal Analysis

The thermal measurements of the building were compared to a simulation of the thermal environment. Figure 2 demonstrates the recordings of the indoor temperature and humidity ranges at the workstation levels around the office. This is based on forty one data sets and it demonstrates the thermal conditions across the office. Relative humidity changes between 30% and 45%. The indoor temperature ranges are quite narrow, mainly between 22.5^{o}C and 23.5^{o}C. This shows a steady thermal environment in the building, which in agreement with an air conditioned sealed building. The PMV analysis indicates a slightly cool thermal environment (i.e. PMV = -0.92 and PPD = 23%). This suggests that a slight increase in the temperature (e.g. 1.5^{o}C to 2^{o}C) is more likely to result in higher levels of thermal comfort.

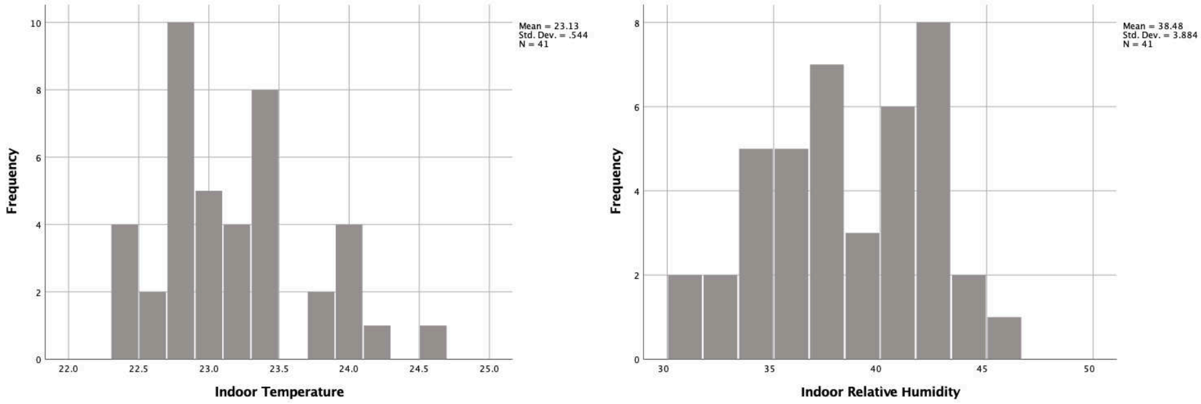

Figure 2. The frequency of indoor temperature and relative humidity recordings

Figure 3 demonstrates the indoor and outdoor temperatures, based on the constant recording using data loggers, which were installed in a specific place in the office. The recording was applied during three working days with five minutes intervals. Overall, 3977 datasets were recorded. The outdoor measuring equipment were in place since early morning, while the indoor measurements started in the afternoon of the first day, due to access issues. As it is demonstrated in Figure 3, the outdoor temperature changes between 15^{o}C and 35^{o}C during these three days with an average temperature of 22.98^{o}C. However, the indoor thermal environment is quite steady throughout the three days with an average temperature of 23.13^{o}C. This is expected, as the building is an air conditioned sealed box.

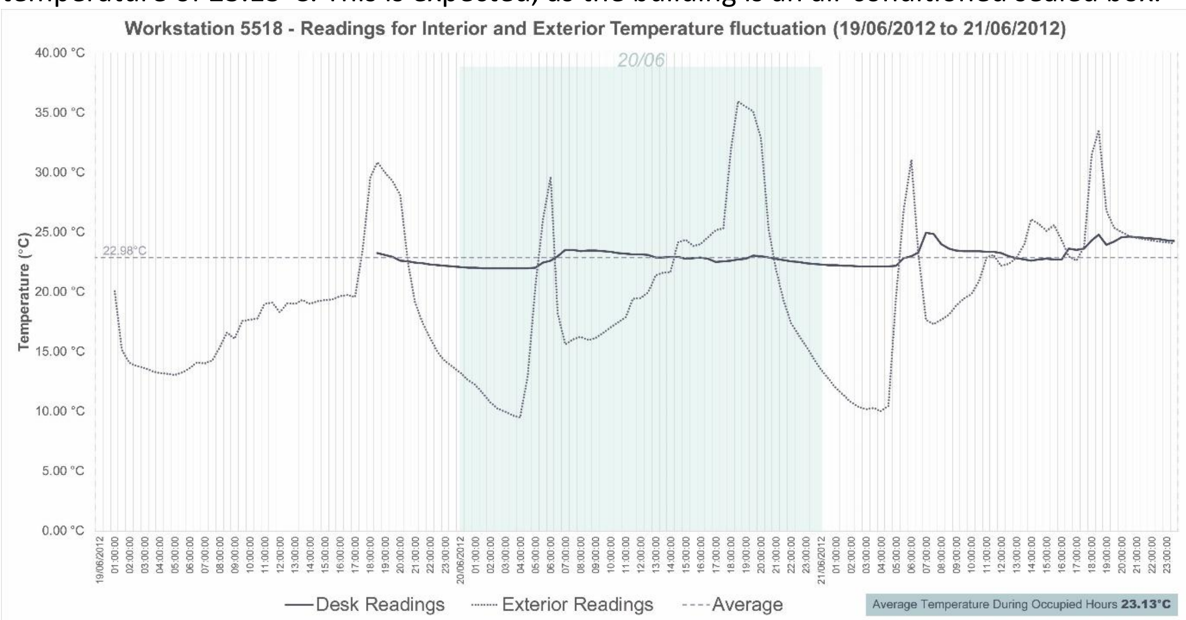

Figure 3. Actual readings of the external and internal temperatures during a three-day period

Thermal simulation was applied, using IES dynamic thermal, as demonstrated in figures Figure 4. Based on the simulation, the outdoor temperatures is expected to change between 11 °C and 22 °C, while the indoor thermal environment is kept steady during the occupied hours with an average temperature of 22.69 °C.

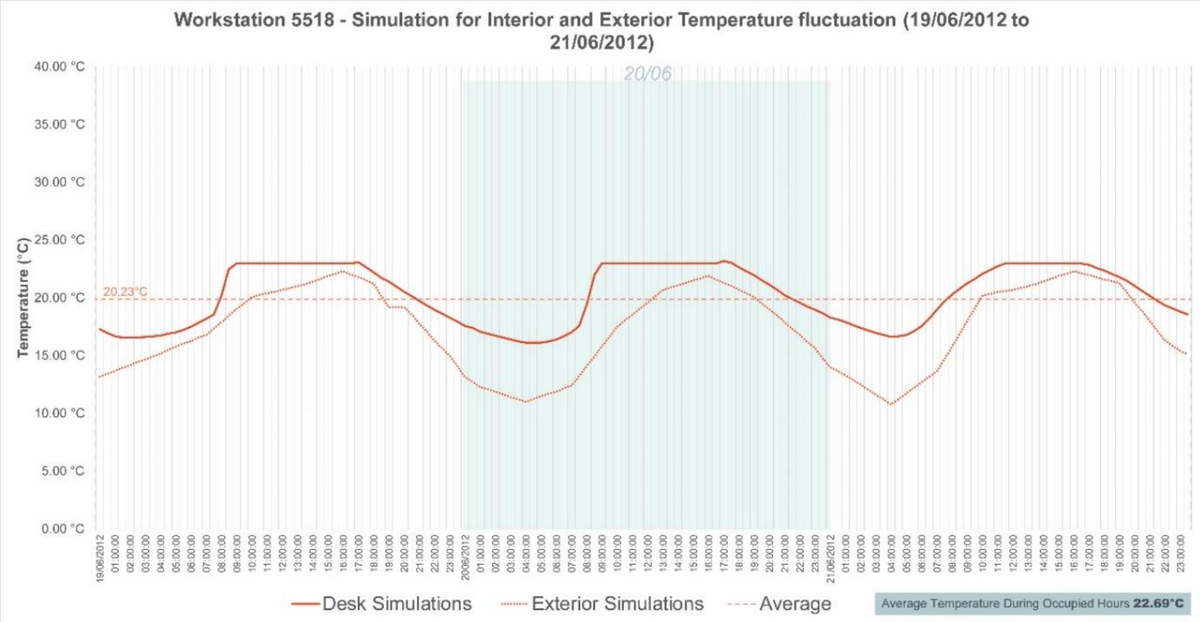

Figure 4. Simulation of the external and internal temperatures during a three-day period

The results of the thermal simulation were compared against the actual thermal readings inside and outside the building. Figure 5 demonstrates the comparison of the outdoor temperature readings and simulation. There is a good correlation between the two; however, the simulation line is much more smooth and it does not show sudden local changes in temperature. The simulated and readings of the minimum temperatures are quite similar; however, the maximum temperatures are significantly different.

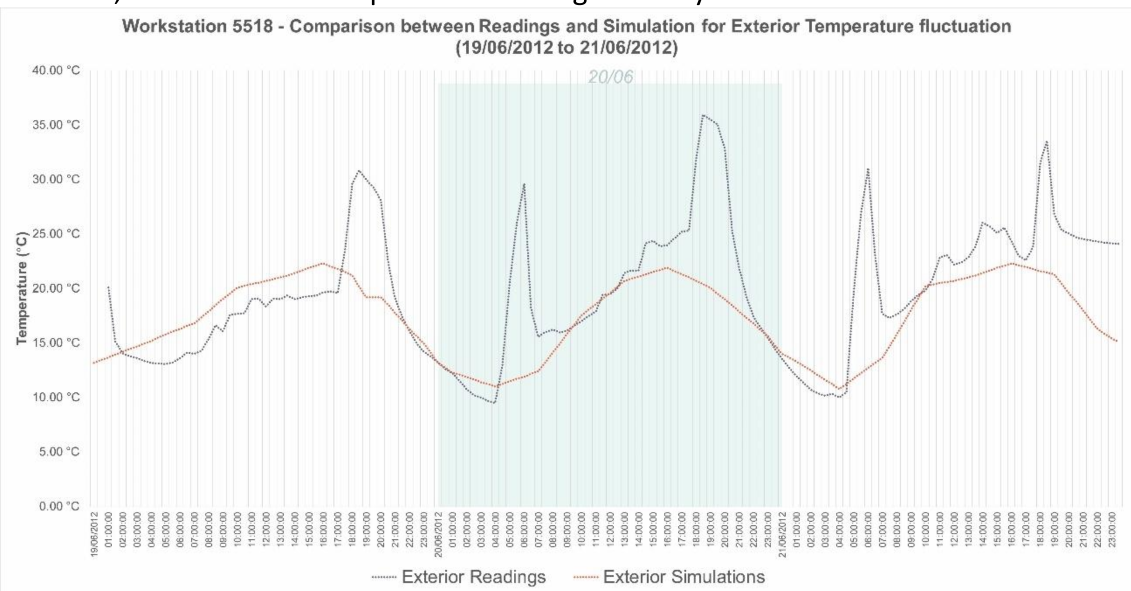

Figure 5. Comparison of simulation and actual recording of the external temperature during a three-day period

Figure 6 illustrates the comparison of indoor simulation and readings. During the occupied hours, there is a good correlation between the two. The simulation also predicts a steady thermal environment in the building with very similar temperature setting with an average temperature of 22.69 °C, while the actual average temperature was measured, as

23.13 °C. The difference between the two is during the out of hours periods, in which the simulation considered the air conditioning to be off, due to energy saving matters. However, the air conditioning is kept on during the night hours, as decided by the facilities manager. Hardly any occupant stays at work after 19.00pm.

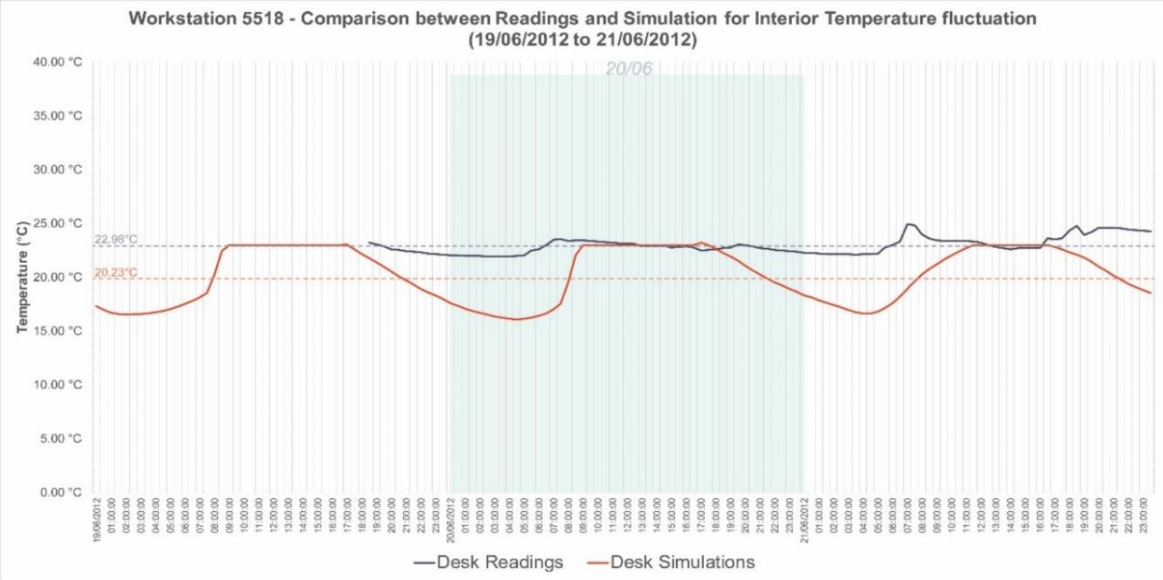

Figure 6. Comparison of simulation and actual recording of the indoor temperature during a three-day period

Figure 7 demonstrates the comparison of the indoor and outdoor simulation and reading during the three days.

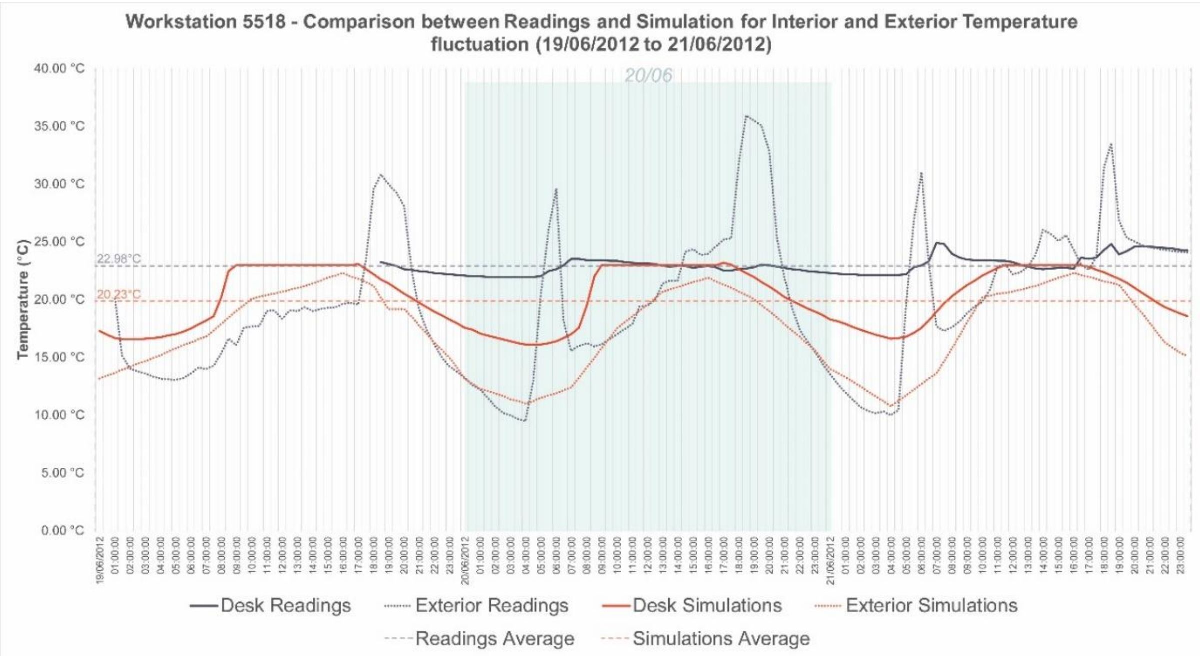

Figure 7. Comparison of simulation and actual recording of the external and internal temperatures during a three-day period

Figure 8 shows the indoor and outdoor simulation and readings during one day and in more detail. The consistency of the indoor temperature during the occupied hours is quite visible. During the unoccupied hours, the difference between the simulation and readings of the indoor temperature can measure up to 6 °C, which can be significant regarding the energy use.

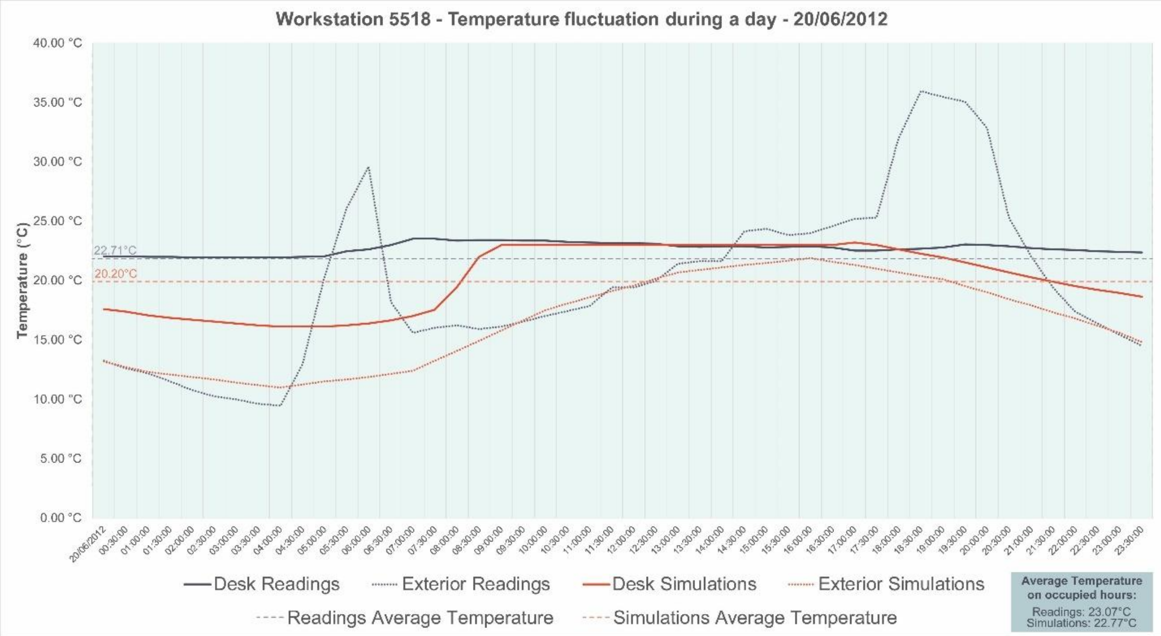

Figure 8. Comparison of simulation and actual recording of the external and internal temperatures in a day

Figure 9 shows the comparison of the outdoor relative humidity between the simulation and readings, which is up to 30% difference.

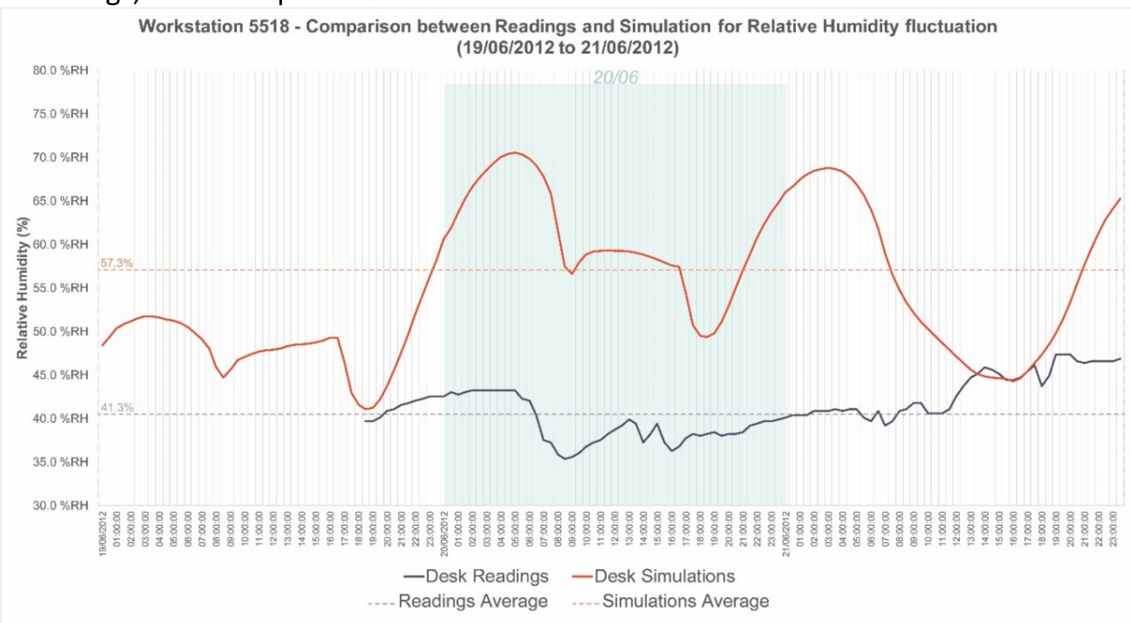

Figure 9. Comparison of simulation and actual recording of indoor relative humidity during a three-day period

Figure 10 shows the difference in indoor relative humidity between the simulation and readings, which is significantly different, up to 27%.

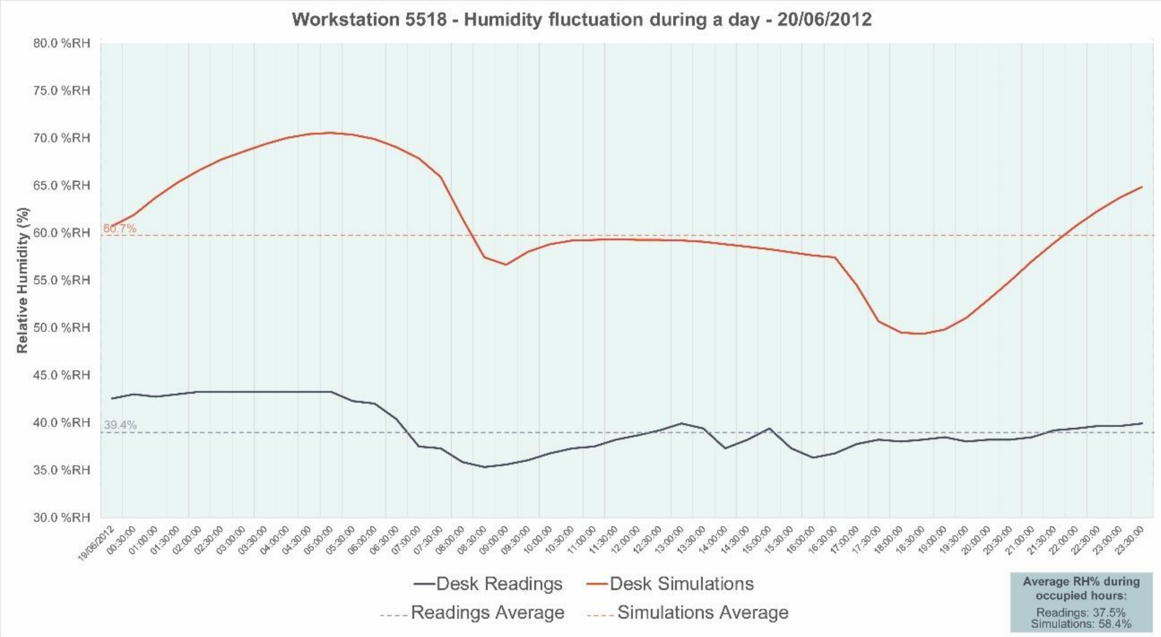

Figure 10. Comparison of simulation and actual recording of indoor relative humidity in a day

Overall, both the simulation and the actual recordings of the thermal environment indicate a uniform and steady thermal environment across the office and during the three day period. This suggests that the building had a good thermal control, and thus, a good thermal performance within a small range. The PMV analysis suggested that the thermal environment falls towards slightly cool and a slight increase in the temperature (e.g. 1.5°C to 2°C) is more likely to result in higher thermal comfort levels.

3.2. Thermal Responses

In this section, thermal responses of the occupants, including thermal sensation, thermal preference, overall comfort and satisfaction are analysed. The frequency of thermal sensation, thermal preference, overall comfort and satisfaction is analysed in Figure 11. Majority of the occupants feel slightly cool and neutral, while they prefer slightly warmer and neutral. This is in line with the PMV analysis, as mentioned above. There is a relatively good degree of comfort level, while satisfaction level varies and in many cases, it appears quite poor.

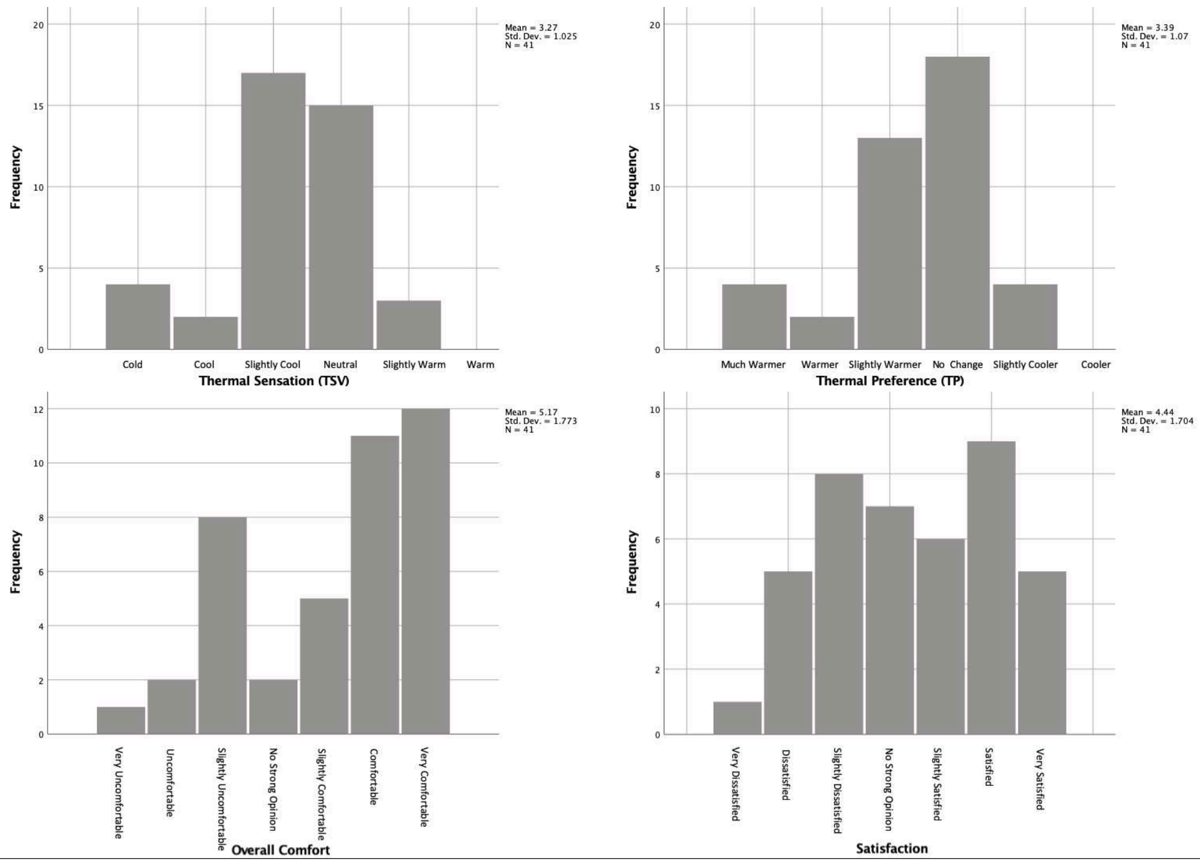

Figure 11. The frequency of TSV, TP, OC, and satisfaction responses

The relationship between thermal sensation, thermal preference, overall comfort, and satisfaction is examined in Figure 12. The regression analysis of thermal sensation and thermal preference shows that when respondents feel neutral, they prefer no change, as it is usually expected. It also shows that occupants, who feel cool, rather than preferring warmer temperature, they prefer somewhere between slightly warmer and warmer. Thus, when feeling cool, they don't prefer the same degree of change in the temperature, rather slightly less intense change (i.e. half a scale). The same condition applies to respondents, who feel slightly warm. They also don't prefer the same degree of change in the temperature, rather slightly less change (i.e. somewhere between no change and slightly cooler). This suggests that respondents can tolerate slightly warm or cool conditions, as they don't prefer much change in the temperature.

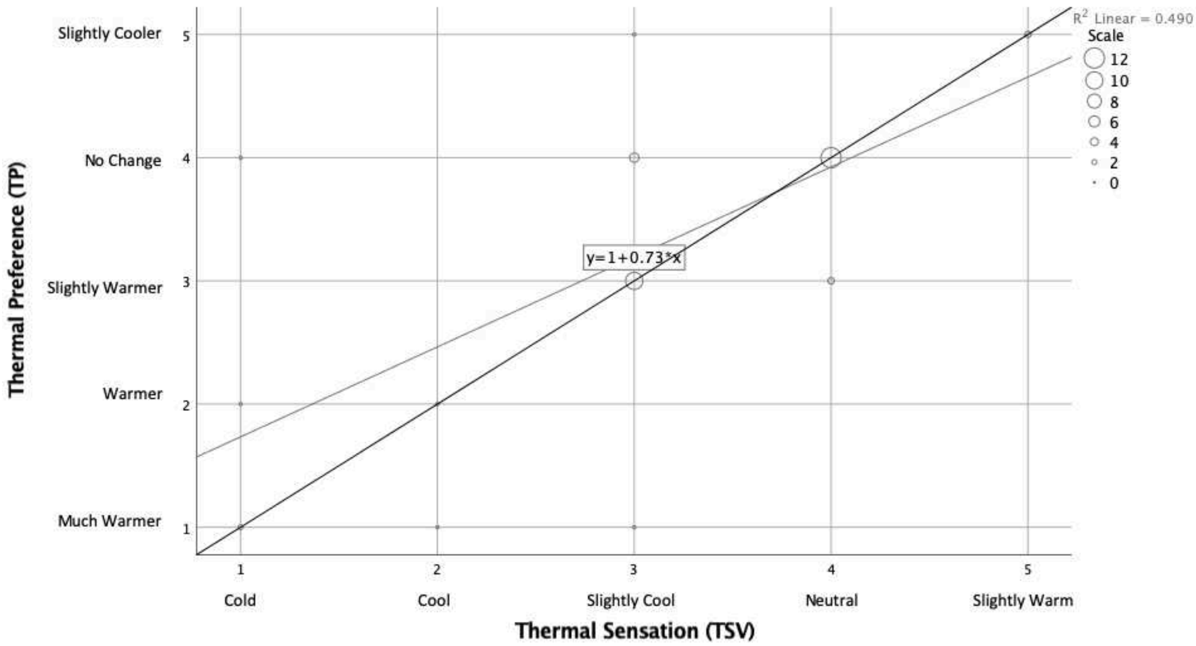

Figure 12. The relationship between thermal sensation and thermal preference

Figure 13 demonstrates the relationship between thermal sensation and overall comfort. It shows that, when the occupants feel neutral (i.e. TSV = 4), overall comfort is at the maximum. This suggests that majority of the occupants are comfortable, when feeling neutral. This is in agreement with the findings of Fanger (1970), McCartney and Nicol (2002), (Liu et al., 2012, Cigler et al., 2012, van Marken and Kingma (2013), Schellen et al. (2013), Indraganti et al. (2013).

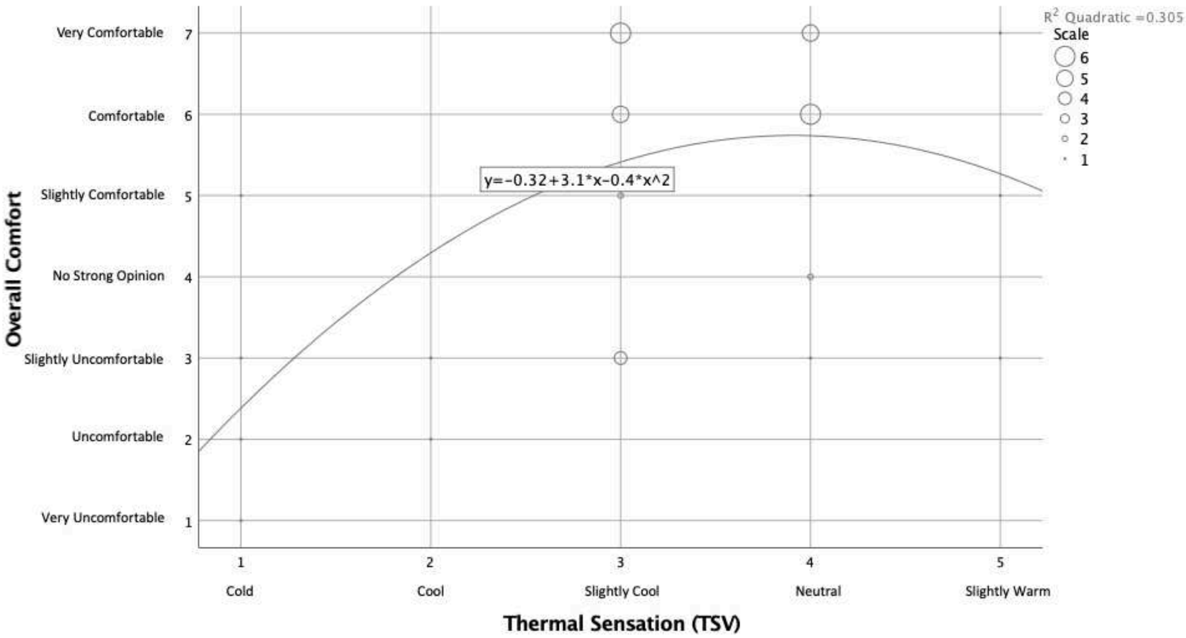

Figure 13. The relationship between overall comfort and thermal sensation

Figure 14 demonstrates the relationship between overall comfort and thermal preference of the occupants. This is quite similar to Figure 13, as the preference on no change has the maximum overall comfort level. This suggests that majority of the occupants prefer no change in the temperature to feel comfortable.

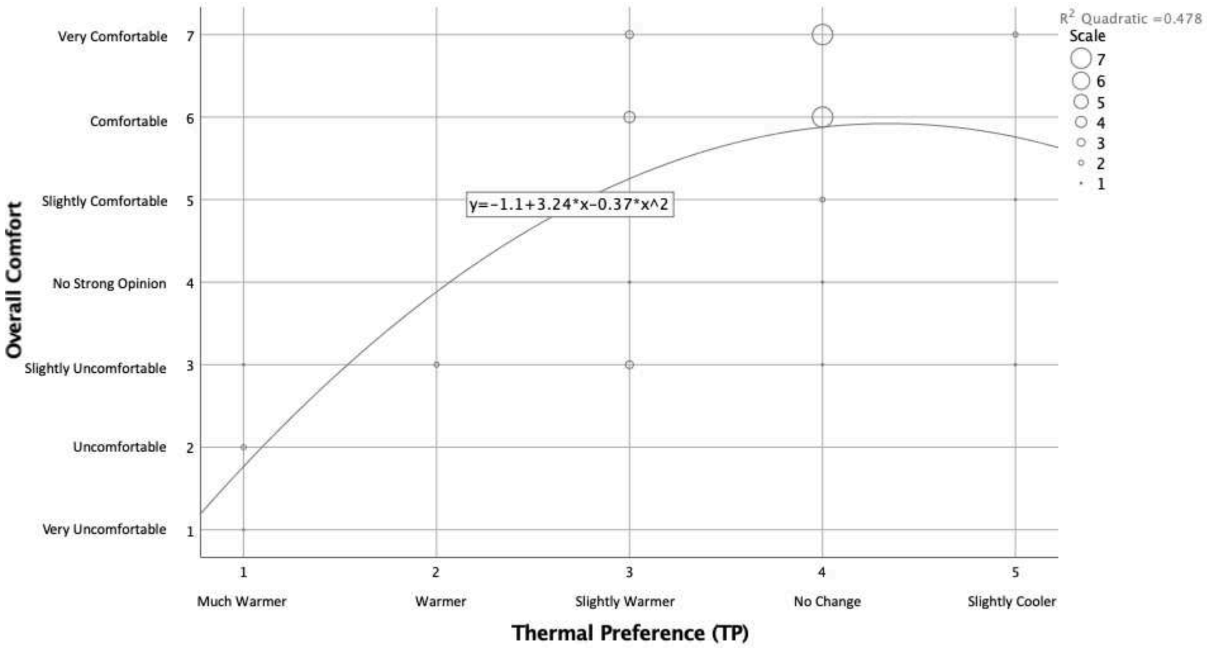

Figure 14. The relationship between thermal preference and overall comfort

Figure 15 illustrates the regression analysis between overall comfort and satisfaction. It shows a good correlation, as the higher the comfort level, the higher the satisfaction level and vice versa.

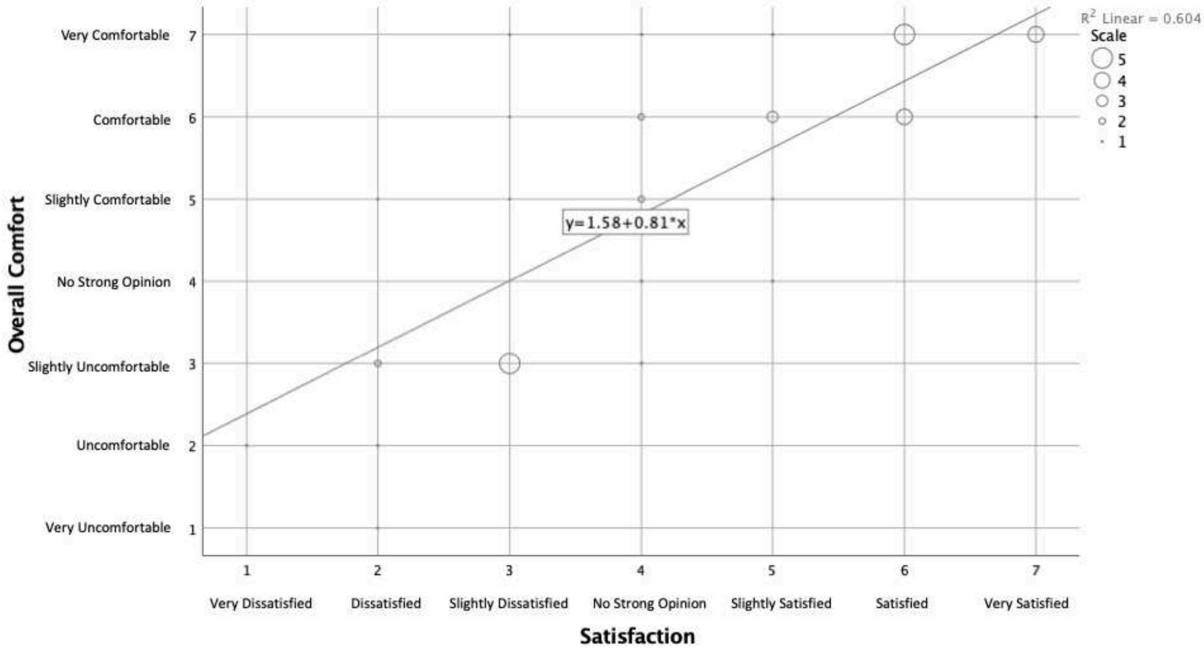

Figure 15. The relationship between overall comfort and satisfaction

Figure 16 shows the relationship between indoor temperature with thermal sensation, thermal preference, overall comfort and satisfaction. The temperature range is very small, mainly between 22 °C and 24 °C. There is a great similarity between all four graphs, as within a small range of temperature occupants responded quite differently. For example, the mean is quite close in all scales of thermal sensation. The same applies to thermal preference, overall comfort and satisfaction.

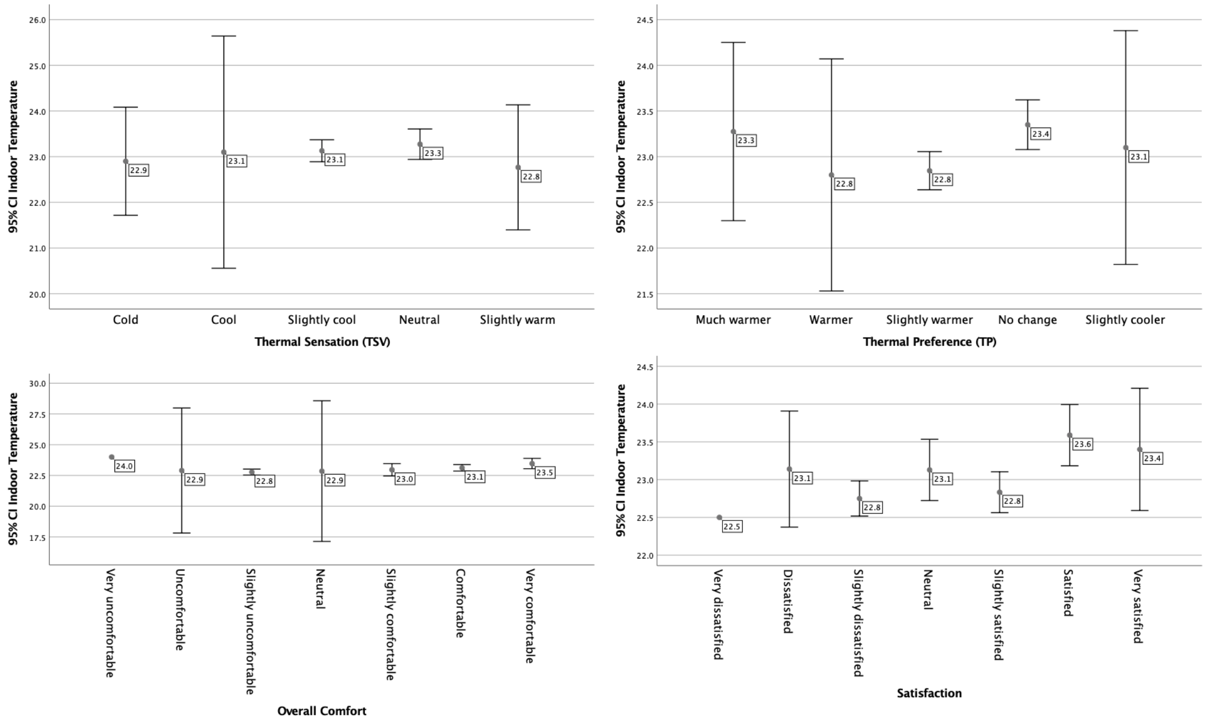

Figure 16. The relationship between the indoor temperature with TSV, TP, OC, and satisfaction

Figure 17 demonstrates the regression analysis of the indoor temperature with thermal sensation, thermal preference, overall comfort and satisfaction. All graphs show quite scattered responses and the slope of the regression lines are not significant. Thus, suggesting that the relationship between indoor temperature with all four variables is not that significant; thus, difficult to draw conclusions.

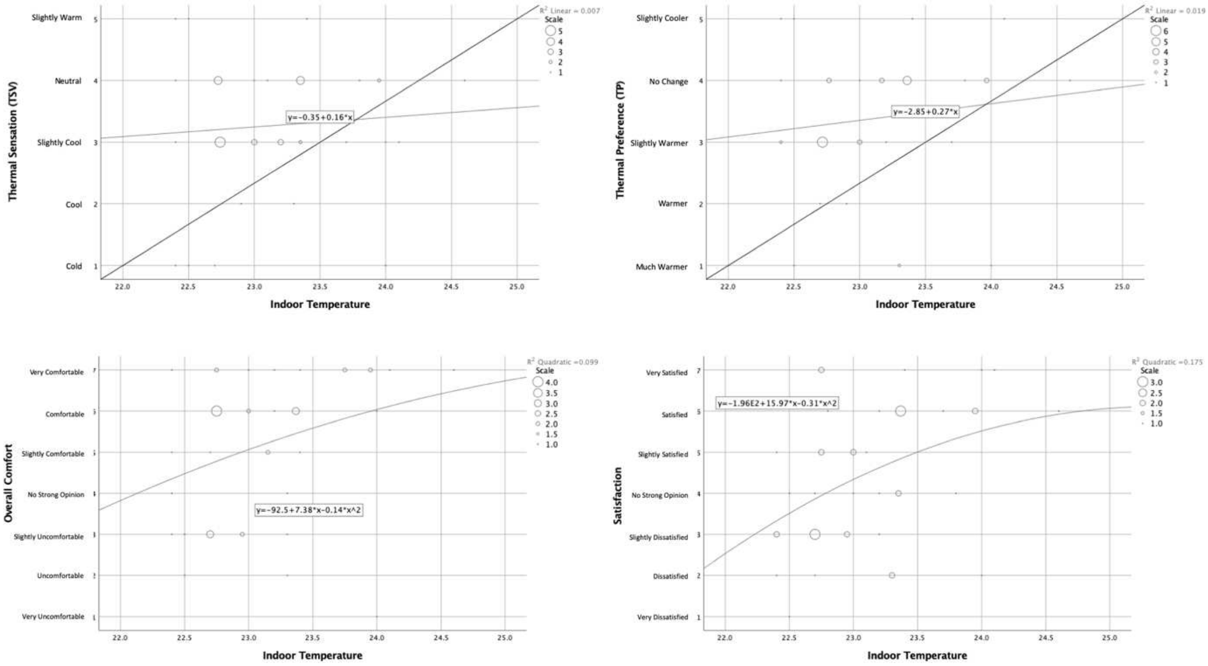

Figure 17. The relationship between the indoor temperature with TSV and TP

Overall, majority of the occupants feel neutral (i.e. TSV = 4), prefer no change (i.e. TP = 4) and they have a relatively high comfort level. There is a good relationship between the four variables, including TSV, TP, OC, and satisfaction. Occupants' thermal responses are significantly varied, specifically considering the narrow range of the thermal environment (i.e.

about 2 °C). It is difficult to draw conclusions on the relationship between indoor temperature and the four variables.

3.3. Visual Thermal Landscaping

In this section, VTL model is applied, as illustrated in Figure 18. Accordingly, a detailed interpretation is discussed regarding each respondent in connection with other respondents, spatial context, teams, and the respondent's other responses.

Respondents S02 and S03 feel cool and prefer warmer conditions at noon and in the afternoon. However, the degree of their sensation and preference is different. S02 is wearing a jumper all day, while S03 is wearing a long sleeve shirt all day. S02 feels cold and prefers warmer at noon, which is reflected in his slightly uncomfortable and dissatisfaction. Although, S03 shares similar comfort and satisfaction levels; he feels slightly cool and prefers much warmer. This suggests that although S03 does not feel that cold, but the level of change he prefers is much higher than S02, who feels cold. In the afternoon, both S02 and S03 feel cool; however, again the level change preferred by S03 is higher (much warmer for S03, as compared to warmer for S02). Feeling cooler than at noon is reflected in S03's drop in comfort (i.e. uncomfortable) and satisfaction levels (i.e. dissatisfied). Although the thermal sensation of S02 and S03 changes throughout the day, their thermal preference does not change.

Occupants S09 and S10 go through very different thermal experiences throughout the day. In the morning and afternoon, S09 feels neutral, prefers no change and he is comfortable wearing a long sleeve shirt. At noon, although the room temperature hasn't changed, S09 feels slightly warm and prefers slightly cooler conditions. Also, there is a drop in his comfort level to slightly uncomfortable. In contrast, S10 is wearing a jumper and still he feels cold and prefers much warmer conditions throughout the day. This is reflected in his overall comfort and satisfaction level, which are poor (i.e. very uncomfortable and dissatisfied in the morning, while uncomfortable and very dissatisfied at noon).

Participants S11, S12 and S13 want totally different things both in the morning and at noon. Although they all feel slightly cool or cold in the morning; S11 prefers slightly warmer, while S12 and S13 are both happy to feel cold and slightly cool, as they prefer no changes in the thermal environment. At noon, they all have different sensations (slightly cool, neutral and slightly warm) and different preferences (slightly warm, slightly cool and no change). Surprisingly, the overall comfort and satisfaction level of S12, who feels neutral and doesn't prefer any change, is quite lower than the other two, who don't feel neutral and prefer a slight change in the temperature. Only in the afternoon, both S11 and S12 feel slightly cool and prefer slightly warmer. However, their overall comfort and satisfaction levels reveal a different level of comfort. S12 is slightly uncomfortable and slightly dissatisfied, while S11 feels very comfortable and slightly satisfied. S13 also feels slightly cool; however, he prefers no change and he is comfortable with the thermal environment. Overall, S11 has been very consistent in his thermal sensation (slightly cool), thermal preference (slightly warmer), overall comfort (comfortable or very comfortable), and satisfaction level (slightly satisfied). He consistently feels slightly cool and prefers a slightly warmer condition; thus his thermal decision is neutral. S13 consistently shows a tendency for slightly cool temperatures, as in the morning and afternoon he feels slightly cool and prefers no change in temperature. At noon, he feels slightly warm and he prefers slightly cooler.

Figure 18. Visual Thermal Landscaping of the case study building in Stockholm

Respondents S14, S15 and S16 want totally different temperatures throughout the day. Although in the morning, S14 and S15 both feel slightly cool; they have opposite preferences. S14 prefers slightly cooler while S15 prefers slightly warmer. S14 is very satisfied and very comfortable, while S15 is slightly dissatisfied and slightly comfortable. Also, S14 is wearing a long sleeve shirt, while S15 is wearing a jumper in July. These suggest that S15 faces more difficulties regarding the room temperature, while S14 although prefers a slightly cooler conditions, he is very comfortable and satisfied with it. Meanwhile, S16 considers the thermal environment as neutral, prefers no change and feels satisfied and very comfortable. Like S14, he is also wearing a long sleeve shirt. This suggests that in the morning, both S14 and S16 are fine with the thermal environment, while S15 is unhappy. At noon, similar situation continues, the only major difference is that S14 prefers no change, while feeling slightly cool. Overall, S15 and S16 have been consistent in their thermal sensation, thermal preference, overall comfort, and satisfaction. S14 has been consistent in thermal sensation, overall comfort and satisfaction; however, his thermal preference changes from slightly cooler in the morning to no change at noon.

3.4. Energy

The energy consumption of the building was assessed using both simulation and the data received from the facilities manager of the building. Figure 19 demonstrates the simulated energy consumption using IES software.

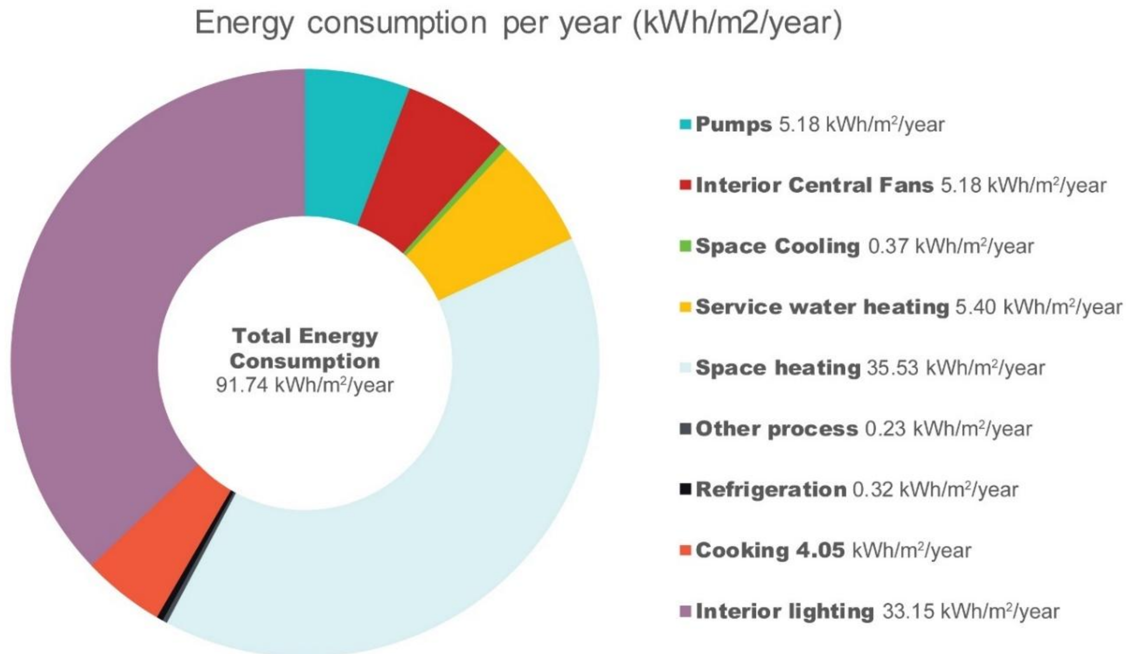

Figure 19. Energy use and breakdown per year, using IES-VE simulation

The simulation indicates 91.74 kWh/m2/year, while the actual energy use was recorded, as 98.60 kWh/m2/year. The two figures are quite close, as demonstrated in Figure 20.

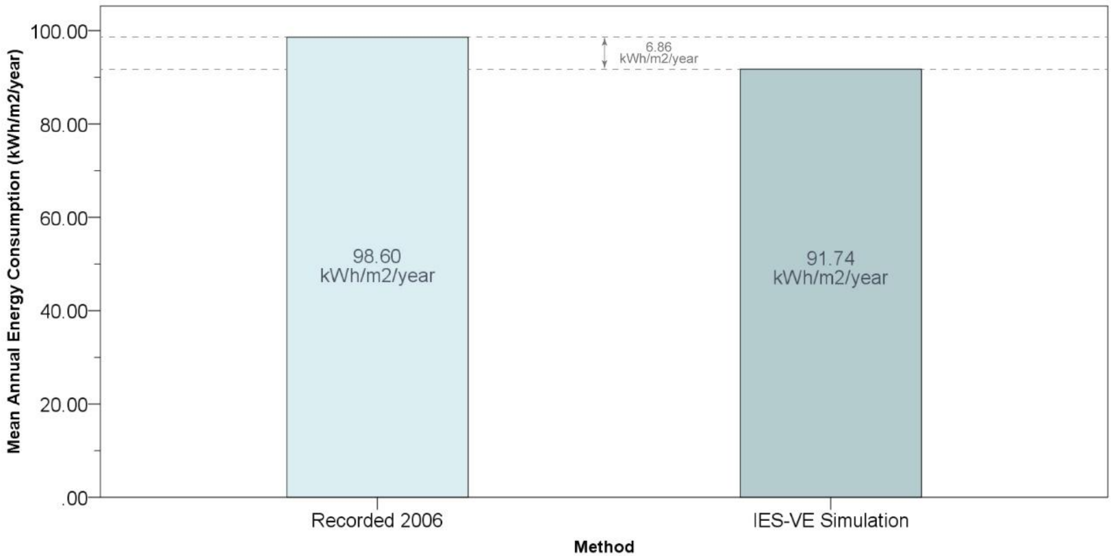

Figure 20. Comparison between simulation and actual data regarding the energy use of the building

4. Discussion

The thermal comfort condition of the occupants fully air conditioned sealed office with no openable windows was investigated in this work. A field study of thermal comfort was applied through a grounded theory approach. The collected data was analysed through simulation, statistical analysis and a qualitative analysis using the Visual Thermal Landscaping model. The results of the simulation were compared against the actual thermal performance of the building, based on the environmental measurements during three days on site. The building performance analysis indicated that the thermal environment in the building is uniform and steady within a narrow band (i.e. mainly between 22.5°C and 23.5°C). This shows a good thermal control and thermal performance of the building, which is consistent with the expectation of a fully air conditioned sealed box. The results of the temperature analysis through simulation were very close to the actual data, except that during the unoccupied hours the simulation considered the air conditioning to be off, due to energy saving purposes. However, in the actual building, air conditioning was left on over night, although no occupants were reported to stay in the building. Also, the simulation did not predict the sudden changes of the outdoor temperature. However, except the sudden changes, the rest of the outdoor temperature analysis was quite similar. The humidity analysis was significantly different (i.e. up to 30% different). Also, the sudden changes of the humidity were not detected through the simulation. There was a good similarity between the simulation and actual data regarding the energy performance of the building. Knowing that simulation is the main tool used for improving the thermal performance of a building. The results of this work suggest that when it comes to a fully air conditioned sealed workplace, the simulation can be quite accurately predicting the thermal environment.

The PMV analysis suggested that the building is expected to be on the slightly cool side, while increasing the temperature by 2°C improves the thermal comfort of the occupants to the neutral point. This is in line with the statistical analysis, which showed that 41% of the respondents felt slightly cool and 32% of the occupants preferred slightly warmer conditions. The statistical analysis observed that within the narrow band of indoor temperature, quite a variety of thermal sensation, thermal preference, overall comfort, and satisfaction levels. No significant relationship was found between the indoor temperature and the thermal preference, overall comfort, and satisfaction of the occupants. Respondents with a thermal sensation of slightly cool or warm preferred less degree of change in the temperature, suggesting a higher degree of tolerance than expected. Overall comfort and satisfaction were correlated. The highest overall comfort level was detected, when the occupants had a neutral thermal sensation or a no change thermal preference.

The VTL model showed that individuals had quite a different perception of the thermal environment, some quite opposite perceptions (e.g. cool, slightly warm and neutral). Also, the degree of change they preferred was quite different from one another, even for the individuals with similar perception of the thermal environment. Knowing that it was a uniform and steady thermal environment, the observed individual differences in perceiving, preferring and experiencing the thermal environment quite distinctly becomes more significant. Some of these individuals seat quite closely together and still they sense and prefer very different thermal conditions. This is quite visible at S09, S10, S11, S12, and S13 workstations. 51% of the respondents prefer either no change or slightly cooler thermal environment. This means that by increasing the temperature up to 2^{o}C, as suggested by the PMV analysis, 51% of the occupants are more likely to feel uncomfortable. This suggests that a uniform thermal environment cannot satisfy all these individuals.

56% of the respondents felt and preferred different thermal environment throughout the day, knowing the thermal environment has been steady. Not only that individuals were observed, as quite different in their perception and preference, but also individual's perception and preference changed throughout the day. This shows the dynamic aspect of thermal comfort. Thirteen occupants feel neutral and two of them prefer slightly warmer conditions. Sixteen respondents prefer no change, while six of them feel other than neutral (e.g. variations from cold to slightly warm). This suggests that changing the temperature for these respondents is likely to result in their discomfort, although their thermal sensation has been other than neural. 94% of the occupants did not change their clothing layer throughout the day. 88% of these respondents either had a sensation other than neutral or preferred a change in the thermal environment at least at some point in the day. Changing clothing layers was not practiced to restore the comfort level. For example, S13 is wearing a jumper at noon, while feeling slightly warm and preferring a slightly cooler conditions. According to the follow up interviews, women in the office did not wear skirts or dresses in the summer in the office, as they found the indoor temperature uncomfortably cool. They also explained that they had to wear extra layers in the office, whilst upon exiting the workplace, they removed those layers.

5. Conclusion

This work examined user satisfaction of a steady and uniform thermal environment. A key part of the analysis was done through the application of a novel Visual Thermal Landscaping method in assessing thermal comfort. This is a qualitative visual method, which is useful for a personalised analysis of thermal comfort according to spatial context and meaning.

Overall, the air conditioned sealed office building provided a uniform and a steady thermal environment, indicating a good degree of thermal control and performance. simulation revealed to be able to accurately predict the indoor thermal environment and energy use of this building. The PMV analysis suggested a slightly cool thermal environment and that by increasing the temperature up to 2oC, a high level of user comfort can be achieved. The results of the statistical analysis was in line with the PMV analysis, showing that 32% of the occupants preferred slightly warmer conditions. The temperature was not significantly related to the thermal sensation and thermal preference of the occupants. It suggested a higher tolerance level, as the degree of preferred change was lower than the scale of thermal sensation. The VTL model highlighted the individual differences in perceiving and preferring the thermal environment. It revealed the complexity of thermal comfort within the spatial context of an open plan office and the difficulty of satisfying all with an individual indoor "optimum temperature". It also showed the dynamic aspect of thermal comfort, as the individuals changed their perception and preference throughout the day, although the indoor temperature was quite steady. Studies suggest to provide a variety of thermal environments within the office, so that individuals can select their workstation. This study finds difficulties with this idea, as individuals may not have the liberty to choose their workstation. Their choice is limited to either the availability of a workstation or the need to sit close to their team to encourage teamwork and knowledge transfer purposes. The latter as was the case in this study. Also, the dynamic aspect of thermal comfort suggests that even if the individual finds a specific thermal condition comfortable, they are likely to change their mind throughout the day. This study suggests the application of personalised thermal comfort systems to enhance user comfort and satisfaction.

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