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Indoor Thermal Environment: Occupants Responsiveness in 4 Multi-Storey Office Buildings in Accra, Ghana.

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Abstract

The issue of comfort and workplace environment satisfaction within office buildings is fast becoming important and has gain interest by a lot of researchers. Since modern day office building designs (in Ghana) have resorted to the use of extensive glazing which contribute to the adverse indoor climate.

This paper presents the results of a study of four multi-storey office buildings in Ghana with regards to occupants' evaluation of their indoor environmental conditions. The buildings comprise of one naturally ventilated (World Trade Centre) and three mechanically ventilated office blocks (Ridge Towers, Heritage Towers and Premier Towers). Occupants in each building filled in a questionnaire to document their perception regarding indoor environment while some thermal and acoustical parameters were measured. Furthermore, the respondents expressed their feelings on the 7-point ASHRAE thermal sensation scale, to determine their Actual Mean Votes (AMV). Altogether, 195 occupants' filled the questionnaire. The data and responses were analysed descriptively with MS Excel. The outcomes amongst others showed that in the naturally ventilated office, a good agreement could be seen with adaptive comfort models whiles in the air-conditioned offices, 97.1% of the occupants felt that their offices were cool. Again, only one out of the four office buildings met the standard criteria for lighting which is 500 lux. The sound levels measured also suggested that one building was not comfortable in terms of acoustic comfort. Both lighting and acoustic inefficiency may affect productivity.

Attention to user perceptions and behaviour could improve the quality of the indoor environment in office buildings

Keywords: Occupants', Indoor environment, Naturally ventilated, Air-conditioned, Actual Mean Vote.

1. Introduction

It is common knowledge that the presence and actions of building occupants have a significant impact on the performance of buildings (Mahdavi and Pröglhöf 2009) as they affect and gets affected by their indoor environments. Thermal controls in office buildings are used to modify the climate for comfort and are achieved through manipulation of the environmental control systems, such as air- conditioners, windows, shades, etc. (Nicol and Roaf, 2005). According to Pino et al. (2012), many modern buildings have taken advantage of glass transparency in their design to create a clear view to the outside. When using a high window-to-wall ratio (WWR; ratio of the glazed area with respect to the total area of the exposed envelope), occupants commonly might feel thermal and/or visual discomfort and they will apply their own strategies to mitigate this problem. Conversely, Heschong, (2002) reported that WWR play an important role in natural lighting which can improve job performance of workers. Occupants in office buildings dress in standardized clothing and show up in their offices to carry out activities that have been assigned to them by their superiors. In their quest to fulfilling these tasks, they are often disrupted by the way they thermally, visually, as well as acoustically feel within the work place such that the tasks assigned them may be delayed.

To this end, technological and cultural pressures (building design, dress codes, heating and cooling control systems) are in danger of producing convergence on a very limited range of temperatures that are perceived as 'comfortable', particularly in public buildings such as offices (Shove 2003), which implies both increased indoor temperature control and increased energy use. Research has demonstrated that the quality of the indoor environment has considerable impact on human health, stress, productivity and wellbeing (Agnieszka and Mats, 2013). The authors (Agnieszka and Mats, 2013) also suggested in their study in Sweden that individual and building characteristics contribute significantly on how occupants perceive their indoor comfort. In their research, air quality was ranked first to have a great impact on occupant satisfaction followed by thermal comfort and sound (acoustic) comfort. Although the data used carries certain subjectivity, the subjective ratings proved to predict overall comfort better than objective indicators (Fransson and Vastfjall, 2007).

Frontczak and Wargocki (2011) in their literature survey conducted showed that thermal, visual, acoustic and air quality is the main indoor environmental parameters contributing to satisfactory indoor environment. Frontczak et al. (2012) used panel data collected by the Center for Built Environment (CBE) through post-occupancy surveys sent to office buildings to investigate which indoor environment quality (IEQ) parameters affect occupants' satisfaction most. The results suggest that the three most important parameters for occupant satisfaction were space available for individual work, noise level and visual privacy. The impact of the main indoor environment parameters, i.e. thermal, visual, acoustic and air quality, on office occupants' satisfaction was as follows: noise level, sound privacy, temperature, amount of light and air quality.

Kim and de Dear (2012) used the Kano Model to differentiate between IEQ factors that impact overall satisfaction in negative, positive or in both directions. They concluded that 'temperature' and 'noise' had predominantly negative impact on occupants' overall satisfaction when expectations were not met.

On the other hand, a study conducted on commercial spaces in Hong Kong by Lai and Yik (2009, 2007) showed fairly different results, indicating that thermal comfort had the highest impact on overall IEQ acceptance, followed by air, noise and visual quality. An investigation conducted in China also suggests that thermal comfort has the highest impact on overall satisfaction (Cao et al., 2012).

However, studies based on indoor environment evaluation of occupants living in Hong Kong apartments indicate that thermal comfort has the highest important impact on overall IEQ (Lai et al., 2009; Lai and Yik, 2009). This was followed by noise and air quality.

Choi et al. (2009); Astolfi and Pellerey (2008) all investigated the importance of environmental conditions only in terms of the subjective evaluations of building users. They examined the importance of indoor environmental conditions for comfort by asking the building users to rank the parameters according to their importance. The results of these studies show that thermal comfort was ranked to have slightly higher importance than acoustic comfort and satisfaction with air quality, and considerably higher importance compared with visual comfort

According to Pino et al. (2012), thermal comfort can be defined as physical and psychological wellness of an individual when temperature, humidity, and air movement conditions are favorable for the activity that has to be developed. Whiles visual comfort is defined as "a subjective condition of visual well-being induced by the visual environment" (EN, 2002). Visual conditions are characterized by such parameters as luminance distribution, illuminance and its uniformity, glare, colour of light, colour rendering, flicker rate and amount of daylight (EN, 2002). Navai and Veitch (2003) defined acoustic comfort as "a state of contentment with acoustic conditions". The acoustic environment is influenced by such physical room properties as sound insulation, absorption and reverberation time (Cowan, 1994).

The recommendations of most agreed standards and codes of practice for office lighting criteria is 500Lux (Burberry, 1997). A study conducted by Yufan and Hassim (2011) on the comparison of occupant comfort in a conventional high-rise office block and a contemporary environmentally concerned building showed that although more than half of the illuminance recorded gave figures less than 500Lux (54.3%), which meant these working stations did not meet the lower limit of the visual requirement, only 26.5% (N - 34) clearly showed that they felt darkness from 'little' to 'fairly'. However, the occupants' perception of their visual environment also depends upon the illuminance they are accustomed to (Tregenza and Leo, 1998).

The recommended criteria and suggested values for general office space sound is less than 45 dB as suggested by Reid (1984) in Yufan and Hassim (2011).

The neutral sound pressure level for aural comfort in typical air-conditioned offices was found to be between 45 dB and 70 dB, with a mean of 57.5 dB (Mui and Wong, 2006).

Studies have showed that physical environmental parameters are all interrelated, and the feeling of comfort is a composite state involving an occupant's sensations of all these factors (Naganoa and Horikoshib, 2005; Eduardo et al., 2004).

As cited by Huang et al. (2012), the Chinese code for the design of sound insulation of civil buildings suggests that the noise level in offices should not be higher than 55 dB. In their survey however, when the noise level was below 49.6 dB, subjects felt satisfied with the acoustic environment. When the noise level increased above this threshold, subjects felt increasingly uncomfortable.

According to Huang et al. (2012), in relation to temperature and humidity, the thermal environment affects occupants' sensation of "warm" or "cool" and "humid" or "dry", and is considered to be the environmental factor to which people pay the most attention.

Again, comparative risk studies performed by the United States Environmental Protection Agency (USEPA) ranked Indoor Air Quality (IAQ) as one of the top five environmental risks to public health (Lai et al., 2009).

Buildings with poor adaptive opportunities often produce intolerable indoor conditions within (Baker and Standevan, 1996) and eventually become power guzzlers (Nicol and Humphreys, 2004). The mere existence of a control system cannot improve the adaptive opportunity in a building (Nicol and Humphreys, 2002).

This paper assesses occupants' views about their indoor environmental conditions in four multi-storey office buildings in Ghana where as a result of the emergence of the 'glass box' almost all high rise commercial buildings have been fully glazed. It also forms part of a long term (12 months) monitoring, measurement and observational study of the thermal performance of the office buildings.

2.0 Methodology

2.1 Selection of buildings

The four office buildings selected for the study are all located in Accra, within the central business district. The buildings are a representative of the many existing multi-storey office buildings with multiple functions. The buildings are Premier Towers (P.T), Ridge Towers (R.T), Heritage Towers (H.T) and the World Trade Centre (W.T.C). Key information concerning these buildings is summarized in Table 1.

2.2 Questionnaire

One hundred and ninety five occupants in the above buildings who showed interest in the research filled a comprehensive questionnaire on their indoor climatic conditions (thermal, visual and acoustic). The questions were structured based on:

a. Personal profiles

b. Perception and evaluation of indoor climate and were sourced from a similar study (Koranteng, 2010) as well as the ASHRAE RP-921 project protocol (Tian and Love, 2008). The questions were not directed on momentary feelings but rather, the respondents were asked to provide retrospective (long term aggregate) views of their indoor environment.

Table 1: General overview of selected buildings

Code	Fl. area(m²) (No. of floors)	Location	Orientation	Floors monitored	Thermal controls	Shades	Windows	Use
P.T.	10, 263 (13)	Accra, CBD	East-West	5th and 6th	Air-conditioned	Internal, Manually controlled	Fixed curtain wall	Multi-purpose
R.T.	14,355.68 (15)	Accra, Ridge	South-East	7th and 8th	Air-conditioned	Internal, Manually controlled	Limited Operability	Multi-purpose
H.T.	9,340.86 (15)	Accra, Ridge	East-West	10th, 11th and 12th	Air-conditioned	Internal, Manually controlled	Fixed curtain wall	Multi-purpose
W.T.C.	14,556.78 (15)	Accra. Ridge	South-East	14th and 15th	Naturally ventilated	Internal, Manually controlled	Operable	Multi-purpose

2.3 Data Acquisition

Within the framework of the related research, the indoor environmental conditions within the offices were monitored for a period of 13 months (May, 2012 – May, 2013). Whiles air temperature and relative humidity values were measured inside a number of offices and outside the building with data loggers, on-site spot measurement of the lighting and sound levels were also taken with hand-held instruments. The hobo loggers measured temperature in the range of -20 to 70 ± 0.4°C, whiles the relative humidity was in a range of 5 to 95%

± 3%. The digital illuminance meter and the sound level meter were used to record the lighting and sound level repeatedly in the offices. The light meter measured in the range of ± 5% rdg ±10d (< 10,000Lux) / ±10% rdg ± 10d (> 10,000Lux). Additionally, the sound level meter had an accuracy of 1.4dB.

2.4 Data Analysis

Descriptive statistics was used for the analysis of the results. The data was processed with MS Excel and Greenline and Hoboware pro softwares. Greenline was used to download the file from the data loggers whiles the downloaded files (temperature and humidity values) were screened for points to be exported to MS Excel with the Hoboware pro. In MS Excel, the text files were screened and built into monthly data tables. Excel formulae sheets had to be generated to produce mean hourly values since the data recorded was in interval of 10 minutes. The outcome of the questionnaire based on the subjective opinion of the occupants was also tabulated for mean and percentage values and graphs drawn using MS Excel.

3. Results

3.1 Occupants

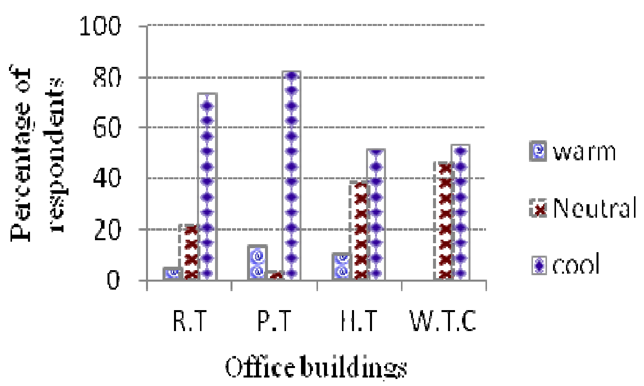
Together, 195 occupants from across the buildings responded to the survey. Out this number, 54 were from P.T whiles 42 were from R.T. The R.T. building had more male (87.7%) respondents than females (14.3%). There was a similar trend in the W.T.C. building where 69.2% of the respondents were males and 30.8% females. The P.T. building however, had equal percentage of males and females answering the questionnaire with the H.T. building having more females (58.3%) than males (41.7%).

On age distribution, it was realized that most of the occupants were within the ages of 25-45 years in all the buildings. 7.1% of the respondents were below 25yrs, 64.3% between 25-35yrs, 14.3% between 36-45 whiles' occupants within the ages of 46-55 and above 56 were 7.1% each in the R.T. building. In the P.T. building, 88.9% of the respondents were below 45years whiles the remaining 11.1% were above 46 years. H.T. building had 8.3% of its respondents below 25 years with 58.3% and 8.3 % between 25-35 and 36-45 years respectively. The remaining 26% were above 46 years. H.T. could be said to have a mixture of all age groups with a greater percentage within the ages of 25-35 years.

The educational background of the respondents was also solicited. 50% of the respondents have undergraduate degrees and the other half with a postgraduate degree at the H.T. building. This may be due to the advanced nature of works carried out within this building. In the W.T.C. building, 84.7% of the respondents possessed both graduate and post graduate degrees with the remaining 15.3% being S.H.S and O-level certificate holders. Altogether, there was a distribution of higher levels of educational background of the respondents and hence their ability to answer the questionnaire rightly with little interpretation.

3.2 General views and complaints

Figs. 1 and 2 show occupants' general feeling concerning temperature and humidity. Whiles Fig. 3 show the percentage of occupants who have concern for the air quality in their offices, that of Fig. 4 illustrate ventilation.



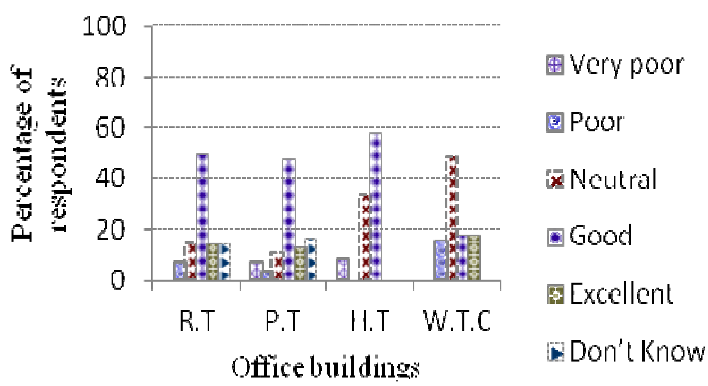
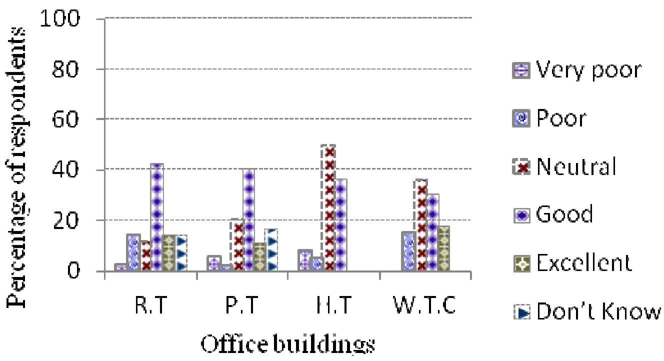


Figure 1: General feeling concerning Temperature

Figure 2: General feeling concerning humidity

Occupants' Actual Mean Votes (AMV) on the 7 point ASHRAE thermal sensation scale is shown (Fig.5). Additionally, Fig.6 addresses occupants' thermal preference on the same sensation scale. Specifically, it shows the percentage of occupants who feel neutral (0) in their offices as against those who believe their spaces are cool, slightly cool and cold (-1, - 2, -3) as well as those who think otherwise (warm, slightly warm and hot: 1, 2, and 3



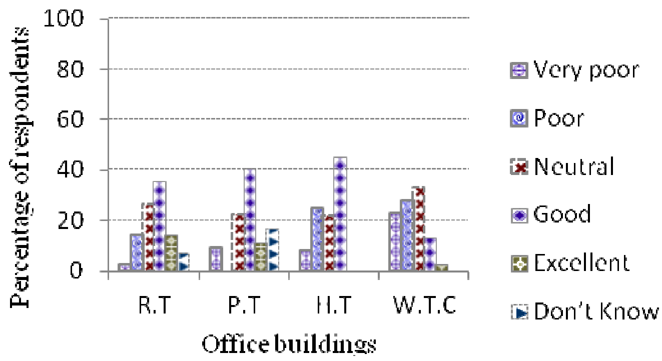


Figure 3: General feeling concerning air quality

Figure 4: General feeling concerning ventilation

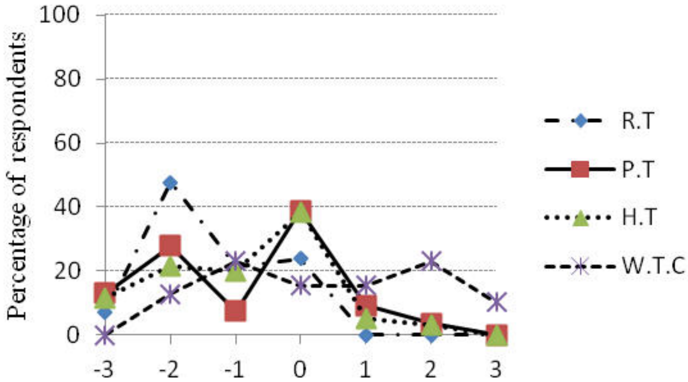


Figure 5: Occupants thermal comfort levels

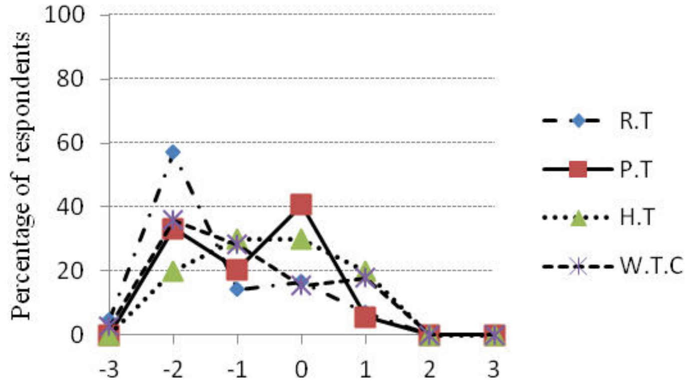


Figure 6: Occupants thermal comfort preference

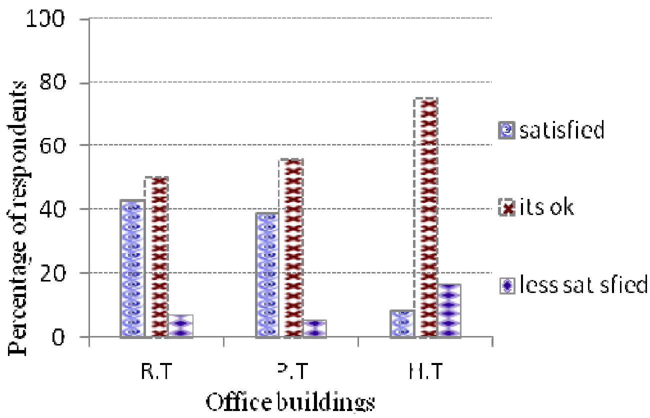


Figure 7: Occupants satisfaction with the air-condition

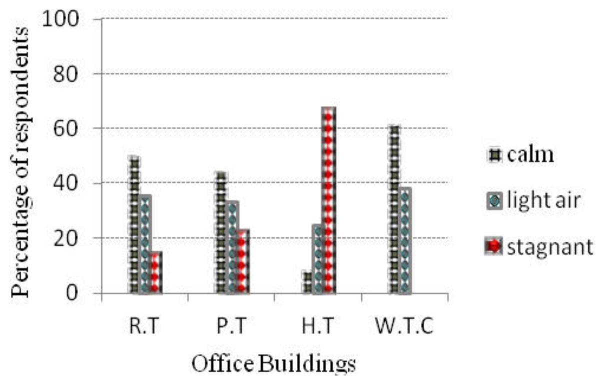


Figure 8: Occupants evaluation of air speed

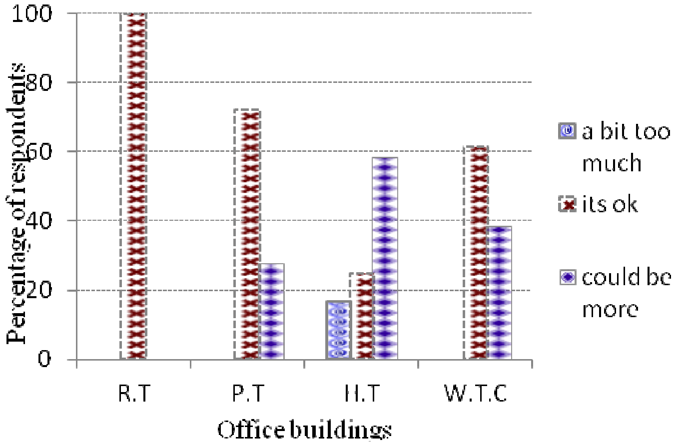


Figure 9: Sufficiency of daylight in offices

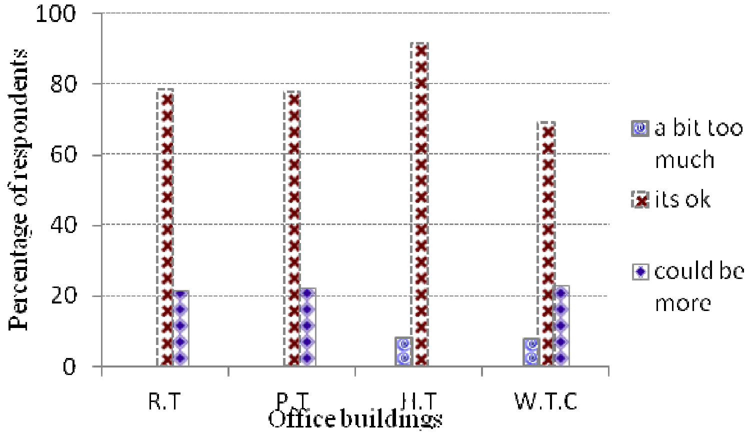


Figure 10: Sufficiency of artificial light in offices

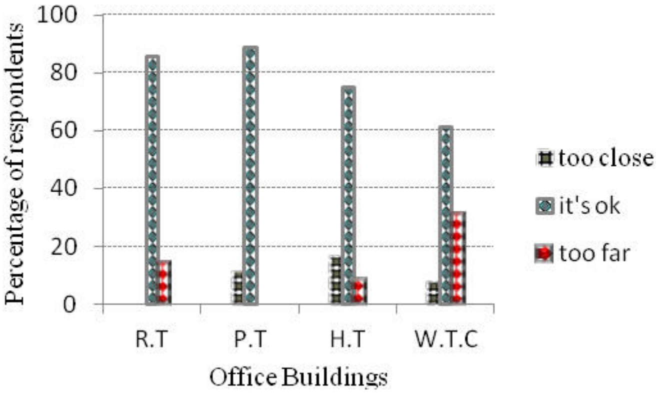


Figure 11: Evaluation of distance of workstation from the window

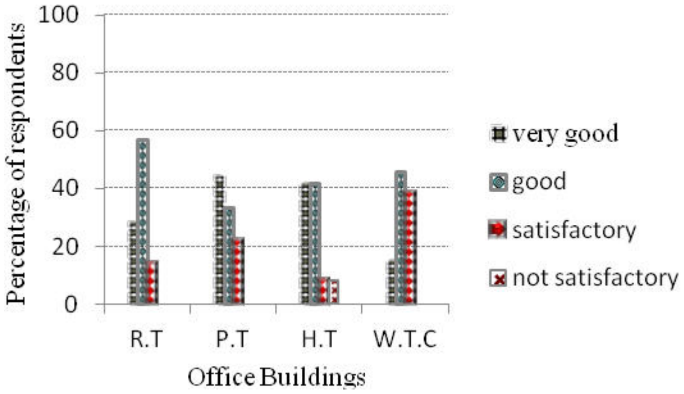


Figure 12: Evaluation of outdoor view from workstation window

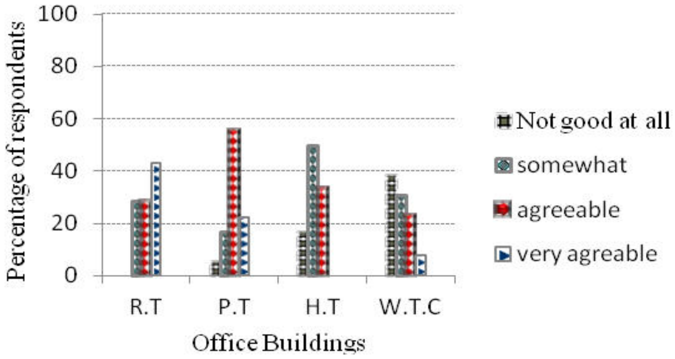


Figure 13: Occupants general perception of the working environment

Table 3: On-site measurements

	R.T.	P.T.	H.T.	W.T.C.
Lighting levels (Lux)	640	480	350	220
Sound levels (dB)	54	55	59	55

4. Discussion

From the data presented in the result section, a number of patterns emerge as well as some remarkable trends. A number of related observations are discussed below.

4.1 Thermal perception

More that 50% of occupants in building R.T. and P.T. felt temperature in their offices was cool. This may be due to the use of air-conditioners with comparatively low temperatures set points (18°C). Mean temperature values measured within these buildings was 24.3°C and 24.5°C respectively. Although H.T. is also an air-conditioned building, only 51% of the occupants felt their temperature condition was cool. One of the reasons could be H.T. 's Wall to Window Ratio, (WWR) which is about 90%. As a result, there is direct solar radiation into the office spaces, making the indoor warm. The aforesaid could be attributed to the orientation of the building (east-west) with its unprotected glazing: confirming the assertion of a number of studies that heat gain through the exterior window accounts for 25-28% of the total heat gain within a space (Al-Najem, 2010 and Yu et al., 2008). A similar finding was reported by Pino et al. (2012) on buildings with high WWR. East-west orientation of buildings in the tropics with exposed windows is known to cause discomfort within the internal spaces (Koranteng et al., 2011). All the occupants in the W.T.C. building felt their temperature was cool and okay: a situation which was plausible because, their glazing windows were operable and shaded with a balcony along the glazed facades and also 85% of the occupants were out of the office during the hot afternoons with the high outdoor temperature values. Again because occupants at the W.T.C. could open a window (adaptive opportunity), they felt comfortable even with a mean temperature of 28.4°C. This comfort sensation is in conformity with the studies of (Nicol and Humphreys, 2004: Baker and Standevan, 1996).

Air quality evaluation followed similar trend as that of temperature where satisfaction was expressed by occupants in the R.T. and P.T. buildings due to the reliance on air-conditioners to create an exclusive environment (Hawkes, 1996).

The votes on occupants' thermal sensation are given, subject to the operative temperature within the offices. These are retrospective subjective judgments. In the naturally ventilated building (W.T.C.), occupants votes ranges from cool (-2) to hot (3). Whiles 23 % of the occupants felt that their spaces were warm, 10% reported their spaces to be hot. In the study of German low energy office buildings, Wagner et al. (2007) found 7% of their respondents voting 'very warm' to their spaces when the temperature was between 25°C to 30°C. In the current study if 'very warm' is equivalent to 'hot', then the results are similar. Once more, the air-conditioned buildings have greater number of occupants who feel comfortable: slightly cool to slightly warm (ASHRAE, 2004). 47.6% of the occupants in the R.T. building felt that their offices were cool (-2), a condition which have been created by the low set point of the air-conditioners (16°C to 18°C). This behavior could have a huge toll on the energy usage of the building. Occupants in this building were always in suits for work which gave an indication of how cool/cold they felt rather than work policy.

On their preferences, all the occupants within the air-conditioned buildings wanted to feel cool to warm (-2 to 2). This was so because of the seasonal differences experienced in Ghana: the wet season where outside conditions are cool (low temperatures) and the dry season where conditions are dry and warm (high humidity).

Occupants in the W.T.C. building had a more forbearing attitude in relation to indoor thermal conditions compared with the occupants in the air conditioned buildings. They accepted higher indoor temperatures in the dry season and lower temperatures in the wet season, and they also accepted wider temperature ranges; an observation which is tantamount to Frontczak and Wargocki (2011) who found similar results in their work.

4.2 Visual and Acoustic environment

The satisfaction with the availability of daylight and electric lighting in the office was generally high (about 60%). However, 58.3% of the occupants in the H.T. building felt that their daylight amount could be more: an expression which some explained as daylight releases stress and daylight is refreshing. Similar finding was reported by Galasiu and Veitch (2006). By observation, the H.T. offices though with a high WWR lacked enough daylight because of the internal partitions blocking day light from reaching the core of the building. Again, occupants in the H.T. building deployed their internal blinds in an attempt to mitigate the direct solar radiation into their offices thereby compromising on daylight. From Table 3, though buildings P.T., H.T. and W.T.C. are all below the standard illuminance level of 500Lux (Burberry, 1997), less than 50% reported that their spaces were dark. This finding agrees with the study by Tregenza and Leo (1998) who concluded that the occupants' perception of their visual environment also depends upon the illuminance they are accustomed to.

In terms of the sound levels (acoustic tendency), all the offices were within the mean of 57.5 dB (Mui and Wong, 2006). Buildings R.T., P.T. and W.T.C. recorded 54dB, 55dB and 55dB respectively; a reading similar to the Chinese code for the design of sound insulation of civil buildings which suggests that noise level in offices should not be higher than 55 dB (Huang et al., 2012). Even the H.T. building's sound level was just 1dB higher than the suggested values which could be due to the external factors (one major road too close to the building).

Moreover, all occupants cumulatively reported that their working environment were conducive by voting somewhat, agreeable and very agreeable to the general perception of the working environment.

5. Conclusion

Occupants' responsiveness in four multi-storey office buildings suggests considerable levels of satisfaction with certain aspects of their indoor environmental conditions. Whiles about 96% of the occupants in the air-conditioned buildings found their indoor thermal sensation levels to be from cold (-3) to slightly warm (2), they actually would prefer slightly cool (-2) to slightly warm (2). Due to the orientation and lack of shading, building H.T, an air-conditioned building experienced uncomfortable conditions internally.

Even though occupants in the W.T.C always were willing to leave their offices in the afternoons because of the negative indoor conditions, they wish for an air-conditioned office environment or a mixed mode.

Although building R.T appears to be over cooled, occupants would not want any condition otherwise, stressing that they would rather feel cold than to feel warm.

The desire for better air quality and thermal comfort were considered essential for occupants' higher performance and productivity.

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