

Occupants' Evaluation of the Operation, Functionality of Building Control Systems and Energy Implications in Multi Storey Office Buildings in Ghana.

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Abstract

A study on office building occupants' evaluation of the operation, functionality of building control systems and energy implications of their behaviour towards the improvement of building designs was conducted. A questionnaire was administered to 195 occupants' in 4 multi-storey office buildings. The buildings are: World Trade Centre (naturally ventilated), Ridge Towers, Premier Towers and Heritage Towers (all mechanically ventilated). The data and responses from the occupants were expressed using descriptive statistics. The results of the 12 months monitoring and survey of the buildings showed that most occupants' behaviour led to increase use of energy during office hours. Not ventilating their offices before using the air-conditioners, lighting systems operating till close of work, setting air-condition temperature points lower than usual (18-20°C) are some of the occupant behaviours. Furthermore, since the opening of windows involved a collective decision making, it was hardly ever opened to ventilate the spaces. Occupants at the Heritage Towers felt that, they were insufficiently informed about how their ventilation and air conditioning system, lighting and blinds operated. All across the buildings, 70% of the respondents reported that they thought about energy conservation when they operated their control systems. Fifty-two percent of the occupants in the air-conditioned offices did not switch off their air-conditioners when they were out of their offices for longer periods of time. Attention should be paid to occupants' behaviour with potential increase in the energy use of office buildings.

Keywords: Control systems, Occupants', Energy, System operation, Office buildings.

1. Introduction

Thermal controls in office buildings are used to modify the indoor environment for comfort. During office hours, occupants' who feel distressed with their environment would only want to apply a control system or two to feel alright. Building occupants apply available control possibilities (operation of heating and cooling systems, windows, lights, etc.) in order to bring preferable indoor conditions (Nicol and Roaf, 2005). However, given the relevant technical properties of any buildings' environmental systems (flexibility, responsiveness, ease of use and zonal resolution), user interactions with these systems do not necessarily lead to desired conditions (Loftness et al., 1995). Becker and Paciuk (2009) affirmed that thermal adaptation and perception of comfort may be impacted by contextual variables, such as local climate.

A study of educational and office buildings in the UK and in India (Steemers and Manchanda, 2010) showed that occupants' overall satisfaction varies depending on the ventilation mode applied in the buildings. Moreover, dwelling quality, size and design were also demonstrated to have significant impact on residents' satisfaction (Lee et al., 2012; Dekker et al., 2011; and Mohit et al., 2010).

Cuttle (1983) as averred by Galasiu and Veitch (2006) administered questionnaires in England and New Zealand to investigate the perceived attributes of windows. The sample of participants consisted of 471 office workers who were asked whether they considered windows to be an important feature of a workplace and, if so, how important that was to them and why. Almost all respondents (99%) thought that offices should have windows, and 86% considered day lighting to be their preferred source of lighting.

A study in Denmark showed that people did not feel confident in regulating the heating systems in their homes and felt that they needed more information (Gram-Hanssen, 2010). Kempton et al. (1992) and Lutzenhiser (1992) as alluded to in Frontczak et al. (2012) reported that people experience difficulties in using other systems, e.g. room air-conditioners, as shown in studies in the U.S.A and Japan where they only used a limited number of features of the air conditioners (Fujii and Lutzenhiser, 1992). On the contrary, Finnish occupants felt quite confident about their knowledge of heating and ventilation systems in their homes (Karjalainen, 2009). The above results show that understanding how people behave indoors and how they operate the systems for controlling the indoor environment demand an in-depth knowledge which is crucial for developing systems that provide comfort for building occupants (Frontczak et al., 2012).

Frontczak et al. (2012) in their study asserted that respondents valued natural ventilation highly and it was very important for them that they could open windows. In office buildings, the situation was quiet different as occupants seating close to windows did not appreciate the thermal comfort that was provided within their spaces. This is confirmed in Charles (2005): Occupants seated next to windows tend to be less satisfied with thermal conditions. Though workstations located next to windows benefit from natural lighting and a view, their occupants often experience a wider range of temperatures because of the warm or cool radiant temperatures from the windows. Blinds, perimeter heating, cooling, insulated windows can help minimize these problems (Charles, 2005).

According to Price and Sherman (2006), people felt quite confident regarding their knowledge on how a ventilation system works and how to operate it properly. However, the authors concluded that respondents were not familiar enough with mechanical ventilation systems to meaningfully respond to questions about them.

Other studies have also showed that people lack understanding of how to use systems properly for controlling the indoor environment and experience problems when operating them (Gill et al., 2010; Xu et al., 2009; and Peeters et al., 2008).

Energy is the most important engine to improve upon the quality of life and fight poverty. Given that by 2020 almost 70% of the world population will be living in cities, 60% will be energy poor (Serageldim and Brown, 1995). Thus for the next decade, thousands of megawatts of new electrical capacity have to be added. Der-Petrossian (1999) state that developing countries may avoid spending $ 1.7 trillion on oil refineries, coal mines and new power plants by spending for the next 30 years $ 10 billion annually to improve energy efficiency and conservation.

Lighting represents a major energy-user in commercial buildings (around 15%), and large amounts of energy can be saved by using well designed lighting controls that can take advantage of the natural light available (Galasiu and Veitch, 2006). In the UK, lighting account for between 13% and 16% of energy use and 18% and 25% of CO2 emissions in a typical office building (Energy Consumption Guide, 2000). An office building study performed in London showed benefits in energy use when window size, solar protection, and internal gains were optimized (Kolokotroni et al., 2006) whiles Barlow and Fiala (2007) substantiate that the conventional response of installing air conditioning into existing offices to maintain comfort conditions results in increasing levels of energy, CO2 emissions and pollution.

Though occupant perception of so-called ‘sealed, centrally air-conditioned buildings with open plan floor layouts that provide minimal adaptive opportunity’, with no option for opening windows, is negative (Hoes et al., 2009), that seems to be the case in recently built Ghanaian office structures.

In the building sector, the increased use of air-conditioners, inefficient curtain walls and sliding windows, and the lack of sustainable design principles, especially in office buildings have contributed to the energy situation (Koranteng, 2010). In Ghana the growth in demand for energy is amongst other factors caused by the numerous air-conditioned commercial buildings being constructed especially in the metropolitan areas of Accra and Kumasi. Since demand far outweigh the supply, power cut, loading shedding etc., have become common practice. Occupants’ behaviour in these multi storey office buildings have always been to abate thermal discomfort .These behaviours have an eventual effect on energy. However the exact effect is insufficiently investigated into especially in developing countries like Ghana.

The current paper presents the results of a study of four multi-storey office buildings in Ghana with regard to occupants’ evaluation of system control options and awareness of the functionality of these systems. The purpose of the study is to document occupants’

- Operation and accessibility of the systems and system controls.
- Awareness of the functionality of the building control systems.
- Awareness of the energy implications of user control actions.

Attention to building control systems, user perceptions could improve design, quality, and energy performance of office buildings.

2. Materials and Methods

Questionnaires, interviews, observation, and long term (12 months) monitoring of indoor thermal parameters were used in studying four multi-storey office buildings in Accra, Ghana. These buildings are different in sizes, number of storey and accommodate different organizations, thus representing a broad spectrum of office types and functions. All four buildings are given special codes which are the initials of their names in this paper: R.T. (Ridge Towers), P.T. (Premier Towers), H.T. (Heritage Towers) and W.T.C. (World Trade Centre). Key information concerning these buildings is summarized in Table 1.

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, 263.00 (13)	Accra, CBD	East-West	5^{th} and 6^{th}	Air-conditioned	Internal, Manually controlled	Fixed curtain wall	Multi-purpose
R.T.	14,355.68 (15)	Accra, Ridge	South-East	7^{th} and 8^{th}	Air-conditioned	Internal, Manually controlled	Limited Operability	Multi-purpose
H.T.	9,340.86 (15)	Accra, Ridge	East-West	10^{th}, 11^{th} and 12^{th}	Air-conditioned	Internal, Manually controlled	Fixed curtain wall	Multi-purpose
W.T.C.	14,556.78 (15)	Accra, Ridge	South-East	14^{th} and 15^{th}	Naturally ventilated	Internal, Manually controlled	Operable	Multi-purpose

2.1 Monitored environmental data

Room temperature and relative humidity values were measured both inside (in a number of office spaces) and outside the buildings over a period of 12 months (May, 2012 –April, 2013). The measurements were done using Hobo Sensors. The gathered environmental data were screened and processed in MS Excel application. The accuracy of the data loggers is presented in Table 2.

Table 2: Measuring equipment (Hobo sensors) technical data.

Parameter	**Measuring Range**	**Accuracy**
Air temperature (T)	-20 to 70 °C	± 0.4 °C
Relative humidity (R.H)	5 to 95 %	± 3%
Air velocity (A.V)	0.1 to 25.0m/s	± 5% ± 0.1m/s

2.2 *Interviews*

One hundred and ninety –five out of a total of two hundred and twenty occupants from the four buildings were randomly selected and interviewed. The interviews provided a basis on which the questionnaires were distributed. The respondents completed questionnaires on personal profile, building control systems (operation, accessibility) and energy implications of their operation. Their perceptions were based on long term aggregate opinion on the aforesaid parameters.

*2.3 **Data Analysis***

For further analysis, data from occupants' descriptive votes was logged into an Excel spreadsheet and using the Excel 'data analysis tools' a series of mean, median and mode values were calculated and graphs drawn for interpretation. Data files downloaded from the loggers were also exported, screened and monthly tables drawn from them using MS Excel.

3. Results and Discussion

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 fair distribution of higher levels of education by the respondents and hence their ability to answer the questionnaire rightly with little interpretation.

In the R.T. building, more than 60% of work done on any working day was performed on the computer whiles in the P.T., 88.9% of work was done on the computer. Building H.T. had 99% of its daily activities executed on the computers likewise W.T.C. with 69% of work carried out on the computer. The aforementioned self assessment gives an indication that occupants' in the R.T., P.T., and the H.T. spent long hours behind their computers and at their workstations and therefore would apply any control system available to feel comfortable and work satisfactorily.

3.2 Operation and accessibility of the systems and system controls

Control systems within the offices included opening/closing of windows, use of the air-conditioners, use of the blinds, lighting and the switches. Occupants' expressed various degree of satisfaction on all of the above systems. Fig. 1 shows occupants ability to open their office windows if necessary whiles Fig. 2 illustrates the importance of the possibility of occupants to open their office windows.

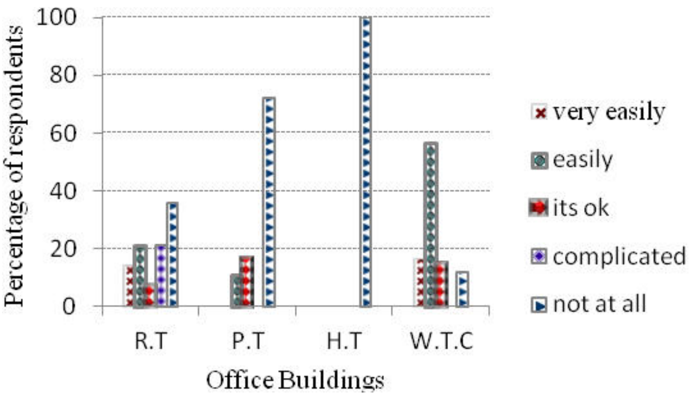

Figure 1: Ability of occupants to open their office windows if necessary.

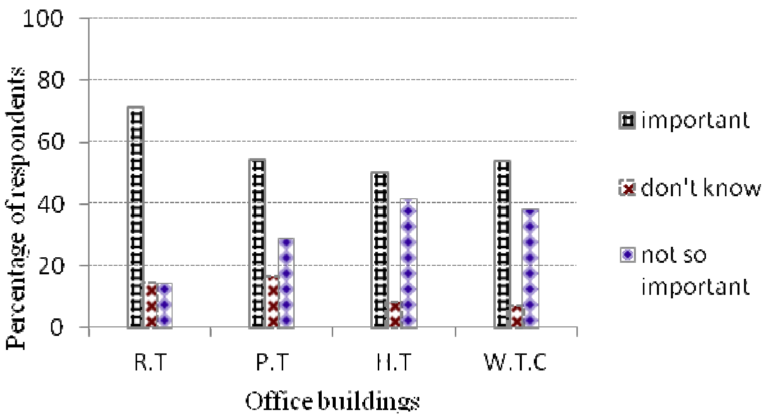

Figure 2: Importance of the possibility of occupants to open their office windows.

Documentation on the decision of occupants to open/close their office windows and satisfaction level on the possibility to ventilate their offices is shown in Figs. 3 and 4. Fig. 5 addresses the importance attached to the possibility to operate curtains/blinds. Accessibility of thermostat, decision making in the operation of thermostat and the satisfaction levels of the position of air-conditioners in the office spaces is pointed out in Figs 6, 7 and 8.

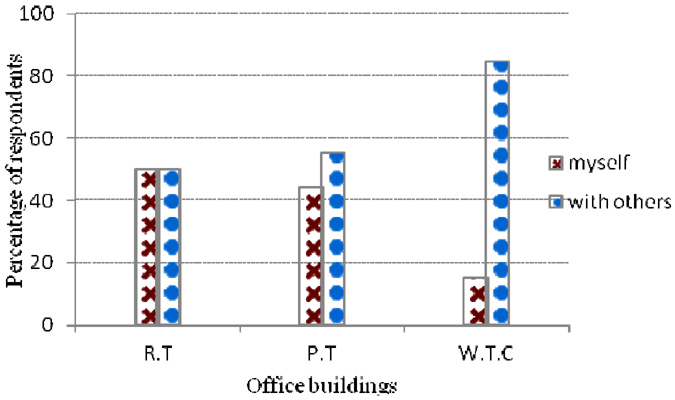

Figure 3: Occupants decision to open/close their windows

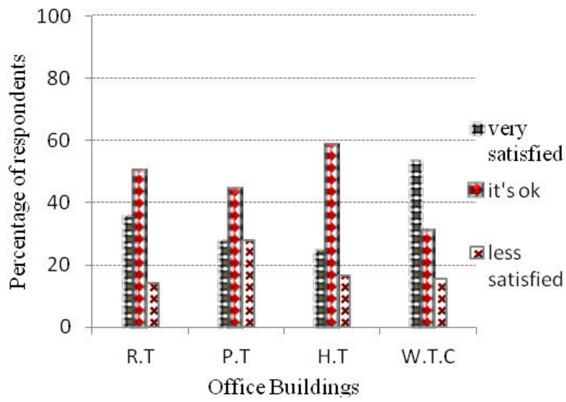

Figure 4: Satisfaction levels on possibility to ventilate their offices

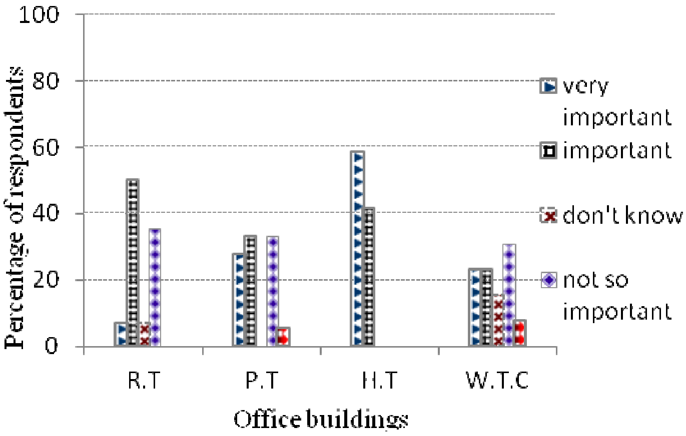

Figure 5: Importance attached to the possibility to operate curtains/blinds.

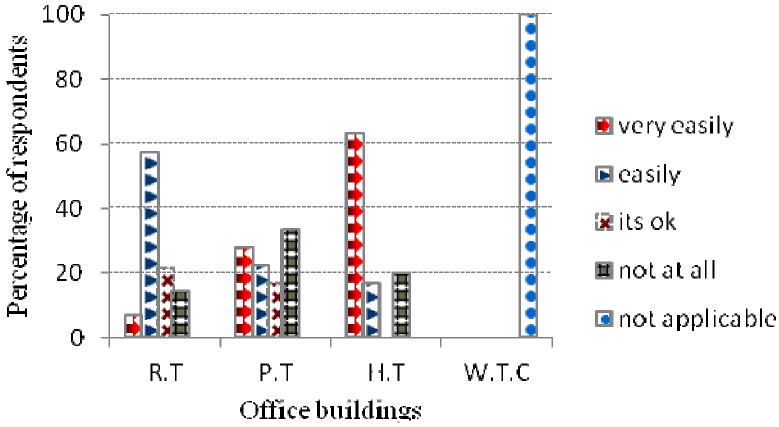

Figure.6: Accessibility of thermostat.

The H.T. is the only building with fixed glazing without the possibility of opening at all. Perhaps a solution against infiltration and ex-filtration as reported in E-Source (2005). But with the east-west orientation, no external shading of the building (H.T.), frequent power cut and load shedding, fixed glazing was a wrong choice. Even though all the other buildings had operable windows; it was hardly opened as has been presented in Fig. 1. The reason for this trend includes the collective decision making to open the windows (Fig.3). Not all the occupants' showed enthusiasm when it came to opening of windows especially those whose workstations were close to them (windows). They complained that opening of the windows distracted them a lot. They again reported that their workstations was uncomfortable and they felt opening the windows will make the situation worse. This report affirms Al-Najem's study (2010) when he concluded that heat gain through the exterior window accounts for 25-28% of the total heat gain. The heat gain is what these occupants' feel. These occupants' (who sat along the windows and the glazed areas) said they were constrained to pull over the blinds to help in the reduction of the direct solar radiation (Charles et al., 2005) all the time. Fewer than 40% of the occupants in the R.T. building did not at all open their windows whiles in the P.T. building, 72.2% of the occupants did not. Apart from them being insufficiently informed about the positive effects the operation of windows has on building occupants (Koranteng and Mahdavi, 2010: Rijal et al., 2007: Mahdavi et al., 2007; and Herkel et al., 2005), the high dependency on the air-conditioner (AC) also account for this trend. The occupants across the three AC buildings however expressed the importance of their building having windows/large glazed portions which aid in clear vision to the outside to catch a glimpse of what was going on.

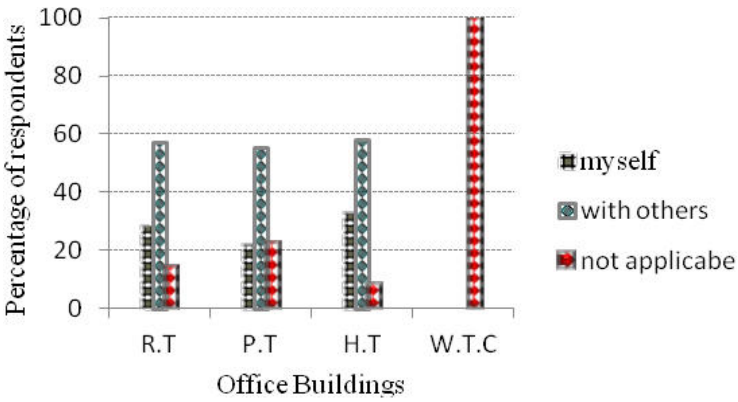

Figure 7: Decision making in the operation of thermostat.

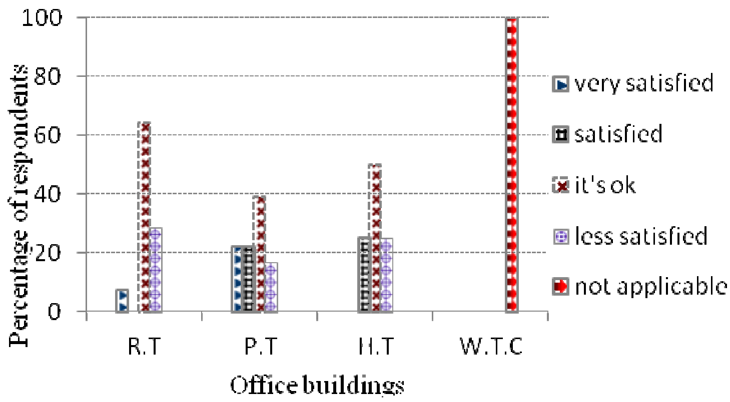

Figure 8: Satisfaction levels of the position of air-conditioners in the office spaces.

All the occupants' in the three AC buildings did not ventilate their offices in the mornings before using the air-conditioners. H.T. occupants' could not do that even if they wanted to. This observation is in congruence with Simons et al. (2012). The poor satisfaction level of the AC in the P.T. building (Fig.8) could be due to multi-occupancy office with large numbers. In the P.T., whiles only 4 workers had enclosed office spaces, the remaining 50 occupants' were allocated open plan workstations measuring a total of 50.4m². In the W.T.C building, 56.8% of the occupants could easily open their windows and did that in the mornings when they came to work. Occupants in the H.T building were very dissatisfied about the fact that they could not open their windows at all and wished they could do that sometimes; especially when there were power failures. This agrees with the study about occupants having negative perception about AC buildings with no option for opening windows (Hoes et al., 2009). 25% of occupants across all buildings felt that it was not at all important to open their office windows and relied solely on the AC's. When asked whether they knew the importance of daylight on their wellbeing? 46% of the occupants across the buildings said they did not and even if they did, they are always bound to deploy their internal blinds. Occupants' in the W.T.C building did enjoy daylight as well as open views so much since their windows were protected with a balcony. The work of Mahdavi et al. (2007) confirms the above results with regards to the behaviour of occupants. Satisfaction with the building control systems in the AC buildings was however higher than in the naturally ventilated building. Though occupants in the naturally ventilated building (W.T.C) had a range of adaptive opportunities, more than 50% preferred working in an AC office. But the heavy reliance on artificial lighting in the office spaces could have a negative effect on energy usage since lighting represents a major energy-user in commercial buildings (Galasiu and Veitch, 2006).

3.3 Awareness of the functionality of the building control systems

Occupants responded on how informed they are about their building control systems. Table 4 shows the summary of the responses to the question 'are you sufficiently informed about how the following systems work in your office: Ventilation, air-conditioning, lighting and blind protection?

Ventilation

	Very well informed	It's ok	Insufficiently informed
R.T.	35.7%	42.9%	21.4%
P.T.	27.8%	44.4%	27.8%
H.T.	10%	16.7%	73.3%
W.T.C.	15.4%	46.1%	38.5%

Air-conditioning

	Very well informed	It's ok	Insufficiently informed
R.T.	50%	42.9%	7.1%
P.T.	33.3%	33.3%	33.4%
H.T.	0%	58.3%	41.7

Lighting

	Very well informed	It's ok	Insufficiently informed
R.T.	50%	42.9%	7.1%
P.T.	33.3%	44.4%	22.2%
H.T.	8.3%	50%	41.7%
W.T.C.	30.8%	46.1%	23.1%

Blind protection

	Very well informed	It's ok	Insufficiently informed
R.T.	28.6%	57.1%	21.4%
P.T.	33.3%	33.4%	33.3%
H.T.	8.3%	50%	41.7%
W.T.C.	7.7%	61.5%	30.8%

Ninety percent of occupants' in the H.T. building had very little idea on how ventilation in their office was achieved and therefore voted 'its okay' and insufficiently informed. Due to the fact that the design of their building had no adaptive opportunity coupled with the east-west orientation, occupants solely relied on ACs which also proved so technical to them and as a result, used only some few settings as also reported by Fujii and Lutzenhiser (1992). There is also a convergence with the study of Price and Sherman (2006). With lighting and blind protection, H.T. occupants again felt that they were not sufficiently informed about their operation and were willing to attend workshops on how to operate these systems effectively. Building R.T. and P.T. occupants' felt more confident and were well informed when they operated their lighting, air-condition systems. Karjalainen (2009), concluded on a similar finding in his study. In the P.T., as much as those who were informed were also not sufficiently conversant with both their AC's and lighting systems. Occupants in R.T. and P.T. buildings were more interested in controlling their systems than in the H.T. and W.T.C. buildings. Most occupants (91%) from all the buildings also indicated that in case of problems concerning the systems, the property managers were referred to. Few offices consulted their maintenance units for faster solutions to such problems.

3.4 Energy implications of user control actions

Due to the fact that nearly 50% of all occupants well insufficiently informed on the functionality of certain control systems, misuse of it (controls) leading to high energy usage and poor performance during operation is frequent. Figs. 9 and 10 show occupants opinion on influence of energy consumption and thought about energy when operating building systems whiles Figs. 11 and 12 indicates temperature setting of air-conditioners and operation of air condition system in the buildings.

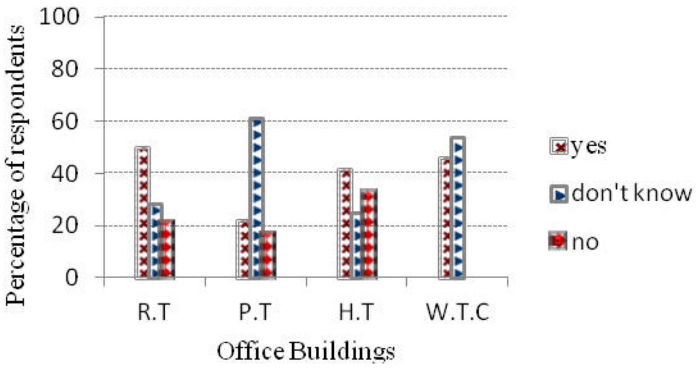

Figure 9: Occupants opinion on their influence on building energy consumption

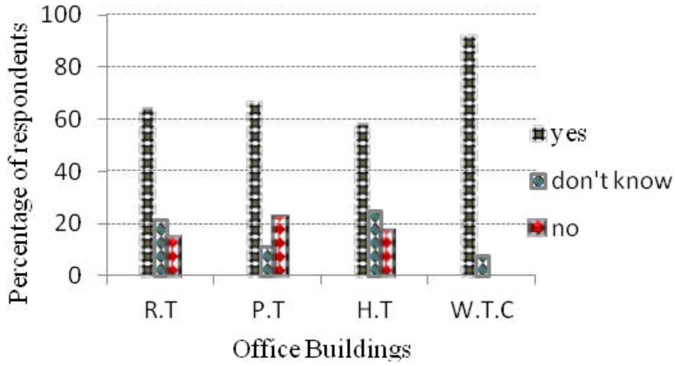

Figure 10: Thought about energy when operating building systems

On average, 70% (Fig.10) of all occupants' in the buildings did think about energy conservation when they operated their building systems. Yet their actions had a negative impact on energy usage: a result which could be caused by both direct and reflected solar radiation into the office spaces (Dibra et al., 2011). Again, more energy is used up since just 50% of the occupants did have sufficient knowledge on how to operate some of the control systems. Also within some offices, though the occupants knew about the implication of system controls on the energy usage, they just did not really care so much since the company will have to pay for the exorbitant electricity bills.

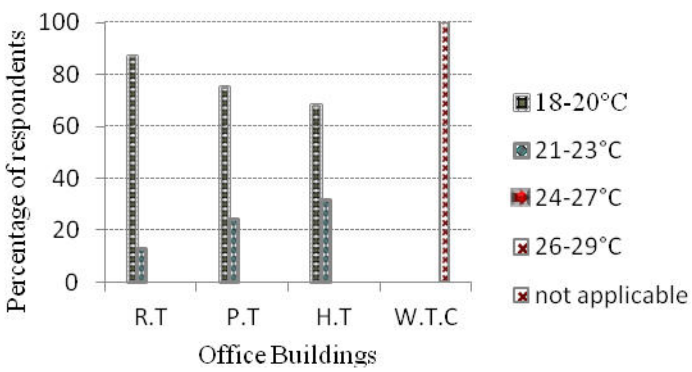

Figure 11: Temperature setting of air-conditioners

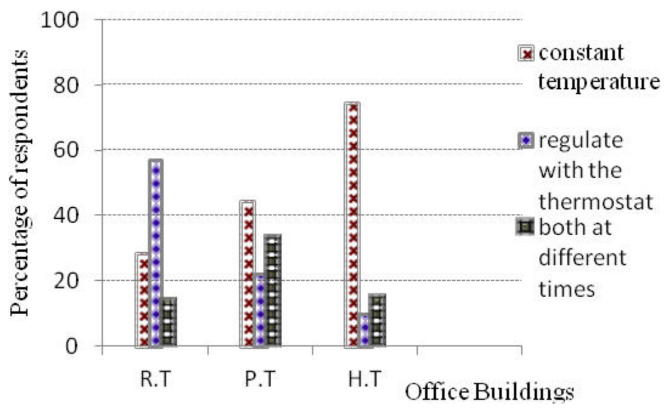

Figure 12: Operation of air-conditioning systems.

All the air-conditioned (AC) buildings had their set points between 18-20°C. These set points show the effect of user behaviour on energy consumption of buildings. In the R.T. building, nearly 80% of the occupants felt cold (-3) to slightly cool (-1) on thermal sensation scale. When asked of their preference less than 8% wanted to feel cold (-3). There is therefore a good indication that a higher set point (up to 26°C) could still provide comfort within the spaces. P.T. on the other hand operated the low set point probably due to heat absorption by the excessive glazing and the large number of occupants' on the open plan workstations. Building H.T. occupants' had their set points that low since they felt very uncomfortable and thought their AC systems were inefficient. There is also a plausible chance that the glazing is not as fixed as it should be and therefore infiltration could be the cause. Additionally, the type of glazing used could also cause direct heat transfers through radiation and conduction. Radiation and conduction heat transfer have been reported in E-Source (2005). A significant percentage of occupants (52%) did not switch off their air conditioners when they were out of their offices even for as long as between 30 to 45 minutes. Whiles 40% of the occupants thought they could influence building energy consumption in the way they operated their building systems, 42% thought otherwise, explaining that they did not really care much about how energy is consumed other than to feel comfortable. This observation could also be as a result of the occupants understanding into the subject area of energy conservation. In the H.T. building, 74.6% of the offices operated the air-conditioners at a constant temperature which is centrally operated, whiles the rest had split systems. This could account for why they could not switch it (AC) off whenever they were out of their offices on short notices. In the R.T. building, 57.1% of the offices regulated their AC's with a thermostat but in the open plan workstations, permission needed to be sought from all the occupants before one could change the settings. Sometimes, this process becomes cumbersome and in most cases proves futile. Due to the above, the AC setting is hardly changed though some occupants feel too cold (uncomfortable) in the course of working hours.

4. Conclusion

Occupants' behaviour was monitored and evaluated in four multi-storey office buildings in Accra, Ghana. The empirical study had the aim of documenting occupants' operation and accessibility of the systems and system controls, awareness of the functionality of the building control systems as well as occupants' awareness of the energy implications of user control actions.

The study showed that windows/glazing were more for clear views to the outside than it was for ventilation in the AC buildings and as such, either hardly opened (R.T. and P.T.) or not operable at all (H.T. building). Again, since the opening of windows was only possible after everyone had agreed, it was never possible to open them.

In addition, it was found that most occupants' were not well informed regarding the available control systems as well as how they functioned.

41.7% of the occupants' in the H.T. building felt that they were insufficiently informed on how their lighting and internal shading systems operated and will be willing to attend workshops on it. Due to the operation and maintenance section which was available in all the buildings, the occupants' did not really pay attention to the control systems and how they operated.

70% of all occupants' in the buildings did think about energy when they operated their building systems. Yet their 'I don't care' attitude and actions had a negative impact on energy usage.

All the AC buildings had their set points between 18-20°C when a higher set point could be appropriate for at least the R.T. and the P.T. buildings. A significant percentage of occupants (52%) did not switch off their air conditioners when they were out of their offices even for as long as between 30 to 45 minutes because of the centralized way of operating the AC's.

In effect, frequent workshops needs to be organized by facility managers in conjunction with the maintenance department of each building to educate occupants on the effect of their actions on building control systems and energy usage in the Ghanaian office building.

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