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IMPACT OF WEATHER DEPENDENT VARIABLES ON COOLING AND DEHUMIDIFICATION LOADS OF AIR-CONDITIONED OFFICE IN WARM-HUMID

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Abstract
Dehumidification in buildings remains a dominant contributor to cooling load in hot-humid climate zone irrespective of the cooling technology used, thus consuming much energy and also contributes to environmental impact through emission of greenhouse gases. Benchmarking and control of energy use in the design and the operation of buildings in developing countries come with much challenges. This paper used ESDL TAS Building Simulation Software to perform dynamic simulation to explore the potential reduction of dehumidification and cooling loads of an air-conditioned office building in the hot-humid climate of Ghana through a parametric study of four weather dependent variables. The combined input variables achieved a reduction of 64.28% and 58.12% in dehumidification and cooling loads respectively of the base case model. Tuning the range of the thermostat temperature and relative humidity settings demonstrated significant savings. Reducing infiltration rate arising from all leakages to a practically feasible minimum, as well as ventilation gain demonstrated appreciable savings in energy use. Tuning of vapour diffusion factor of building materials, however, did not have significant effect on the loads. The outcome of the study is expected to inform the design and operation of air-conditioned office buildings in developing countries of hot-humid climate conditions to achieve optimum energy consumption for cooling of spaces.

Keywords: Air-conditioning; Dehumidification load; Ghana; Thermostatic set point; Warm-humid climate; Weather dependent variables

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INTRODUCTION

Energy demand for buildings continues to surge globally by nearly 3 % per annum, making the control of energy consumption in buildings a more important issue (Farzan, 2019). According to Allouhi et al. (2015) and D'Oca (2018), buildings are responsible for 30% and 55% of global energy and electricity demand respectively. Of the total energy demand by buildings, up to about 75% is consumed in space conditioning for heating and cooling (Longo et al., 2017). Vapour-compression air conditioning units are identified as the highest end-use energy service equipment and accounts for about 50% of the total energy consumed in buildings (Chua et al, 2013; Vakiloroaya et. al, 2014). In warm-humid climate zones, the vapour-compression air conditioning units are the dominant cooling techniques used for space conditioning through removal of both sensible and latent heat loads to achieve acceptable comfort levels (CIBSE Guide A). In a study on energy efficiency and cost saving opportunities in public and commercial buildings in Ghana by Opoku et al. (2019) revealed that, if the business as usual scenario is followed with low energy efficiency ratio air-conditioners, there will be the need to install electricity generation capacity of about 480 MW by 2030 to handle influx of low energy efficient air-conditioners alone.

Dehumidification in buildings remains a dominant contributor to cooling load in warm-humid climate zones irrespective of the cooling technology used, thus consuming much energy and also contributes to environmental impact through emission of greenhouse gases (Chua et al, 2013; and Vakiloroaya et. al, 2014). The Global Dehumidifiers Market has projected growth rate of 7.3% from 2018 to 2023 and more consumers have shown increased inclination towards having better air quality of space (KBV Research, 2018). Dehumidifiers are an essential part of building and factory operational systems for basically extracting particles of water in the ambient air, to prevent condensation. High amounts of energy are consumed in space cooling of buildings in hot climate zones with no thermostatic control techniques, thus presenting a great potential for energy saving (Moon et al., 2011). Thermostatic control in buildings could also help occupants to both adjust to a desired comfort level whilst minimizing the environmental impact as a consequence of energy use in buildings.

A number of studies have been conducted on new technologies and strategies to minimise building energy consumption. These technologies and strategies employ techniques such as efficient equipment, phase change materials for building fabric, building demand management systems, moisture permeability retarders, ejector refrigeration technologies; heat recovery technology; variable refrigerant flow (VRF) system; heat recovery systems. Other strategies which are directed towards dehumidification techniques include desiccant materials; cooling towers and rotary desiccant wheels which are able to cut down the dehumidification load by about 5-30% (Chen et al, 2013; Ronghui et al, 2014; Buker and Riffat, 2015; Sultan et. al, 2015). Moreover, Qin et al. (2009) opines that the dehumidification load can be reduced by using alternative cooling load calculations; heat and moisture transfer in building envelopes, as well as the hygrothermal interactions between an envelope and its environment. In spite of the effectiveness of the above listed techniques in minimizing dehumidification load, their application in warm-humid developing countries such as Ghana remain a challenge as a result of cost and lack of know how. According to the Ghana Electricity Outlook (2012), the constraint posed by cost in the application of dehumidification load minimization techniques has led to a high rate in electricity consumption in the commercial and institutional building sectors.

Studies conducted by Lam et al (2010), Wang et al (2011), Lu et al (2012) and Kolokotroni et al (2012) on impact of external climate condition on energy consumption, concluded that there is a strong correlation between climate and energy consumption arising from cooling.

Cooling and dehumidification loads are dependent on the latent gain that arises from the internal moisture generation by the metabolic rate of the occupants, external climate condition, architectural design and weather dependent variables such as ventilation rates, infiltration gain and vapour diffusion through the building envelope (Mardiana-Idayu and Riffat, 2012; Evins, 2013; Buker and Riffat, 2015). However, the extent to which weather dependent variables can be adjusted to minimize cooling and dehumidification loads in office buildings in warm-humid climates has not been significantly demonstrated in literature.

In the context of the above, this study aimed at investigating how dehumidification and cooling loads arising from weather dependent design variables could be minimized at a cost-effective approach and acceptable indoor environmental conditions. To achieve the above aim, this study specifically sought to: i) to assess the percentage constituents to the overall load of a typical whole office building; and ii) to identify potential cost-effective approaches to minimize dehumidification and cooling loads on a typical whole office building using parametric dynamic numerical simulation. The outcome of the study is expected to inform the design and operation of air-conditioned buildings in developing countries of hot-humid climate conditions to achieve optimum energy consumption for cooling of spaces.

1.1 Energy Saving through Thermostatic Settings

The role of thermostatic set points, through Building Automation and Control Systems (BACS), helps to exploit the inherent trade-off between energy consumption and thermal comfort to ensure efficient energy use and a cost-effective approach in the operation of modern buildings (Allouhi, et al., 2015, Longo et al., 2017). According to Kontes et al. (2017), thermostatic set points are tuned to define a theoretical and practical upper band for potential energy savings. However, over-relaxing comfort can lead to dissatisfied users and incur indirect costs related to productivity loss (Manning et al., 2007, Moon et al., 2011). It is also evident from field experiments in spaces with dry-bulb temperature control that, users tend to adjust elements such as windows, blinds, lights and thermostats in response to thermal discomfort, which could potentially be detrimental to energy performance (D'Oca et al., 2014, Li et al., 2014, Azar et al., 2015).

A number of studies have been reported in literature with substantial reduction in energy consumption in residential buildings through adjustments of thermostatic set points. An investigation by Farzan (2019) on the effectiveness of thermostat control strategy to adjust the room temperature resulted in energy saving by up to 36 % in the auxiliary heater unit of a cooling system in a 90m^2 building. A residential building was simulated by Moon and Han (2011) in the North America climates revealed that lowering of the thermostat temperature level from 2 to 4℃ for 8 hour per night, saved 5-15 % on the energy bill annually. Separate studies carried out by Cholewa et al. (2017) and Monetti et al (2015) on the actual energy saving employing thermostatic valves in a residential building demonstrated savings ranging between 7.1% and 23.3%.

Wang et al. (2013) formulated an energy consumption calculation model to estimate the energy consumption of air-conditioners (AC) in a data centre in South Africa. An adjustment of the AC temperature set point was found to be more effective when the ambient temperature is higher, thus less energy is consumed when the temperature setpoint is higher. The maximum daily average energy consumption for various set points was in February, with the highest ambient temperature, and the minimum was in July which has the lowest ambient temperature. A research by the National Institute of Standards and Technology estimated that infiltration is responsible for about 15% of the total heating energy and 4% of the total cooling energy for U.S. office buildings (Emmerich et al. 1995). Ren and Chen (2015) identified the weather of a place to be a dominant driving force for infiltration.

It can be appreciated from the above that, the extent of energy saving depends on a number of factors, among them are the employed thermostatic technique, temperature set point, level of ambient temperature and climate zone. Energy saving levels could be high when ambient temperature is high, and also when temperature set point is higher.

2.0 Research Methodology

A simulation approach employing a dynamic numerical simulation was adopted to normalize confounding factors such as differences in obtained and actual weather file and construction mixtures (Amos-Abanyie et al., 2013). The Environmental Design Solutions Limited Thermal Analysis Software (ESDL Tas) was selected for modelling, calculating the thermal loads and analysis of the effects of varying parameters. ESDL TAS software is a dynamic building simulation package with 3D modeller, building simulator and result viewer (EDSL, 2007).

A series of tasks were employed to achieve the aim of the study: (1) data collection comprising building parameters, operational schedules and weather data; (2) development of a base model to establish the constituents of the overall cooling load of the building; and (3) parametric simulations through a sensitivity analysis of operational settings of the base model. The simulation approaches by Chowdhury et al (2008) and Rysanek and Choudhary (2012) were adopted and modified for this study.

2.1 Data Collection

The development of simulation models for building performance analysis requires several design variables such as building parameters, operational schedules and weather data. With respect to building parameters, data required were the thermophysical properties of the basic building fabric materials, building geometry and form, and building description including details of measurements of building physical parameters. Building parameters were obtained from the specifications and architectural drawings of the conventional mode of building design as specified in the Ghana Building Regulations (Amos-Abanyie et al., 2013). Operational schedule parameters considered in the development of the model are internal conditions; infiltration and ventilation requirements; internal gains and patterns of use, annual cooling calendar, typical thermostat setting for temperature and relative humidity based on the human comfort conditions for the tropics. The building envelope fabric properties and the internal condition variables are presented in Figures 1 and 2.

Table 1: Building envelope Fabric Properties

	Envelope Fabric	**Description**	**U-values (w/m²°C)**
1	Wall (internal and external)	Single mortar wall layer with light weight plaster in the internal and external as well as paint finish.	2.92
2	Roof and ceiling	Reinforced concrete	0.902
3	Window pane	6mm eclipse 43/54 clear	5.68
4	Window frame	Smooth Planed timber	1.44
5	Foundation/Ground floor	Sand, dark clay, concrete, and finished with floor tiles	0.43
6	Door	Smooth Planed timber	0.573
7	Door frame	Smooth Planed timber	1.44
8	Inter floor Ceiling	Reinforced concrete	2.13

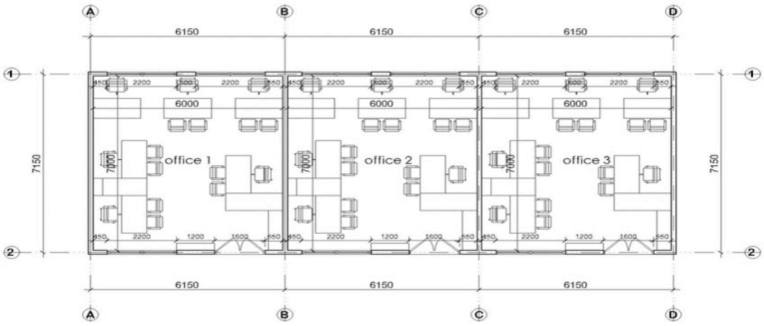
Table 2: Internal Condition Variables

	Internal Gain Variables	Value
1	Occupant sensible heat gain(W/m²)	6-7
2	Lighting sensible heat gain(W/m²)	8-12
3	Equipment sensible heat gain(W/m²)	15
4	Occupant Latent heat gain(W/m²)	5
5	Lighting Latent heat gain(W/m²)	-
6	Equipment Latent heat gain(W/m²)	-
7	Infiltration (ACH)	0.5
8	Ventilation (ACH)	2
9	Upper dry bulb temperature for comfort cooling	24°C
10	Lower dry bulb temperature for heating	-50°C
11	Upper relative humidity	50%
12	Lower relative humidity	40%
13	Compact Fluorescent task illuminance (lux)	500

According to Chua et al (2013), the availability of an accurate meteorological input weather data is critical for performance predictions using building simulation programs. For this study, hourly meteorological weather data for Accra was obtained from EnergyPlus weather data base. The weather data comprised outdoor dry-bulb temperature, relative humidity, wind speed, solar radiation, and ground temperature. The geographical coordinates of Accra, Ghana is at Latitude 5.56ºN and Longitude 0.2ºE and at an altitude of 61m above sea level. The southern part of Ghana has a tropical climate mainly hot and humid with temperature range from 22 to 34℃, and relative humidity goes up to 97%. The average wind speed is 3.5 meter per second with an average irradiation of 1402 Wm^{-2} (GMA, 2019).

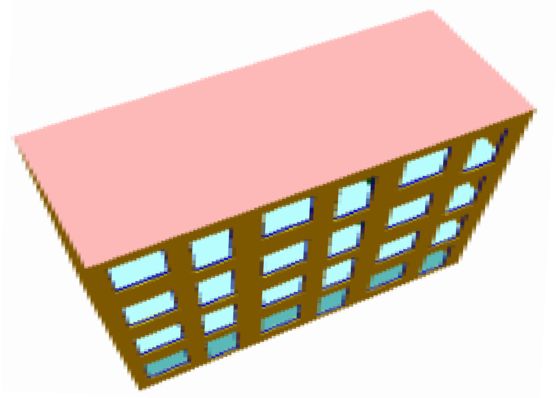
Base Case Model Development

A Base Case model simulating the features of a typical mid-rise rectangular four storey office building in Ghana (Figure 1) was modelled and used for the study (Amos-Abanyie et al., 2013). The building has a total floor area of about 1848m^2, and oriented along the east-west axis with the windows generally on the north and south facing walls. The office spaces have an average window-to-floor ratio of 30%. The windows are made of aluminium window frames with clear window glass. There are about 105 sedentary occupants with occasional movements of people in and out of the offices at an internal gain of 24^{0}C and 50% relative humidity (The CIBSE Guide A & B). The offices operate on 8 hours schedule on weekdays through the year and remain closed on weekends and public holidays. The predominant electric energy dependent equipment are air-conditioners, personal computers, printers, artificial lighting and photocopiers.



(a)

(b)



(c)

Figure 1: Base Case Office Building Model: (a) Typical ground floor plan; (b) Interior perspective view, and (c) Exterior view.

Performance Evaluation of Simulation Models

The parametric simulation for the sensitivity analysis was based on four parameters: (1) varying thermostat setting: temperature setting and relative humidity setting; (2) varying ventilation gain; (3) varying infiltration gain; and (4) varying vapour diffusion factor of cement-based building fabric. Five different values of each sub-groups were selected and simulated keeping all other variables constant, with the base case model cooling load as a baseline. The effect of the combined input variables on the dehumidification and cooling loads were also compared with the recommended CIBSE Guide (A) for good practice in cooling energy consumption.

RESULTS AND DISCUSSION

Demand Loads for the Base Case

Figure 2 presents the various loads of the Base Case with cooling load having the highest demand of approximately 140,000.00kWh, (296 kWh/m^2) followed by dehumidification load and solar gain load with demands of 102,000.00kWh (328 kWh/m^2) and 50,000.00kWh (105 kWh/m^2) respectively. The obtained cooling load of the base case is higher compared to an assessment by Qin et al (2009) in the warm-humid climate condition as a result of variation in weather elements of the cases considered. The annual total demand loads and monthly total demand loads in kWh for various loads of the base case model are presented in Figures 3 and 4 respectively. In Figure 3, the monthly total demand loads show a similar pattern as the annual total demand load. There is an observed same demand loads pattern for various months for lighting, occupancy, equipment and internal load. However, demand loads for cooling, dehumidification and solar gains show varied patterns for the various months. Generally, the demand loads show patterns that follow the seasonal variations in weather conditions. The months from May through to August happen to be the rainy season and experiences relatively lower levels of solar radiation (Amos-Abanyie et al., 2009), thus resulting in reduced solar gains and thus a low demand for cooling of spaces. On the other hand, the periods from January to April and September through to

December experience warm conditions with relatively high levels of solar radiation. The daily average energy consumption for various set points were found to be higher in periods with high ambient temperature, and lower with the lowest ambient temperature (Wang et al., 2013). Use of lighting, equipment, internal loads, and occupancy levels are not seasonally varied so the demand levels are generally same for the various months of the year. There is no demand load for heating since the prevailing climatic condition is tropical and requires no need for heating of spaces. Dehumidification load pattern is influenced by the monthly humidity pattern of the region of study reported in Amos-Abanyie et al. (2009).

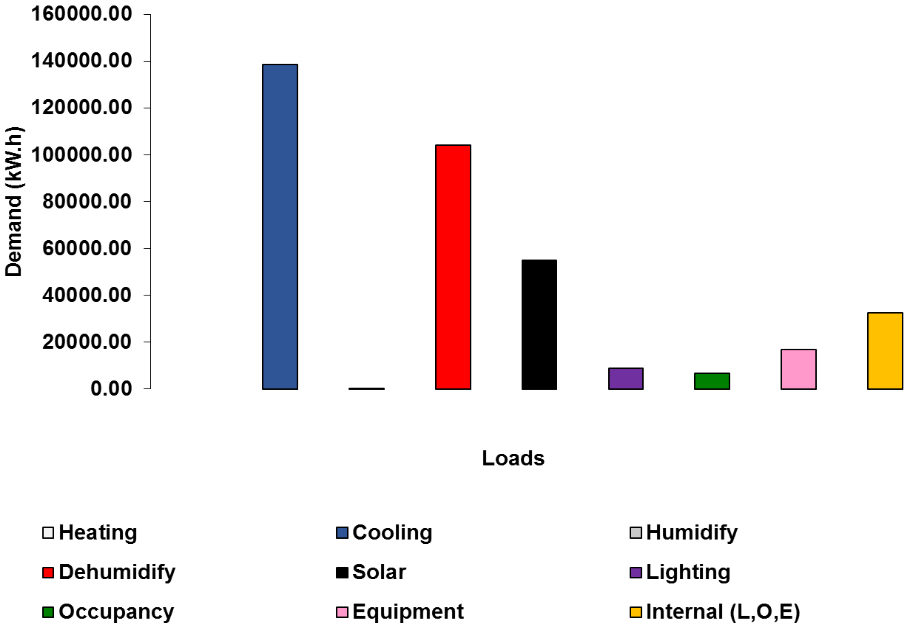


Figure 2: Annual Total Demand Loads for the Base Case

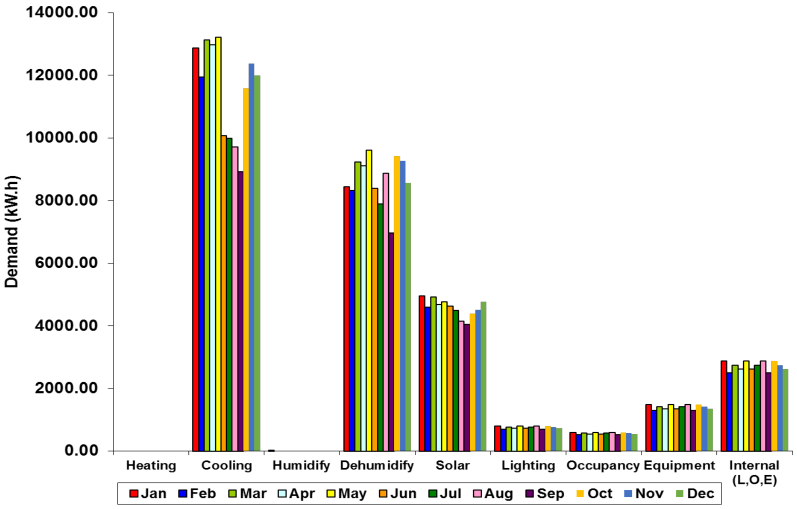


Figure 3: Monthly Total Demand Loads for the Base Case

Parametric Analysis

The results of the parametric simulations for the sensitivity analysis of varying thermostat temperature and relative humidity settings, ventilation gain, infiltration gain, and vapour diffusion factor of cement-based building fabric on dehumidification and cooling loads of the base model are presented in this section.

The cooling and dehumidification loads resulting from the sensitivity analysis of thermostat temperature settings and relative humidity settings are presented in Figures 4 and 5 respectively. From Figure 4, both dehumidification and cooling loads decrease with increasing temperature. A decrease of thermostat temperature setting of the Base Case Model from 22ºC to 24ºC resulted in an increase in cooling and dehumidification loads by 14% and 10% respectively. Thermostat temperature setting of 26ºC resulted in a reduction of cooling and dehumidification loads by 19% and 11% respectively. The above reductions demonstrate an improvement upon studies by Moon and Han (2011) in the North American climates that achieved annual savings of 5-15 % on the energy bill by lowering the thermostat temperature level by 2 to 4℃.

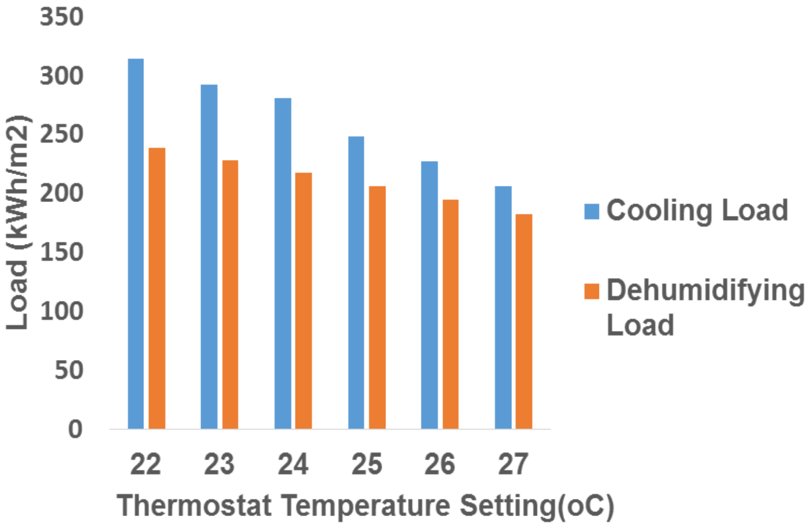


Figure 4: Impact of thermostat temperature setting on Loads

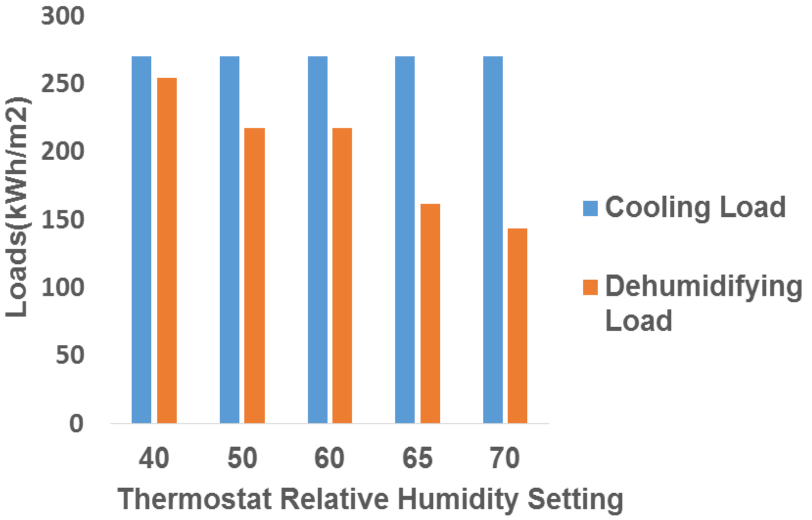


Figure 5: Impact of thermostat relative humidity setting on loads

With respect to increasing thermostat relative humidity as presented in Figure 5, dehumidification load decreases, while cooling load remains constant. However, since the research seeks to achieve reduction in cooling load arising from dehumidification load, it is guided by the CIBSE Guide A & B which recommends maximum relative humidity for indoor comfort stated as 60%. Moreover, the percentage mean votes and the predicted percentage of dissatisfaction showed that the thermostat relative setting of 60% is thermally comfortable for hot-humid climate (ASHRAE 55). Setting thermostat relative humidity setting to 60% leads to a reduction of dehumidification load by up to 17% compared to the load at 40% and cooling load remained unchanged (Figure 5).

The impact of varying ventilation and infiltration gains on loads are presented in Figures 6 and 7 respectively. From Figure 6, dehumidification load and cooling load increases from 150 to 370 kWh/m2 and 250 to 300kWh/m2 respectively with increasing ventilation gain from 1.0 to 5.0 ACH. However, the variation of dehumidification loads with increasing ventilation gains is more significant as compared to cooling loads. Relatively lower ventilation rates could have implications on indoor air quality, with increases in carbon dioxide concentrations and odour perceptibility (Cao et al., 2016, Cheng et al., 2017).

From Figure 7, it can be inferred that dehumidification and cooling loads increase from 210 to 370 kWh/m^2 and 210 to 605kWh/m^2 respectively with increasing infiltration gains from 0.5 to 2.5 ACH. The variation of dehumidification loads with increasing infiltration gains is really substantial as compared to cooling loads. The cooling loads gradually increase with increasing infiltration gains. From Figure 7, there is a strong correlation between infiltration gains and dehumidification loads. The results demonstrate that designing a tighter building in warm-humid climate remains vital in minimizing the infiltration gains leading to a lower dehumidification load. This will not only significantly impact on the building energy performance, but could also have implications on indoor air quality.

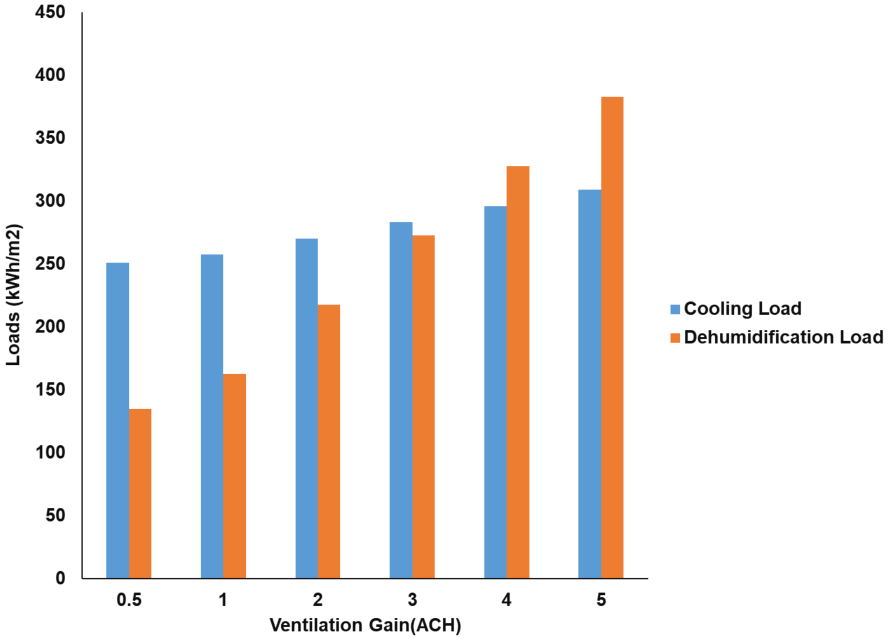


Figure 6: Impact of Varying Ventilation Gain on Loads

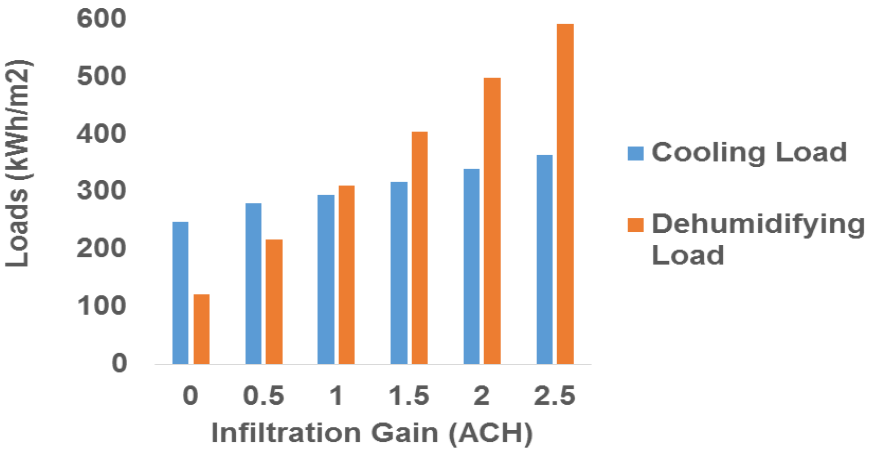


Figure 7: Impact of Varying Infiltration Gain on Loads

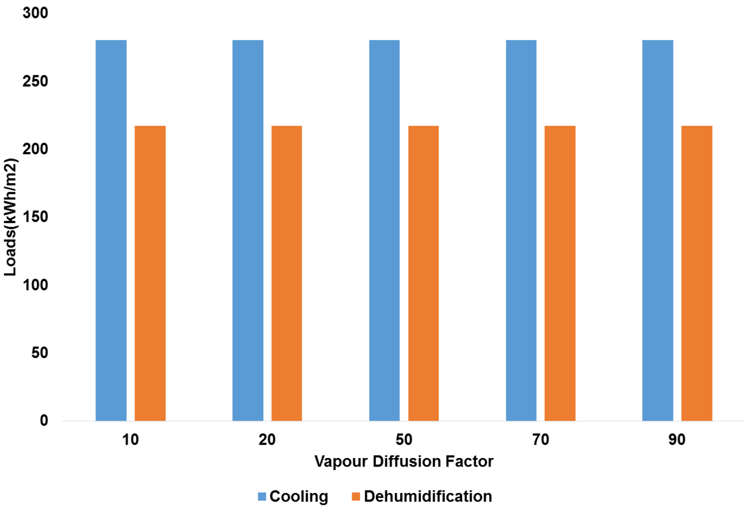


Figure 8: Impact of Varying Vapour Diffusion Factor on Loads.

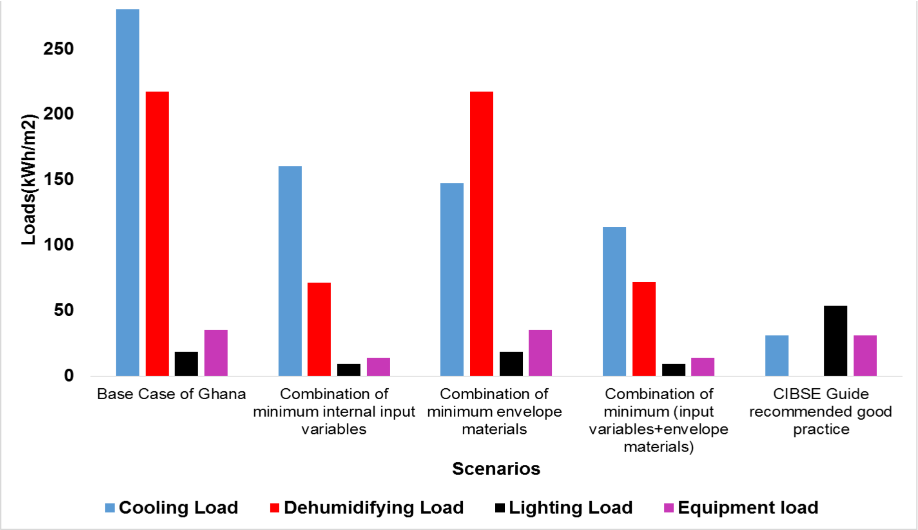


Figure 9: Comparison of minimum input variables simulation loads with recommended CIBSE Guide Loads

From Figure 8, the vapour diffusion factor of the cement-based building fabric did not have an impact on any of the cooling and dehumidification loads. The reason to this could be attributed to the fact that the ESDL TAS admittance cooling load calculations method do not account for the vapour diffusion factor accurately.

The combined parametric simulation of the input variables shown in Figure 9, demonstrates a significant reduction of 64.28% and 58.12% in dehumidification and cooling loads respectively, compared to the base case load. The recommended CIBSE Guide for good practice for cooling energy consumption was, however, not attained. From the combinations of minimum sensitive variables scenarios simulations, dehumidification load was found to be the dominant contributing load to the overall cooling load.

Implications of the Findings

Weather dependent variables strongly impact on building energy performance, depending on factors such as the climate in which a building is located, building type, and building envelope constructions, key amongst them being infiltration (Almarzouq and Sakhrieh, 2018). This study employed a parametric approach to examine weather dependent variables to explore the potential reduction of dehumidification and cooling loads of air-conditioning whole office building envelope in the warm-humid climate.

The findings of this study established that reducing infiltration rate reduces the energy requirement for cooling. This confirms study by Emmerich and Persily (1998) in which substantial energy savings, in the order of 15% of cooling load, resulted from air tightening building envelopes of office buildings. Infiltration in buildings can result in several negative consequences such as reduced thermal comfort, degradation of indoor air quality, increase in energy consumption, moisture damage, and others. Younes et al. (2011) identified that, relatively high infiltration rates can alter the thermal performance of the material in the building envelope and burden a building’s air-conditioning system, thus resulting in thermally uncomfortable internal conditions (Liddament, 1986).

The mode of building construction in the tropical developing countries facilitates air leakage through cracks and openings between the door and windows and their frames due to shortfalls associated with artisanal and quality control practices. Th adoption of automatic doors employing swinging, sliding, or rotating mechanisms also represent a major avenue for air infiltration. Since they remain open for much longer than manual doors, significant amounts of air infiltrates (Younes et al., 2011). According to Ng et al (2018), the approach to accounting for infiltration and air tightness in building energy modelling ignores or simplifies effects of leakage through envelopes. Infiltration rate input into energy simulation models should be ascertained and accounted for since they significantly impact anergy use by air conditioning.

High outdoor air temperature conditions and increased number of external hot days associated with the projected impacts of climate change by the IPCC (2018) could have a negative impact on cooling load in buildings. Under such conditions envelope tightening efforts in the design of office buildings through simple draught-proofing measures to achieve low infiltration rates (Jenkins, 2009), will become imperative to ensure low cooling requirement as well as to improve the internal comfort conditions.

Even though the study revealed that low infiltration rates result in reduced energy consumption for cooling, the incorporation of night-time cooling in office buildings could become a challenge as a result of limited cool night air (Tian et al., 2019).

In Manning et al. (2007), the humidity levels in a space contribute to occupant's comfort and also affect the perceived temperature. Higher temperature setting results in larger savings than the set-up because an air conditioner may likely run for a shorter period of time during the day. When an air conditioner runs the humidity level drops in a space because water is removed from the air in the form of condensate on the air conditioner coil. A higher temperature setting, not only will the temperature in a space be higher to cause environmental and severe human comfort problems, but the humidity level also increases because of the reduced air conditioner operation period (Manning et al., 2007). Although the human body can maintain a core temperature of around 37◦C, a number of factors such as clothing, physical exercise, and dehydration may affect the balance of heat in the human body, and as such affect thermal comfort (Givoni, 1982).

As energy costs increases, it has become imperative to adjust lifestyle towards a more sustainable fashion to save energy. Use of programmable thermostats facilitate saving energy consumed in cooling units. Blum (2005) reported that rising fuel costs and high heating bills led to a high patronage for programmable thermostats in North America. For instance, increasing the temperature on a thermostat in a cool weather, in the tropics, or while out of a space to conserve energy is becoming a common practice among building occupants. Adoption of programmable thermostats will offer the ability to program different strategies in warm and cool weather conditions to achieve additional savings in cooling load (Energy Star 2005). Occupants of spaces and facility managers have to be educated on the adoption of programmable thermostat to modify the temperature setpoint of air conditioning systems to save energy. The dominant forms of air conditioning systems used in offices are window and split air conditioners which comes with an inbuilt thermostat for the occupants to monitor their comfort requirement in the form of thermostat temperature (Davis and Gertler, 2015).

CONCLUSION

The paper employed the ESDL TAS dynamic numerical simulation software to investigate the impact of weather dependent design variables to minimizing dehumidification and cooling loads of a typical whole office building in the warm-humid climate of Ghana through a parametric study. The results show that controlling the thermostatic set points of temperature and relative humidity reduces the energy consumption for both cooling and dehumidification of air-conditioning system. However, the variation of the thermostatic relative humidity set point has no influence on the cooling load. Reasonable variations of ventilation gains and infiltration rates significantly impact both dehumidification and cooling loads. The variation in vapour diffusion factor of materials does not impact any of dehumidification and cooling loads.

It is recommended that Building Automation and Control Systems (BACS) are adopted in the design and operation of buildings in developing countries of warm-humid climate conditions to exploit the minimization of energy consumption for cooling and thermal comfort to ensure efficient energy use and a cost-effective approach in the operation of modern buildings.

References

Allouhi, A., El Fouih, Y., Kousksou, T., Jamil, A., Zeraouli, Y. and Mourad, Y. (2015). "Energy consumption and efficiency in buildings: current status and future trends", Journal of Cleaner Production, Vol. 109, pp. 118-130. (DOI: 10.1016/j.jclepro.2015.05.139).

AlMarzouq, A. (2018). Effects of glazing design and infiltration rate on energy consumption and thermal comfort in residential buildings. *Thermal Science*

Amos-Abanyie, S., Akuffo, F. O. and Kuutin-Sanwu, V. (2013). "Effects of Thermal Mass, Window Size and Night-Time Ventilation on Peak Indoor Air Temperature in the Warm-Humid Climate of Ghana", The Scientific World Journal, Vol. 2013, Article ID 621095. https://doi.org/10.1155/2013/621095

Amos-Abanyie, S., Akuffo, F. O. and Quagrain, V. (2009). "Unveiling Energy Saving Techniques for Cooling in Residential Buildings in Ghana", International Journal of Ventilation, Vol. 8 No. 1, pp. 23-35, DOI: 10.1080/14733315.2006.11683829

Azar, E. and Menassa, C. C. (2015). "Evaluating the impact of extreme energy use behaviour on occupancy interventions in commercial buildings". Energy Build. Vol. 97, pp. 205–218.

Blum, J. (2005). Beating the Heating Bill – Residents Rush to Upgrade Homes for Energy Efficiency. Washington Post, December 4 2005: F01. Washington: Washington Post Company.

Buker, M. S. and Riffat, S. B. (2015). Recent developments in solar assisted liquid desiccant evaporative cooling technology—A review. Energy and Buildings 96 (2015) 95–108

Cao, S., Zhu, D. and Yang, Y. (2016). Associated Relationship between Ventilation Rates and Indoor Air Quality. *RCS Advances*. Issue 112. https://doi.org/10.1039/c6ra22902f

Chen, X., Omer, S., Mark Worall, and Riffat, S. (2013). "Recent developments in ejector refrigeration technologies", Renewable and Sustainable Energy Reviews, Vol. 19, pp. 629-651

Cheng, X., Zhang, H., Pan, W., Liu, S., Zhang, M., Long, Z., Zhang, T. and Chena, Q. (2017). "Field study of infiltration rate and its influence on indoor air quality in an apartment", Procedia Engineering, Vol. 205, pp. 3954–3961

Cholewa, T., Siuta-Olcha, A. and Balaras, C.A., (2017). "Actual energy savings from the use of thermostatic radiator valves in residential buildings Long term field evaluation", Energy and Buildings, Vol. 151, pp. 487-493. DOI: 10.1016/j.enbuild.2017.06.070.

Chua, K. J., Chou, S. K., Yang, W. M. and Yan, J. (2013). Achieving better energy-efficient air conditioning – A review of technologies and strategies. Applied Energy 104 (2013) 87–104.

D'Oca, S., Fabi, V., Corgnati, S. P. and Andersen, R. K. (2014). Effect of thermostat and window opening occupant behavior models on energy use in homes.Build. Simul., 7, 683–694.

D'Oca, S., Hong, T. and Langevin, J. (2018). "The human dimensions of energy use in buildings: A review", Renewable and Sustainable Energy Reviews, Vol. 81, pp. 731-742. (DOI: 10.1016/ j.rser.2017.08.019).

Davis, L. W and Gertler, P. J. (2015). Contribution of air conditioning adoption to future energy use under global warming. Proceedings of the National Academy of Sciences. 112(19):5962-5967

Emmerich, S. and Persily, A. (1998). Energy Impacts of Infiltration and Ventilation in U.S Office Buildings Using Multizone Airflow Simulation. IAQ and Energy '98, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Evins, R. (2013). A review of computational optimisation methods applied to sustainable building design. Renewable and Sustainable Energy Reviews 22 (2013) 230–245

Farzan, H. (2019). The Study of Thermostat Impact on Energy Consumption in a Residential Building by Using TRNSYS. *Journal of Renewable Energy and Environment*. Vol. 6, No. 1, (Winter 2019) 15-20.

Ghahramani, A., Zhang, K., Dutta, K., Yang, Z. and Becerik-Gerber, B. (2016). Energy savings from temperature setpoints and deadband: quantifying the influence of building and system properties on savings. Applied energy. Volume 165, 1 March 2016, Pages 930-942

Givoni, B. (1982). Man, Climate and Architecture. 2nd Edn. London: Applied Science Publishers.

IPCC (2018). Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

Jenkins, D. P. (2009). The importance of office internal heat gains in reducing cooling loads in a changing climate. International Journal of Low-Carbon Technologies.

KBV Research (2018). Global Dehumidifier Market Analysis (2018-2024) pg. 237 https://www.reportlinker.com/p05490375/Global-Dehumidifier-Market-Analysis.html (Assessed: January 2020)

Kolokotroni, M., Ren, X., Davies, M. and Mavrogianni, A. (2012). London's urban heat island: Impact on current and future energy consumption in office buildings. Energy and Buildings 47 (2012) 302–311

Kontes, G. D., Giannakis, G.I., Horn, P., Steiger, S. and Rovas, D.V. (2017). Using Thermostats for Indoor Climate Control in Office Buildings: The Effect on Thermal Comfort. *Energies*, *10*, 1368.

Lam, T.N.T., Wan, K.W., Wong, S.L. and Lam, J.C. (2010). "Impact of climate change on commercial sector air conditioning energy consumption in subtropical Hong Kong", Applied Energy, Vol. 87, pp. 2321–2327

Larsen, K., Larsen, J., Delgado, M., Herndon, W. and Mohan, S. (2017). Assessing the Effect of Rising Temperatures: The Cost of Climate Change to the U.S. Power Sector. https://www.impactlab.org/wp-content/uploads/2017/09/RHG_PowerSectorImpactsOfClimateChange_Jan2017.pdf [Assessed: January 2020]

Li, C., Hong, T. and Yan, D. (2014). An insight into actual energy use and its drivers in high-performance buildings. Appl. Energy 2014, 131, 394–410.

Longo, S., Palomba, V., Beccali, M., Cellura, M. and Vasta, S. (2017),). "Energy balance and life cycle assessment of small size residential solar heating and cooling systems equipped with adsorption chillers", Solar Energy, Vol. 158, 543-558. (DOI: 10.1016/j.solener. 2017.10.009).

Manning, M. M., Swinton, M.C., Szadkowski, F., Gusdorf, J. and Ruest, K. (2007). The Effects of Thermostat Set-back and Set-up on Seasonal Energy Consumption, Surface Temperatures and Recovery Times at the CCHT Twin House Facility. ASHRAE Transactions, Vol. 113, (2007), 630642.

Mardiana-Idayu, A. and Riffat, S. B. (2012). "Review on heat recovery technologies for building applications", Renewable and Sustainable Energy Reviews, Vol. 16, pp. 1241– 1255

Monetti, V., Fabrizio, E. and Filippi, M., (2015). "Impact of low investment strategies for space heating control: Application of thermostatic radiators valves to an old residential building", Energy and Buildings, Vol. 95, 202-210. (DOI: 10.1016/j.enbuild.2015.01.001).

Moon, J. W. and Han, S. H. (2011)."Thermostat strategies impact on energy consumption in residential buildings", Energy and Buildings, Vol. 43, No. 3, 338-346. (DOI: 10.1016/j.enbuild.2010.09.024).

Morakinyo, T. E., Balogun, A. A., Adegun, O. B. (2013). Comparing the effect of trees on thermal conditions of two typical urban buildings. Urban Clim. 2013, 3, 76–93. [CrossRef]

Ng, L., Quiles, N. O., Dols, W. and Emmerich, S. (2018). Weather Correlations to Calculate Infiltration Rates for U.S Commercial Building Energy Models. Building and Environment Volume 127

Opoku, R., Edwina, I. A. and Agyarko, K. O. (2019). Energy efficiency and cost saving opportunities in public and commercial buildings in developing countries: The case of air-conditioners in Ghana. Journal of Cleaner Production 230 (2019) 937-944

Peffer, T., Pritoni, M., Meier, A., Aragon, C. and Perry, D. (2011). How people use thermostats in homes: A review. Building and Environment 46 (2011) 2529e2541

Qin, M., Belarbi, R., Aït-Mokhtar, A. and Allard, F. (2009). Simulation of coupled heat and moisture transfer in air-conditioned buildings. Automation in Construction 18, 624–631

Ren, Z. and Chen, D. (2015). Simulation of air infiltration of Australian housing and its impact on energy consumption. *Energy Procedia* 78 (2015) 2717 – 2723

Ronghui, Q., Lina, L. and Yu, H. (2014). Energy performance of solar-assisted liquid desiccant air-conditioning system for commercial building in main climate zones. Energy Conversion and Management 88 (2014) 749–757

Rysanek, A. and Choudhary, R. (2012). “A decoupled whole-building simulation engine for rapid exhaustive search of low-carbon and low-energy building refurbishment options”, Fuel and Energy Abstracts. Vol. 50. 10.1016/j.buildenv.2011.09.024.

Simons, B., Koranteng, C., Adinyira, E. and Ayarkwa, J. (2014). “An Assessment of Thermal Comfort in Multi Storey Office Buildings in Ghana”, Journal of Building Construction and Planning Research, Vol.2 No.1, DOI:10.4236/jbcpr.2014.21003

Sultan, M., El-Sharkawy, I. I., Miyazaki, T., Saha, B. B. and Koyama, S. (2015). An overview of solid desiccant dehumidification and air conditioning systems. Renewable and Sustainable Energy Reviews 46(2015)16–29

Tian, Z., Yang, J., Lei, Y. P. and Yang, L (2019). Sensitivity Analysis of Infiltration Rates Impact on Office Building Energy Performance. Earth and Environmental Science 238.

Vakiloroaya, V., Samali, B., Fakhar, A. and Pishghadam, K. (2014). “A review of different strategies for HVAC energy saving”, Energy Conversion and Management, Vol. 77, pp. 738–754

Wang, J., Zhai, Z., Jing, Y., Zhang, X. and Zhang, C. (2011). Sensitivity analysis of optimal model on building cooling heating and power system, Applied Energy 88 (2011) 5143–5152

Wang, N., Zhang, J. and Xia, X. (2011). “Energy consumption of air conditioners at different temperature set points”, Energy and Buildings, Vol. 65, pp. 1-6. 10.1109/AFRCON.2011.6072174.

Younes, C., Shdid, C. A. and Bitsuamlak, G. (2011). Air infiltration through building envelopes: A review. Journal of Building Physics 35(3) 267–302.