

Carbon Footprint Analysis at the Operation Phase in a Student Residential Hall in Hong Kong

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Abstract. According to the climate action plan published by the Environment Bureau in Hong Kong, it is expected that the absolute carbon emission to have a reduction of 36% per capita by 2030 (base year 2005). Using walkthrough combined with energy simulation, we have investigated the energy consumption pattern of a student residential hall. Due to the fluctuation nature on the number of residents in a student residential hall, we have simulated several scenario: 1) typical occupancy, 2) typical occupancy with energy optimization, 3) peak occupancy, 4) peak occupancy with energy optimization in order to estimate the range of consumption. In scenario 4, effective energy use pattern for air-conditioning system was implemented and approximately 480 tonnes (6.5%) of carbon emission can be reduced for a 50 years building life span consideration. Various energy conservation measures should be taken into consideration in order to further reduce carbon emission in the future.

1. Background

To deal with the world-wide issue of global warming or climate change, as discussed in the 2015 United Nations Climate Change Conference, there is an urgent need for the reduction of the greenhouse gas emission. In Hong Kong, the Government has proposed a target of reducing carbon emissions by 50–60% by 2020 since 2010. [1] In the *Hong Kong Climate Change Report 2015*, the Government has advised it will use China's pledge to reduce carbon intensity by 60–65% between 2005 and 2030 and formulate various measures to mitigate climate change. [2] To accede the China's climate plan and the Paris Agreement, the Government has recently outlined the long-term measures to combat climate change and attain the updated carbon intensity target for 2030 in the *Hong Kong's Climate Action Plan 2030+*. [3] The new target is to reduce Hong Kong's carbon emissions by 65%–70% by 2030 from the 2005 levels, which is equivalent to 26–36% absolute reduction and a reduction to 3.3–3.8 tonnes in per capita emissions.

To achieve the updated carbon emissions target, various strategies such as reducing coal-fired electricity generation, widen the use of renewable energy, as well as implementing energy-saving measures for buildings and transportation had been proposed. As a start to contribute to this carbon reduction mission and to devise the suitable environmental management system in our institute, we have initiated a life cycle assessment study of one of the institute halls of residence and used data simulated by eQuest for comparison. The result obtained will help to extend the life cycle assessment study to the whole institute in future.



A few literatures have mentioned the life cycle carbon emission assessment for residential buildings or similar buildings on function like hotels. However, these studies mainly focus on the material comparison or at the construction phase of the building.[4-5] Construction materials affect the energy performance of whole building. However, from the viewpoint of the whole life cycle of the building, operation stage (or use phase) constituted the largest proportion of energy consumption, i.e. carbon emission from energy generation. In terms of the characteristics of a building's operation phase, up to 85% of total carbon emissions by building type due to the use of heating and cooling energy and electrical facilities could be accounted [5]. In this study the operation stage will be focused and the electricity consumption of HVAC system and other electrical facilities such as lighting system will be evaluated.

2. Methodology

Information and parameters to predict carbon footprint through eQUEST are collected and summarized. Most of the items for simulation are referenced from the design report of the institute's residential hall including building geometry (floor plan in CAD files), building area and number of floor, floor height (floor to floor and floor to ceiling), types and dimensions of door and window, HVAC system, design temperature and air flow, etc. Figure 1 shows the typical floor plan used in this eQuest modelling study. Other parameters like number of existing residents and electricity consumptions are gathered from the hall manager. The DD (Design Development) Wizard will be used instead of SD (Schematic Development) Wizard since it can be used to create buildings with multiple shells and provide more flexibility in assigning them to building areas. Carbon emission varies with energy use and the fuel mix of energy generation. The following equation are used:

$$\text{CO}_2 \text{ Emission}(\text{kg CO}_2) = \text{Electricity consumption}(\text{kWh}) \times \text{Emission Factor}(\text{kg CO}_2 \text{ per } 1 \text{ kWh}) \quad (1)$$

The net electricity consumption should be used for calculation. A net electric consumption refers to total energy consumption minus any renewable energy generation. the GHG emissions factors (EFs) is 0.540 kg CO₂ e per 1 kilowatt-hour (kWh) in 2015 in Hong Kong for electricity uses.[6] The system boundary is defined as the energy consumption of the MVAC, lighting and water heating system during the operation phase.

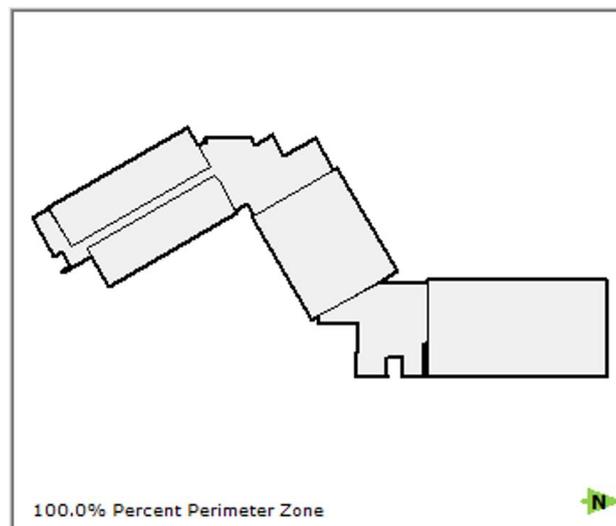


Figure 1. The floor plan (3/F) used in this eQuest modelling.

3. Results

3.1 Measurement and Validation

The residential building consists of 12 floors and the 12th floor has been unoccupied for a consecutive 12 months so it will not be considered. G/F remained in working condition in the whole year, so it can be regarded as a fixed consumption floor and will also not be considered. This scenario simulates the energy consumption of 1/F to 11/F from 1 January to 31 December 2016. 24-hour operation is set for 1 January to 31 May and 1 September to 31 December due to school day. [7] Low occupancy is set for school day due to existing low density situation. [8] In summer holiday from 1 June to 31 August, the building operation schedule is set to be closed for business. It is assumed that there is no user in the building except regular inspection which will only trigger light tube in corridor. Energy saving light tubes are installed in corridor and they will only be triggered when movement is detected, the influence should be low to this validation. Each floor has a height of 3,150 mm from floor to floor including 150 mm concrete between two floor. All floors have similar component, setting and structure. A floor consists of bedroom, mechanical/electrical room, corridor, activity room, common area. Usually more than 40% of space occupied by bedroom for student or guest, 10% for mechanical/electrical room or corridor each, others sum up to 100%. The complete common areas, each contains television, refrigerator, cooking ranges and resident controlled air conditioning system, are located on 1/F, 4/F, 7/F. There is no exterior door nor exterior window shades but only exterior window with 1500 mm width and 1550 mm height. The percentage of window against net wall area (floor to ceiling) is slightly different in each floor. Two types of air-conditioning system are installed for different areas. Variable Refrigerant Volume (VRV) System, HVAC system 1 in simulation, will be used to simulate the podium area such as lobby, corridor, common area, activity room, etc. Split-type air-conditioning unit, HVAC system 2 in simulation, will be used to simulate the bedrooms and warden's flats. Variable Refrigerant Volume (VRV) System will operate for 24 hours per day in podium area to maintain a comfortable environment. Split-type air-conditioning unit is set to operate 8 hours during students' sleeping hour. The design temperature for indoor condition is 23°C dry bulb $\pm 1^\circ\text{C}$. For the domestic water heating, an instantaneous type electric hot water heater is installed in each bedroom for bathing. Ten gallon per person per day of hot water use is assumed, the consumption is therefore approximately 50L.

As shown in Figure 2, the largest proportion of usage is space cooling. To assist space cooling, ventilation is also an important component so it occupies the second largest proportion of energy used. Typically, the trend of energy consumption in entire year should be ideally linear, a line goes up from January then reach the climax at August and becomes low again unit December. Since Hong Kong is located in subtropical regions, the weather is hot and humid during May to August. The relatively low usage in June and August is due to the low occupancy in the summer holiday. No space heating burden should be considered as no heating equipment is provided. The design parameter of outdoor temperature in winter is 7°C so no heating for warming indoor temperature is required. Water heating is mainly used to operate instantaneous type electric hot water heater for bathing. There is refrigerator in common area but consumption on refrigeration is not considered in the simulation because all of the single electrical device consumption is categorized to miscellaneous equipment. Miscellaneous equipment also include television, cooking ranges, charger, etc. either in common area or bedroom. The remaining consumption is area lighting. All the activity rooms and common areas use glass instead of concrete as an external wall to introduce day light for illumination. Automatic sensor is put in the corridor to minimize the energy consumption. The light bulb will only be triggered when the sensor detects any movement. If no movement is detected again within a minute, the light will be turned off to standby mode.

The simulated data was then used to compare with the real situation during the measured occupancy period. As seen in Figure 3, although the occupancy condition is set to zero due to summer holiday period, the simulated wage of July and August are still high and quite different from real situation. In simulation, occupancy rate affects all usage in building but only affects to a lesser extent to the majority of resident-orientated usage. the electricity usage of resident-orientated usage like lighting, water heating and miscellaneous equipment has dropped significantly in June to August however it

does not make tremendous change to total consumption. The saving of air-conditioning from bedroom can cover the higher consumption of the central air-conditioning system in public area due to hot weather so the consumption level of space cooling is similar to May and September. The simulated result is higher than realistic situation during July and August, a possible reason can be attributed to the fact that the real operation schedule of air-conditioning system in summer holiday had been adjusted to a more environmental friendly mode. For example, the system was turned off at night as no resident is needed to be served. It is a massive energy saving if the system is off from 11 p.m. to 7 a.m. and it can also explain the difference between real consumption and simulated result. The coefficient of determination of the simulated and real data was calculated to be 0.9712, which demonstrated that the simulated model agrees quite well with the actual situation.

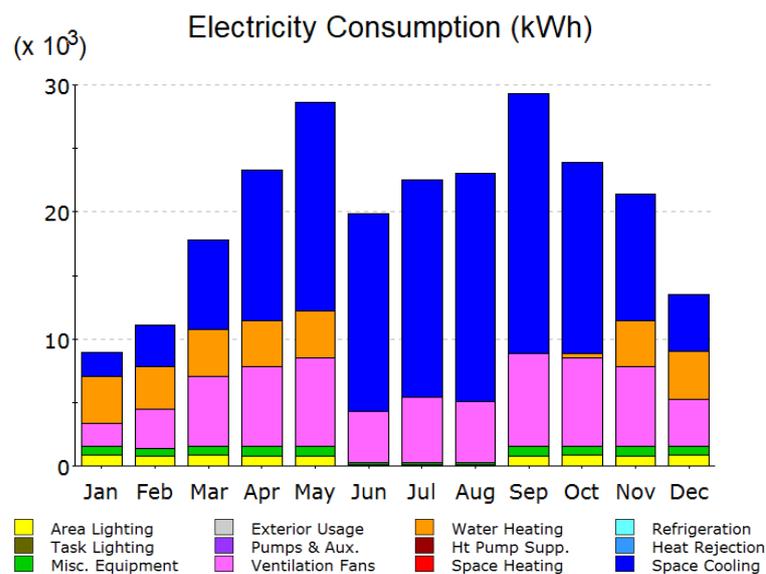


Figure 2. Simulation result of the institute's residential hall in 2016.

3.2 Prediction of Energy Usage

3.2.1 Typical Occupancy

Due to the unforeseen number of occupancy in a student residential hall, several scenarios have been attempted in order to obtain a reasonable range of energy usage. Scenario 1 simulates a typical occupancy of VTC Student Dormitory based on the recent number of residents. All other settings remain the same as the validation's case like 24 hour operated MVAC system, 50L domestic hot water for a person, etc. The total energy consumption of typical usage is 303,510 kWh in 2017. Most of the energy is used to maintain a comfortable living environment by air-conditioning and ventilation. More than a half of energy, i.e. 177,510 kWh, is consumed by space cooling and 84,420 kWh is used to operate ventilation fans. 22,480 kWh is used for water heating, while 9,190 kWh is used for miscellaneous equipment and 9,880 kWh is used for area lighting. For the trend of energy consumption, space cooling and ventilation are fluctuating due to varying weather condition. Miscellaneous equipment used and area lighting are stable for every month and the consumption is nearly a constant for both of these two items. Scenario 2 simulates a typical occupancy with an energy saving approach. MVAC system can be optimized in a more energy efficient manner after understanding the behavior of resident. A student dormitory is not equivalent to a hotel, it does not need to be maintained as perfect condition as a hotel for clients who has an option to spend their time to enjoy the facilities rather than going to the bed. It is expected that the student should go to bed or stay in their bedroom after 11 p.m. As the earliest lesson is at 9 am at the institute, they can take rest until 6 am in the morning. To reduce unnecessary energy usage at night, this scenario proposes only

regular air exchange to be operated during normal sleeping hour from 11 pm to 6 am, air-conditioning will cease due to less requirement in that period. All other settings remain at the same condition as scenario 1. The total energy consumption under typical use is lowered to 278,810 kWh. Most of the energy is still used to maintain a comfortable living environment by air-conditioning and ventilation. 160,630 kWh is consumed by space cooling and 76,610 kWh is used to operate ventilation fans. Other parameters remain unchanged with the same number of resident. 22,480 kWh is used for water heating, 9,190 kWh is used for miscellaneous equipment and 9,880 kWh is used for area lighting. Compare to scenario 1, the reduction of electricity consumption is 24,700 kWh which is equivalent to a reduction rate of around 8%.

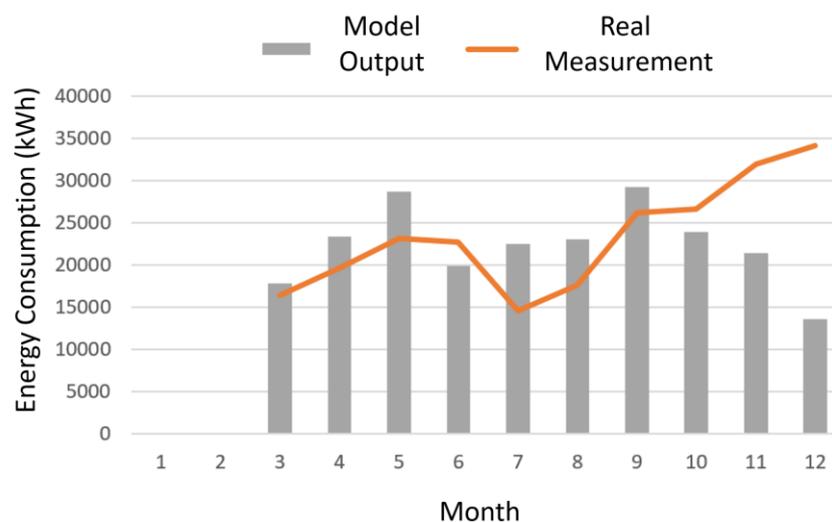


Figure 3. Data comparison between simulation and real situation

3.2.2 Peak Occupancy

Scenario 3 simulates peak occupancy of residential hall to find out the maximum energy that could be consumed. All settings remain the same as scenario 1 except number of residents. The total energy consumption under peak use is 410,360 kWh in 2017. More energy is used to maintain a comfortable living environment especially in May and September. 222,270 kWh is consumed by space cooling and 108,700 kWh is consumed to operate ventilation fans. 43,350 kWh is used for water heating, 23,410 kWh for miscellaneous equipment and 12,610 kWh for area lighting. The consumption for space cooling and ventilation increase from 261,930 kWh for typical use to 330,970 kWh for peak use. Although the quantity of resident is doubled theoretically, the energy used is not doubled. Because air-conditioning and ventilation for public place is generally fixed, the increase is mainly come from the use of the air conditioner in bedroom during hot and humid weather. On the other hand, consumption of water heating depends on occupancy rate unless students take shower in somewhere else. Thus the increasing rate is nearly double, from 22,480 kWh to 43,380 kWh. The last two parameter, miscellaneous equipment and area lighting, demonstrate a greater difference in increasing rate even though they consume at a similar level of electricity during typical occupancy. The former has a huge rise, from 9,910 kWh to 23,410 kWh, while the latter only has a slight increase. It is because the energy use factor is set larger manually due to several possibilities including higher probability of public devices usage, much more personal electrical devices usage and larger volume of cloth washing, etc. In contrast, area lighting consumption increased by 2,730 kWh to 12,610 kWh. It shows that the day light benefits both public area and bedroom as over 30% of surface area can introduce day light for illumination. Again, the consumption in public area is close to a fix value, thus the increase mainly comes from bedroom and activity room. With energy saving, i.e. scenario 4, the total energy consumption is lowered to 385,030 kWh. Most of the energy consumed is to maintain a comfortable living environment by air-conditioning and ventilation. 204,850 kWh is consumed by space cooling

and 100,790 kWh is used to operate ventilation fans. Other parameters remain unchanged due to the same number of residents. 43,350 kWh is used for water heating, 23,410 kWh is used for miscellaneous equipment and 12,610 kWh for area lighting. Compared to scenario 3, the reduction of total electricity consumption is 25,330 kWh which is equivalent to a reduction rate of around 6%. The result is very close to the decline between scenario 1 and scenario 2. Since the total energy consumption is higher, the decreasing percentage is lower at a similar reduction value.

3.3 Prediction of Life Cycle Carbon Emission

PV panel and wind turbine generated 20,790 kWh and 2,800 kWh respectively per year in the residential hall. [9] Before determining the carbon emission, these energy savings are subtracted from total electricity consumption in the simulation result. No other energy source such as liquefied petroleum gas was used in the student dormitory therefore electricity is the only source of carbon footprint in the operation phase. The latest GHG emissions factors (2015) of 0.540 kg CO₂ e per kWh provided by CLP for electricity generation is adopted for the following calculation. The result will be presented in CO₂ e per m² and per capita for convenient comparison with other building's performance. The surface area of the residential hall from 1/F to 11/F is 15,075 m². The density is 440 residents for typical occupancy (50%) and 880 residents for peak occupancy (100%). The carbon emissions of each scenario are shown in Table 1.

	Typical Occ	Peak Occ
No energy saving	345.5 kg CO ₂ /capita	237.3 kg CO ₂ /capita
	10 kg CO ₂ /m ²	13.9 kg CO ₂ /m ²
Energy saving	313.2 kg CO ₂ /capita	221.8 kg CO ₂ /capita
	9.1 kg CO ₂ /m ²	12.9 kg CO ₂ /m ²

Table 1. Carbon emissions per capita and per m² for each scenario.

For a typical building's life span of 50 years, if energy saving mode is adopted, a total of 684 tonnes of CO₂ e can be reduced, which is equivalent to about 6.5% of carbon reduction for 50 years of operations.

3.4 Energy Conservation Measures

Currently, the following energy conservation measures have already been implemented at the residential hall:

- Use of occupancy sensor and photo sensor for lighting control.
- Introduction of massive day lighting for illumination.
- Use of T5 fluorescent and compact fluorescent light fitting.
- Use of LED televisions.
- Use of dual-flash buttons instead of press-type or handle-type water cisterns.
- Energy metering and monitoring system for energy management, etc.

More energy conservation measures are suggested for future retrofit of the building to further decrease the carbon emission, such as:

- Purchase electrical equipment with Grade 1 energy label. Energy Efficiency (Labelling of Products) Ordinance requires energy labels to be displayed on prescribed electrical products before being supplied in Hong Kong to facilitate consumers in choosing energy-efficient electrical appliances.
- Reschedule the HVAC plan. A comprehensive investigation should be conducted through questionnaire at the beginning of every semester to understand the general behavior of residents in

dormitory like when do they leave and return and how often do they stay in common area.

- Use air-conditioner in good practice. Reminders should be posted near the switches of the air-conditioner to remind the users of the best practices in using air-conditioners such as setting the air-conditioner temperature at 25.5°C.

Install tap aerators. These water saving devices control the amount of water that flows through the tap without affecting the water pressure as they mix the water with air. The aerator acts as a sieve, separating a single flow of water into many tiny streams which introduces the air into the water flow. As there is less space for the water to flow through, the water flow is reduced, resulting in water savings.

4. Conclusion

The present study involved a carbon audit for the operation phase of the student residential hall at Tsing Yi campus from 1/F to 11/F using walkthrough combined with modeling software. The scope of this study includes the energy use of MVAC system, lighting system, water heating and other electrical equipment. An existing condition was first measured and applied as a baseline study to validate the accuracy of the simulation. Four scenarios are simulated for the following year, in which two for typical occupancy and two for peak occupancy. The average carbon emission is 13.9 kg CO₂ e per m² per annum and 237.3 kg CO₂ e per capita per annum under peak occupancy. The carbon emission is 7,310 tonnes CO₂ eq for 50 years' operation. Scenario 4, also under peak occupancy, introduces an effective energy use pattern for air-conditioning system which only operate between 6 am to 11 pm. If this approach is to be adopted, carbon emission will be 6,831 tonnes CO₂ e and 684 tonnes of carbon emission can be reduced in the entire 50 years life span. Finally, some energy saving opportunities was suggested for this residential building. Both the material use in construction stage and selection of electrical equipment as well as the user behavior are crucial to reduce carbon emission.

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