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Impact of Lifestyle Changes and Emerging Workplace Trends on Energy Consumption in a Research Building

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Abstract

Energy consumption in buildings is significantly influenced by lifestyles of occupants. In order to achieve sustainable built environments, it is imperative to examine the energy saving potential of lifestyle changes. However, the behaviors of occupants and energy consumption patterns vary according to building type. Research buildings are mixed-use in nature and occupants often perform computationally demanding tasks that require energy intensive equipment. This study examines the impact of changes in occupants' lifestyles on energy consumption in a university research building, in light of emerging workplace trends. A survey was conducted to determine plug-load ownership and usage schedules, and preferred air conditioning setpoint temperature. Inefficient workspace allocation and computer usage were identified as prime causes of energy wastage in the building. Potential energy-saving lifestyle change scenarios were developed to address these inefficiencies, including use of localized co-working spaces, night-time usage of computers, and increasing air conditioning setpoint temperature. Nighttime computer usage reduced overall energy consumption by 4% and increasing setpoint temperature by up to 6%. Reallocation of office space into localized co-working spaces had the most consequential impact, achieving energy savings of 25%. This highlights the significance of lifestyle changes related to emerging workplace trends towards attainment of energy efficiency targets in buildings.

Introduction

Workplace culture has witnessed significant changes due to emerging trends such as remote working, use of co-working spaces and general virtualization of work. These are directly associated with lifestyles of building occupants, thus influencing energy usage in buildings. However, the energy impact of occupant lifestyles in special-use buildings such as university research buildings is dissimilar to residential and office buildings. University research buildings have unconventional occupancy and equipment schedules, since research students tend to use the facilities outside normal office hours. This calls for investigation of the energy saving potential of lifestyle changes and workplace trends in research buildings.

Occupant behavior and energy consumption in buildings

Energy efficiency in buildings is not only dependent on the building's design, but is also affected by occupants' energy related lifestyles and how they set their comfort criteria (Barthelmes et al., 2019). The omission of occupant behavior, lifestyles and motivations often causes discrepancies between energy consumption at the building design and operation stages (Chen et al., 2017). A major obstacle that designers face is the uncertain nature of occupant behavior, which makes it difficult to characterize their impact on energy consumption (Clevenger et al., 2014; O'Brien et al., 2020). This problem is also compounded by the influence of other factors such as material properties, climate, appliances, among others (Yu et al., 2011).

Simulation and survey methods have thus been extensively applied to characterize occupant behavior in buildings. The most common target building types for lifestyle-related energy studies are residential and office buildings (Heinrich et al., 2022; Otsuka & Narumi, 2019; Tam et al., 2018). Barthelmes et al. (2017) and Pioppi et al. (2020) achieved energy savings of up to 28% and 17% through elimination of wasteful behaviors related to control of heating and cooling setpoint temperature, equipment and lighting schedules, and operation of window blinds. However, studies on occupant behavior and lifestyles in research buildings remain scarce.

Emerging workplace trends and energy consumption in buildings

Remote working or 'working from home' and use of co-working spaces are the most prominent emerging workplace trends. Remote working was popularized during the COVID-19 (coronavirus disease of 2019) pandemic which altered collective lifestyles (Novianto et al., 2022). Office work was consequently performed from residential environments thus impacting domestic energy consumption. Kawanami and Tabata (2023) noted a 4.2% increase in residential energy consumption compared to pre-pandemic times. Remote working is predicted to continue post-COVID-19 (Smite et al., 2023). However, this delocalizes energy consumption and requires a complete life cycle analysis to evaluate its impact.

The use of co-working spaces is also an increasingly common workplace trend. Dong et al. (2019) investigated the impact of different office layouts on energy consumption. The authors observed that per capita energy consumption during office hours was lowest in the case of co-working spaces. Mantesi et al. (2022) undertook a mixed method study to investigate the impact of flexible office usage on energy consumption in office buildings. Their exploratory study identified effective ways of implementing flexible working patterns, achieving 50% reduction in energy consumption.

Implementing co-working spaces in existing buildings requires alteration of occupants' conventional lifestyles. Staddon et al. (2016) investigated the most effective behavior change interventions in an office environment. Due to the communal nature of workspaces, Environmental Restructuring was identified as one of the most successful energy-saving interventions. It can be defined as the modification of occupants' physical environment to influence their behavior. Co-working spaces can be described as a form of Environmental Restructuring. The authors recommended investigation of the energy saving potential of forms of intervention such as coercion, restriction and training. However, motivating occupants to alter their lifestyles remains a significant challenge as stated by Pioppi et al. (2020). This was also noted by Barthelmes et al.(2019) who emphasized the need for 'easy to understand' energy consumption feedback to the occupants and 'easy to adopt' daily routine changes to raise awareness and stimulate energy conscious behaviors.

Study objective

As demand for sustainable buildings increases, the impact of activities of building occupants and their control actions to enhance the air quality, thermal, visual, acoustic indoor environments will gain more prominence (Day et al., 2020; Hoes et al., 2009) Understanding the impact of occupant behavior can facilitate design and operation of energy efficient buildings (Chen et al., 2017). Optimization strategies for building designs will thus need to include occupant behavior. However, the impact of occupant behavior and lifestyles on energy consumption in research buildings has not been extensively studied. Despite the dissimilar social dynamics in different buildings, behavioral change strategies developed for the residential and office contexts can also be applied in other building types (Mulville et al., 2017). In this regard, this study investigates the energy saving potential of lifestyle changes by occupants of a university research building, incorporating localized co-working spaces as an emerging workplace trend.

Methodology

Site description

A 9-story research building located at National Taiwan University in Taipei City, Taiwan, was selected as a case study. Figure 1 shows depictions of the research building. It hosts five research divisions within the civil engineering department. The building is mostly used by faculty and graduate students to conduct research in various civil engineering disciplines. It was constructed using pre-cast technology and material properties are listed in Table 1.

The building has a total floor area of 9900m^2 and consists of one basement floor, a seismic isolation floor, and eight above ground floors. The building houses a materials laboratory, lecture rooms and offices for graduate students and faculty. It differs from a normal office building in the following key ways:

i. It contains energy intensive equipment and computers compared to standard equipment in normal offices.
ii. Occupant density and equipment usage in the research building fluctuates based on project timelines, compared to predictable occupancy in normal office buildings.
iii. Occupant lifestyles in the research building involve irregular working schedules that impact energy consumption differently compared to predictable routine schedules in normal office buildings.

Table 1 Building material properties

Surface	Material	U-value (W/m^{2}K)
Roof	2 mm polyurethane , 100 mm light concrete, 1.5 mm steel plate, 2 mm mineral wool panel, Air layer, 15 mm mineral wool acoustic panel	0.94
External wall	8 mm porcelain tiles, 180 mm reinforced concrete slab, Air layer, 25 mm plasterboard	2.16
Windows	8mm double Low-E, 8mm Air	2.40

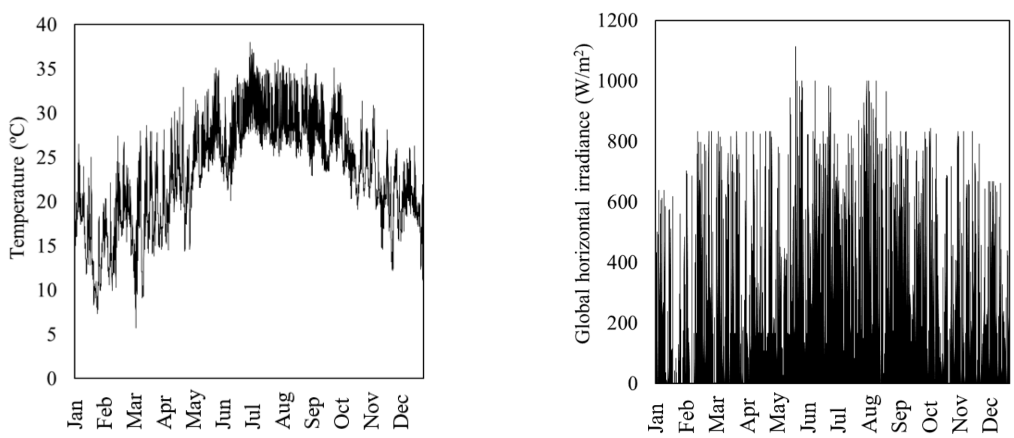
Energy consumption in the research building is mostly driven by computer usage by graduate students who utilize high performance energy intensive computers to perform design and simulation tasks. With an energy use intensity (EUI) of 122 kWh/m^2, the building is among the highest energy consuming buildings on the campus. It is therefore a prime case study on the energy impact of occupant lifestyles and emerging workplace trends.

Site climate

Taipei experiences a humid subtropical climate with discernible variations in temperature across the seasons as shown in Fig. 2. The city records distinct fluctuations in temperature throughout the year, with summer highs and winter lows. The annual average temperature hovers around 23°C. Summers are characterized by high humidity with peak temperatures ranging from 33°C to 38°C, while winters witness milder conditions, occasionally dropping to around 10°C. The annual rainfall in Taipei is prominently influenced by the monsoon season, spanning from May to September. The city receives annual global solar irradiance of approximately 1,100 kWh/m^2 and average wind speeds of 2.5 m/s, notably increasing during typhoon seasons. Design considerations are mainly aimed at insulating buildings from the hot and humid summer.

a) Actual building *b) DesignBuilder model*

Figure 1 Research building case study



a) Temperature *b) Global horizontal irradiance*

Figure 2 Site climate

Simulation procedure

The university maintains records of hourly electricity consumption and devices connected to WiFi in most of the buildings. This data was obtained to validate simulation results and determine hourly occupancy in the building. A survey was conducted to determine the ownership and usage of appliances in the building, as well as their schedules. An equipment audit was also performed to determine the rated power consumption of the main loads in the building. Lamps installed in each space in the building were also counted.

Faculty and administrative staff often maintain a predictable 8:00 to 17:00 schedule. However, graduate students are the main occupants of the building and they maintain flexible schedules. Occupants from each graduate student office were interviewed to determine the common air conditioning setpoint temperature. The first occupant to arrive in the office often turns on the lamps and air-conditioning while the last occupant to depart turns them off. The average arrival time of the first occupant in each office and the latest departure time were also estimated based on the interviews.

Hourly occupancy was estimated using the number of personal computers (PCs) connected to the building's WiFi. The interviews revealed that most occupants connect their PCs to the building's WiFi as soon as they arrive. The research building was modeled using DesignBuilder building performance simulation software. Simulation inputs included occupancy and electrical load schedules, equipment rated power, material properties, and weather data. Simulations were performed to determine present day energy consumption which was compared to electricity consumption measurement records from the building in previous years. Based on the simulation result of present energy consumption, lifestyle change scenarios were developed to minimize energy consumption in the building. Figure 3 shows the overall study flowchart.

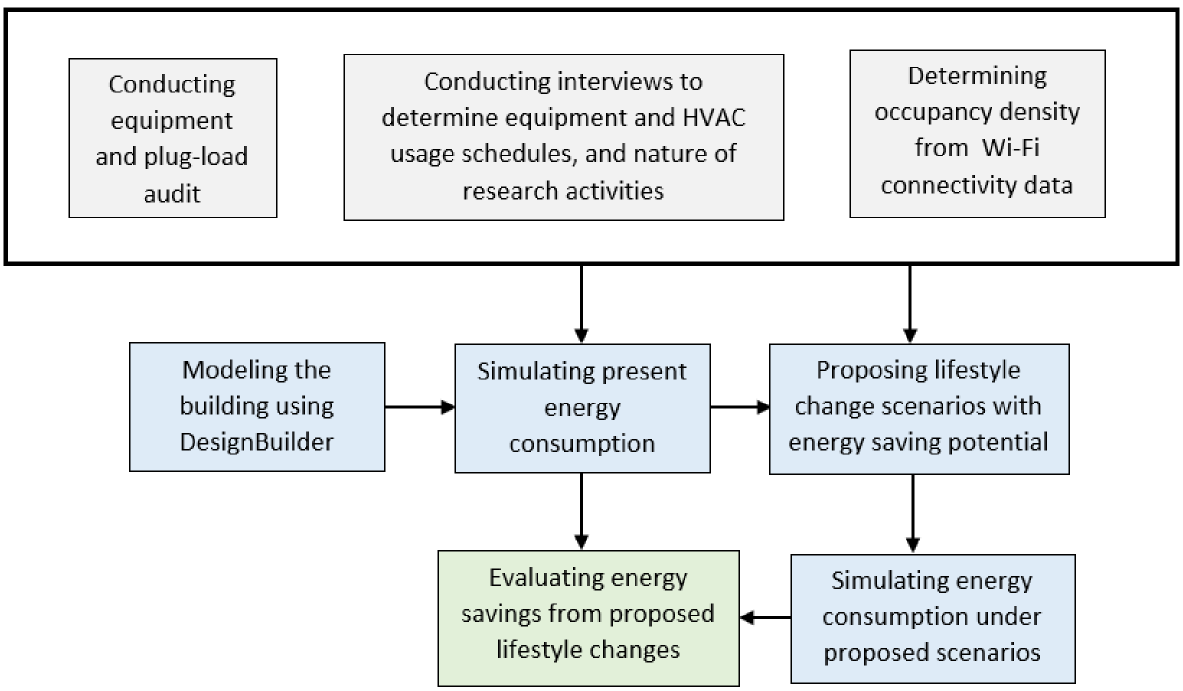


Figure 3 Study flowchart

Simulation scenarios

It was also observed that the inefficient allocation of workspaces based on different divisions within the department resulted in significant space wastage. Some offices were under-occupied, which caused underutilization of the HVAC system and lamps in such spaces. This consequently resulted in energy wastage. A simulation scenario was envisaged whereby occupants alter their normal office space usage and adopt localized co-working spaces. These offered an effective space management option that could minimize both space and energy wastage. Simulations were performed based on hourly building occupancy data.

Due to the energy intensive nature of computerized tasks performed in the research building, another scenario was developed to constrain tasks such as simulations to low occupancy night time hours. Present computer usage schedules were altered to incorporate nighttime hours instead of conventional daytime hours to reduce the impact of the cooling load from heat dissipated by the computers. Additional elaboration of the lifestyle change scenarios is presented under the results section.

Previous studies have proven that increasing air conditioning setpoint temperature is an effective way of minimizing energy consumption by HVAC systems. Therefore, simulations were performed at different setpoint temperatures. Energy savings were calculated in relation to the baseline present case.

Results and discussion

Electrical loads

The building is served by a central, water-cooled air conditioning system. The supply side of the HVAC system consists of two chillers with coefficient of performance (COP) of 6, and two cooling towers. The chillers supply chilled water to fan coil units installed within the building. The HVAC system does not include a heating system. LED tube T5 lamps rated at 26W each are installed within the building. The main energy intensive loads are high performance computers used to undertake computationally demanding tasks. It was established from the equipment audit that each student uses computers with an average load of 120W each when performing normal tasks. The building also hosts a server room with equipment rated at 40kW. Air conditioning in the server room as well as corridor and washroom lighting remains on throughout the year. Electric equipment in the materials laboratory is occasionally used since most tasks are performed manually.

Nature of research tasks

A survey questionnaire was administered to graduate students to obtain a general overview of the nature of research tasks conducted in the research building, and 20 responses were received. Seventeen of the 20 respondents described the main nature of their research tasks as computer simulations, as shown in Fig 4. Other tasks undertaken involved methodologies related experimentation and artificial intelligence (AI). Some students also stated that they combined several methodologies within their research framework. The respondents were also asked whether they required a high performance PC to perform their research tasks and 85% said ‘Yes’ while 15% said ‘No’. When asked whether they often leave their research tasks running on their computers during periods when they are not in the office, 80% gave a ‘Yes’ response and 20% said ‘No’. The average amount of time in a day spent working on the research tasks was 7 hours, which is one hour less than the normal 8 hour work-day.

The survey revealed that most students performed research involving computer simulations on high performance PCs, although the sample size was quite small.

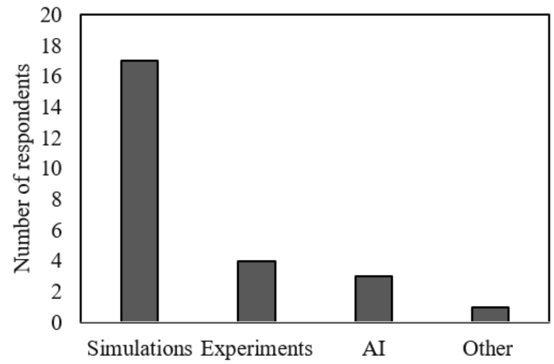


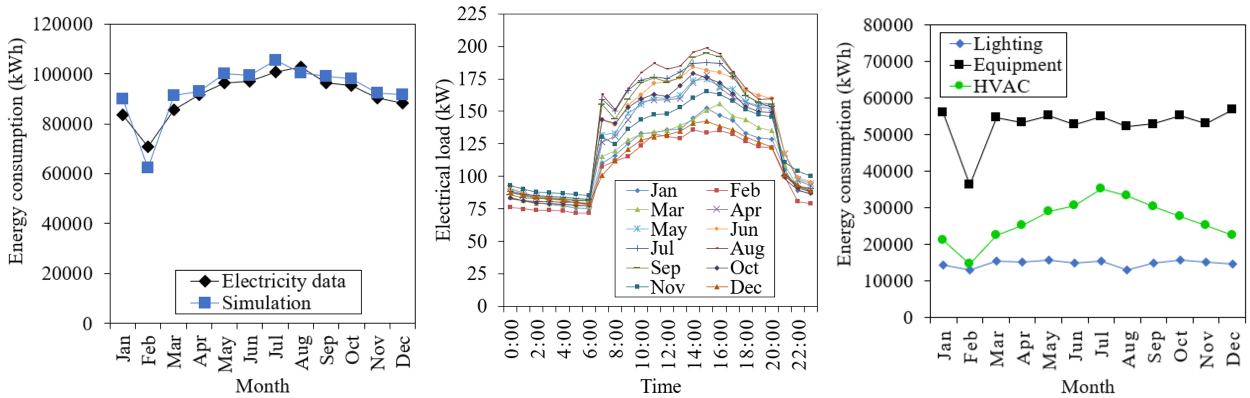
Figure 4 Nature of research tasks described by interviewees

Present energy consumption

Measured meter-recorded and simulated electricity consumption were compared as shown in Fig 5(a). It was observed that February had the lowest electricity consumption, coinciding with the semester break, during which occupancy was very low. This period was also during the winter season when HVAC usage for cooling is not required. Summer months between June and October experienced higher temperatures and HVAC usage, thus a high electricity consumption is observed. The trend between measured and simulated electricity consumption was comparable but the simulation slightly overestimated electricity consumption.

Figure 5(b) shows the hourly electrical load in the building. It was observed that during night time between 00:00 and 06:00, electricity load was still around 70 to 90 kWh, despite low occupancy. This mainly results from equipment in the air-conditioned server room that remains on throughout the year. The HVAC system’s chillers are turned on at around 08:00 in the morning hence a spike in electricity load can be observed at this time in Fig 5(b). A slight drop can be observed between 08:00 to 09:00. After the initial electrical load required to cool the water, less energy is needed to maintain the temperature of the chilled water. The electrical load rises as more occupants enter the building, peaking at 14:00 to 15:00, before dipping steadily as the occupants exit the building in the evening. The chillers are turned off at 21:00, hence a sudden drop in electrical load is observed.

Monthly energy consumption by lighting, equipment and HVAC is shown in Fig 5(c). Lighting energy consumption remained relatively constant since lamps in the corridors, stairway, lobbies and restrooms remained on throughout the day. Office occupants also tend to leave the lamps on during occupied hours. Energy consumption by HVAC peaked in July which is the hottest month in Taipei. Equipment was the main electrical load in each month, with a significant drop in February during the winter break.



a) Measured and simulated energy *b) Measured hourly electrical load* *c) Simulated monthly consumption*

Figure 5 Present energy consumption

Implementation of localized co-working spaces

The present occupancy capacity on each floor of the selected building is shown in Table 2 and the typical floor layout is shown in Fig. 6. The present workspace distribution is such that each floor consists of 4 open-plan offices each accommodating 20 research students and 8 private offices each accommodating one occupant. This translates to 80 occupants per floor in the open-plan offices and 8 in the private offices. Each division within the civil engineering department is allocated one floor and each occupant has a permanent workstation. This leads to space wastage since not all allocated space is utilized. Maximum occupancy recorded during the year was 181 as shown in Fig. 7(a), while the combined capacity of office space is 450, indicating that less than half of the space is utilized. This impacts energy consumption since AC units and lamps are turned on in most offices even during times of low occupancy.

Table 2 Occupancy capacity

Floor number	No. open plan offices	Open plan office occupancy capacity	No. private offices	Private office occupancy capacity
1	-	-	-	-
2	-	-	-	-
3	-	-	8	8
4	-	-	-	-
5	4	80	8	8
6	4	80	8	8
7	4	80	8	8
8	4	80	8	8
9	4	80	8	8

The maximum occupancy recorded at each hour during the whole year shown in Fig. 7 was selected for reallocation of spaces. Occupancy is observed to peak in the afternoon at around 14:00 and it drops during lunch and dinner hours at 12:00 and 18:00 respectively.

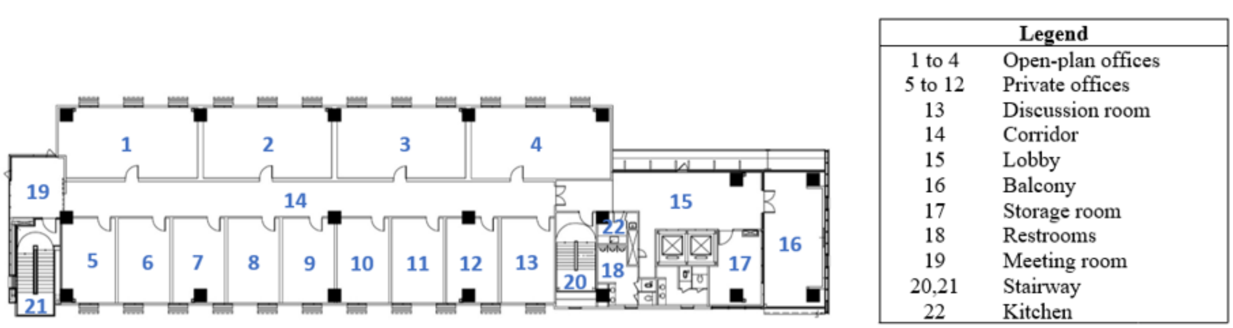
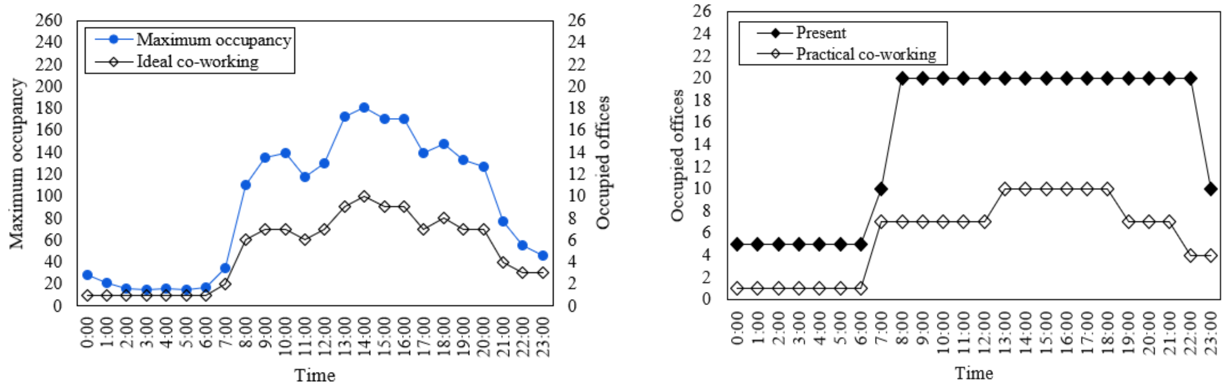


Figure 6 Typical floor layout



(a) *(b)*

Figure 7 Hourly occupancy schedules

In order to implement localized co-working spaces, one open-plan office is occupied until it is filled to capacity before arriving occupants occupy the next open-plan office. Figure 7 (a) also shows the ideal co-working space allocation whereby the number of occupied offices follows the occupancy trend. However, this would inconvenience the occupants since they would have to keep relocating to new work stations after every hour. The practical allocation shown in Fig. 7 (b) was therefore adopted to minimize this inconvenience.

Three occupancy schemes were designed to implement localized co-working spaces within the building. These schemes only targeted the office spaces and did not include laboratories and lecture rooms.

Scheme 1 - In this scheme, occupancy of private offices remains the same. Open-plan offices are converted into localized co-working spaces for graduate students.

Scheme 2 - In this scheme, half of private offices are retained for essential administrative functions. Occupants of the remaining private offices move to special co-working spaces with half the capacity of those in scheme 1.

Scheme 3 - All occupants share co-working spaces and private offices are eliminated. Permanent work stations within the co-working spaces are allocated for essential administrative functions.

Energy simulations were performed to investigate the impact of each scheme on HVAC, lighting and equipment energy consumption. The three schemes resulted in overall energy savings of 23% to 25%, as observed in Fig. 8. Lighting energy consumption was reduced by 15%, 16% and 22% in schemes 1, 2 and 3 respectively. Energy consumption by HVAC was reduced by 21%, 22% and 27% under schemes 1, 2 and 3, respectively. Occupants tend to leave their computers on throughout the day, including during periods when they are not in use. Co-working spaces limit computer usage to productive time, hence energy savings of around 25% are observed from equipment usage in the three schemes. The differences between overall savings between the three schemes were marginal. Scheme 1 appears to be sufficient and easier to implement.

Night-time computer usage

Equipment primarily consisting of computers consumed the highest amount of energy in the selected research building, as earlier observed in Fig. 5(c). Research students mainly perform computationally demanding tasks such as building modeling and simulation and artificial intelligence applications. As a result, high performance computers (HPCs) are preferred to facilitate faster task completion. However, HPCs are also high-power consumers (Chen et al., 2020). An initial assumption was made that replacing the energy intensive HPCs with low consumption PCs would significantly reduce energy consumption. An experiment was therefore performed to compare energy consumed to complete the same simulation tasks between a commonly used Assembled HPC and a less energy intensive HP Elitedesk 800 G3. Table 3 shows the specifications of the two computers.

DesignBuilder allows users to run multiple simulations concurrently, thus it was possible to monitor the increase in electricity load with increasing computational load as more simulations were added. A total of seven similar simulation tasks were run on the two computers and energy consumption was measured using an energy meter. Despite the lower rated power of the HP Elitedesk 800 G3 as shown in Fig 9 (a), overall energy consumed to complete the tasks was 36% more than the HPC. Simulation time using the HPC was also almost three times faster.

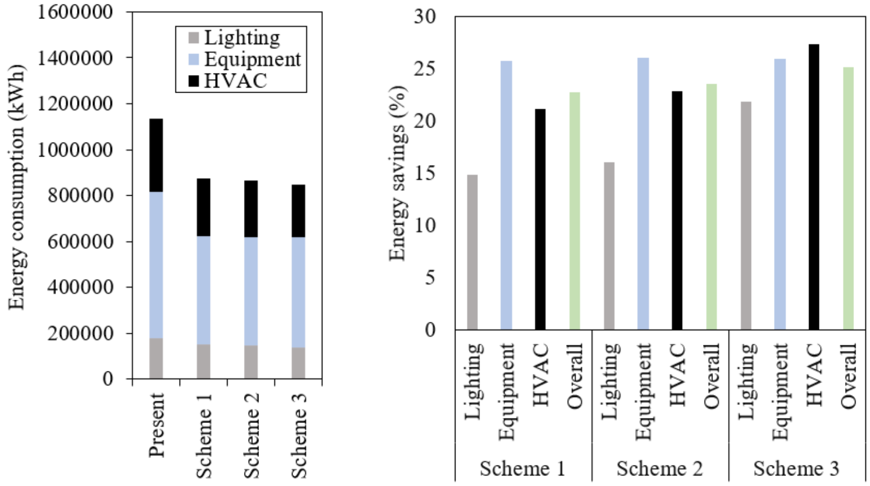


Figure 8 Energy consumption and savings from localized co-working spaces

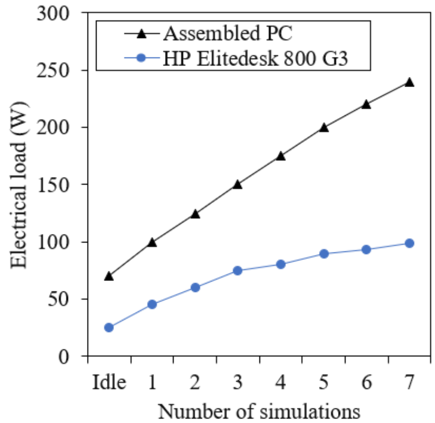
Since replacement of HPCs with less energy intensive computers proved to be ineffective, a lifestyle change scenario was developed whereby research students run their simulations during low occupancy night time hours. The centralized HVAC system in the building is switched off at 21:00, hence running the simulations during night time hours will reduce the impact of thermal load from the computers on HVAC energy consumption. Since simulations often take long periods of time, the occupants are not required to be physically present. They can set up their simulations before leaving the building at 21:00 and let them run through the night. A radiant fraction of 0.2 was assumed for the computers. This lifestyle change resulted in a 13% reduction in HVAC energy consumption and a 4% reduction in overall energy consumption, as observed in Fig 9 (b).

Increasing air conditioning setpoint temperature

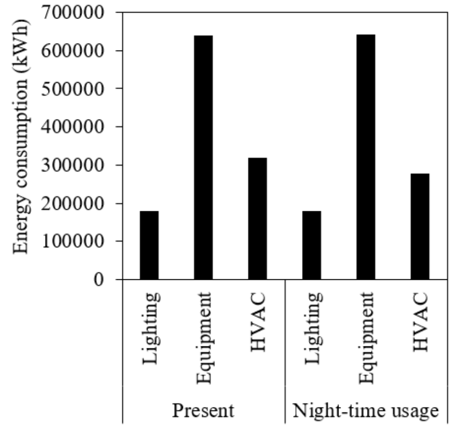
The survey revealed that office occupants set their thermostats at an average of 24°C. Simulations were performed for scenarios with increased setpoint temperature ranging from 24°C to 27°C, as shown in Fig. 10. Raising setpoints from 24°C to 27°C could reduce HVAC energy consumption by 20% compared to the present case. Overall energy savings of 6% can be achieved with a setpoint temperature of 27°C. More efficient units with higher COPs could provide further savings. However, it should be noted that the decision to upgrade existing HVAC systems does not fall on the occupants but rather on the university's administration. It is therefore not directly linked to the lifestyles of the occupants.

Table 3 Specifications of selected low and high-performance computers

	HP Elitedesk 800 G3	**High performance assembled PC**
Processor	Intel Core i7-7700 3.6GHz	13th Gen Intel core i7-13700K 3.4GHz
RAM	16GB	64GB
GPU		NVIDIA GeForce RTX 3060
Electricity load in idle state (W)	25	70
Time to complete simulations (Minutes)	55	21
Energy consumed to complete simulations (kWh)	0.11	0.07

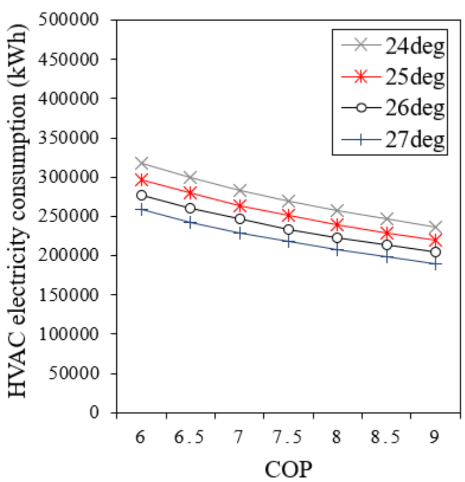


(a) Electrical load during simulations

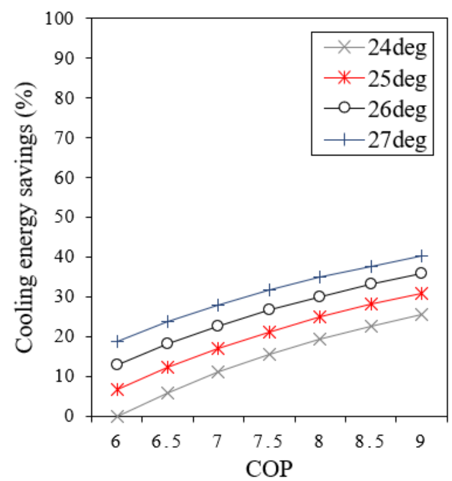


(b) Annual energy consumption

Figure 9 Energy consumption from computer usage



(a) Energy consumption by HVAC



(b) Cooling energy savings

Figure 10 HVAC energy consumption and savings

Conclusion

This paper examines the energy reduction potential of lifestyle changes and emerging workplace trends in a university building. Through survey data, usage of space and plug loads by occupants was determined. These were adopted as inputs for energy simulation using DesignBuilder. Inefficient space and computer usage were identified as the most consequential drivers of energy consumption in the building. Three scenarios were formulated to address these key areas.

The energy saving potential of implementing localized co-working spaces was investigated using three occupancy schemes. These schemes were aimed at enhancing space management between private and shared open-plan office spaces. The number of shared offices in use at any given time was adjusted to follow hourly occupancy in the building. This reduced the energy usage during periods of low occupancy since only the required offices were occupied. Energy savings from the three schemes were comparable hence either of them would be effective, reducing energy consumption by 25%. Localized co-working spaces proved to be the most effective at reducing energy consumption. They also freed up extra space that can be utilized for other functions.

Equipment usage was responsible for most of the electricity consumption. It was experimentally determined that downgrading from high performance to low performance computers was not effective at reducing energy consumption, since HPCs reduce computational time thus consuming less energy for overall task completion. A scenario was developed for nighttime computer usage which reduced the thermal load from computers on the HVAC and saved 4% of overall electricity consumed. Another lifestyle change investigated was increasing air conditioning setpoint temperatures which reduced energy consumption by 6%. However, these lifestyle changes are coercive in nature and therefore further investigation is required to determine how receptive the occupants might be to radical alteration of their normal lifestyles. It is also essential to cultivate energy-saving awareness in order to motivate occupants to change their lifestyles.

Future work

The results of the study revealed that changes in lifestyles of occupants yield significant energy savings. However, we did not examine the ease of implementation of suggested changes and the willingness of the occupants to alter their preferred conventional lifestyles. We will expand the study to propose interventional strategies that are likely to succeed at providing an enabling environment for occupants to change their lifestyles without compromising their comfort and well-being.

It was also observed that energy consumption within the research building was mainly influenced by energy intensive computer usage to perform computationally demanding modeling, simulation and artificial intelligence tasks. We are currently expanding the study to compare the computational energy performance and requirements of common software preferred within the civil engineering field. We aim to provide task-based recommendations of the most energy efficient software and quantify the energy savings that will result from their usage.

Emerging workplace trends have had a noticeable impact on the nature of work. Several studies have indicated that these trends are bound to become the norm. We therefore intend to examine the energy and environmental impact of trends such as online learning, virtualization of work and cloud computing, within both residential and office contexts.

Acknowledgment

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