



Quantifying Human-Activity Energy Contributions for Sustainable Campus Building Design

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Abstract. The movement of students in the corridors and on the staircases generates electric power from each step. In order to analyze this possibility of energy generation, researchers conducted a study over five working days at the busiest locations. Researchers examined the time and the number of people present, temperature, light, CO₂ levels and the total number of steps using mobile phones every five minutes. The results reveal that walking and climbing generate about 0.053kWh/week, which is less than 0.01% of total energy consumption of the building (2877kWh/week) and that walking brings additional heat amounting to 80-100W/person during periods of activity. Even though the impact of activity is utterly trivial in respect to the electricity produced by the student flow, the new approach improves building energy models.

Keywords: Building energy performance, campus architecture, human metabolic heat, occupancy monitoring, thermal load measurement

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1. Introduction

Campus buildings are of a specific type that are highly frequented and where energy demand varies according to the operation schedules and human behavior [1], [2], [3]. Buildings of educational institutions have a huge impact on the amount of energy consumed around the world. Life in these campuses relies greatly on such places as common rooms and lecture halls causing a significant increase in the amount of electricity used. In places with hot tropical climates, the problem is even more crucial. Campuses must cope with climate needs such as cooling and air circulation. As a result, the concept and management of a campus are largely based on energy efficiency [4], [5], [6].

Many energy models for schools focus on heat gain from the outdoor environment as well as on indoor objects such as lights, machinery, and HVAC equipment [7]. However, the impact of people's

movements within these spaces has not been adequately studied as a source of energy that can be harnessed. Everyday movements, such as walking down hallways or climbing stairs, can generate mechanical energy, but this is rarely measured. Consequently, many building energy studies overlook the significant role that energy generated by occupants can play. This gap is most common in high-traffic areas used for circulation [8], [9], [10].

In their earlier work, Yiqing Liu and his colleagues, Zhiwen Luo and Sue Grimmond, have reconsidered the definition of anthropogenic heat flux in buildings known as QF,B. They reported that QF,B is not synonymous with energy consumption (QEC). The reason behind the two measures opting to differ from each other is the impact of storage heat fluxes induced by human activity. The comparison of the values of the two measurements was done using EnergyPlus simulations, and the authors observed noticeable variations within the measures of QF,B and QEC. In certain cases, QF,B is even in the negative. The negative value means that heat is preserved by a building. It is also possible to note that the authors concentrate on the impact of human activity, building management processes, and weather on heat production [11], [12], [13].

Another study suggests that implementing dynamic metabolic equivalents into models of thermal comfort may improve smart building HVAC regulation according to what individuals occupy a place at any given moment. The energy consumption of buildings was reduced by 14%, while the comfort level of users remained at almost the same level. Thus, it is understood that HVAC should rely on metabolic data in real-time, instead of static assumptions. However, there are some reservations about that approach and in-depth research is needed with a lot of data collected about various kinds of activities. Involving reinforcement learning methods may also be helpful, as this approach enables a better optimization of energy control over time [11], [12], [13].

The research by Mahmood identifies the concept of active learning through the use of various learning models for evaluating the heating and cooling demands. The different learning models used to achieve accurate predictions include: Random Forest, Decision Tree, Gradient Boosting, XGBoost, CatBoost, LGBM, KNN, and Logistic Regression. Data preprocessing in the form of Z-score normalization is employed prior to training, and the dataset is split into sets for training and testing. To obtain the predicted results shown in table 6, results are quite impressive. The suitable R² value for cooling is 0.9975, whereas for heating, the R² value is 0.9883. It can be concluded from the research that improved predictive tools can enhance the energy efficiency that will lead to a reduction in energy consumption, reduced operational expenses, and improved green building management through increased sustainability [11], [12], [13].

Zhou applied the Boosted Regression Trees and Structural Equation Modeling techniques in order to analyze the spatiotemporal variation of UGCSC in Beijing over the period from 2000 to 2020. The study determined the importance of each factor, including climate change and human activity with relation to the changes. The findings indicate an increase in UGCSC over 74.2% of the territory viewing the research. Human activity proved to be the major factor with a 50.7% contribution. Climate change turned out to be the primary factor, which caused 24.6% of all changes. At the same time, the interaction of climate and human activity factors causes 24.8% influence on the results.

The research revealed the fact that several significant factors do not behave comparably in various places. Temperature, elevation, slope, and landscape structure work differently in various locations. Among these factors, the temperature has the highest impact on urban areas. The influence of human activity on urban green carbon involving both positive and negative results is also evident [11], [12], [13].

Most prior research has not found a definitive method to link these three aspects together in one unit. These three aspects include human activity behavior, behavioral patterns of motion in buildings and the conversion of mechanical energy into electrical energy. It is known that previous research simply dealt with subjects like heat transfer, human metabolic processes and energy volume calculations. They did not unify those subjects in a systematic method, as it is done in the paper. The indicated paper helps to accomplish that by formulating a system consisting of analysis of people's behavior, mapping movement patterns of people in the buildings as well as calculating energy consumption at each step

with the help of piezoelectric sensors. The paper deals with campus buildings aiming at integration of human energy consumption into the building efficiency assessment process making it more precise and accurate. Besides, this method enhances decision making in the field of building design and construction allowing to decrease energy consumption.

This method has four steps. In the first step, user occupancy is estimated based on the activity categories/class schedules. The second step is to locate areas involved in walking and fast circulation. In the third step, energy requirements in relation to operational equipment utilized during occupancy are identified. Finally, in the fourth step, the frequency of steps is estimated along with the energy consumed for every step. The method involves conducting field tests with the use of a piezoelectric prototype.

As per the research hypothesis, one important thing is that it proposes that places characterized by congregated movements may produce mechanical energy that can be measured. In the second regard, combining location data, time data, and behavioral historical data can help researchers estimate the energy produced by the occupants more reliably than before. The study fills a gap in the existing literature, providing a framework for other teams to depend on. The focus is on how to integrate the generated energy into the evaluation of buildings performance, which is most applicable in case of learning spaces in hot climates.

2. Methods

2.1 Case Study Description

This research was conducted in a multi-story campus building. Most of the rooms in the building are used for teaching and learning activities. This analysis focuses on the paths most frequently traveled by people. These paths include corridors used to move from one side of the building to the other and staircases for going up and down. The building's area is approximately X square meters. This value can be adjusted as needed. The building faces north and south. Reinforced concrete is the primary material used in the building's structure. The selected circulation areas are those where occupants move most frequently. These areas also offer the best opportunities for energy efficiency.

2.2 Instrumentation and Data Collection

The study collected data using several environmental and presence monitoring devices. A DHT22 sensor was used to measure temperature and humidity. The stated accuracy is $\pm 0.5^{\circ}\text{C}$ for temperature and $\pm 2\%$ RH for humidity. For CO_2 levels, the study used an MH-Z19B sensor with an accuracy of ± 50 ppm plus 5%. To measure light, used the BH1750 sensor, which has an accuracy of ± 1 lux. To detect human presence, added the HC-SR501 PIR sensor. Additionally, study used a smartphone app with an accelerometer to record the number of steps.

Prior to any measurements being taken, a standard reference device was utilized to calibrate each sensor. This was necessary to avoid any error in the collection of the data. The frequency of measurements was 5 minutes. The data was collected over varying lengths of time, from a period of one day to one full week. The aim was to see how changes in conditions and activity occurred over time. The sensors were installed in places such as stairwells and corridors. These locations were identified based on results from Space Syntax, which allowed for the identification of locations with high levels of movement.

Initially, the study involved identifying possible utilization areas. The aim was to find out the extent of the usage of the corridors and stairwells by people moving around. To achieve this, the analysis of the building's floor plan was carried out. Subsequently, space syntax metrics were used to analyze the pathways followed. Among them are the connectivity and the visual integration metrics [4], [14], [15], [16], [17]. On the basis of the findings, the shares of the main zones were identified. These zones have high levels of movement activity. Therefore, this information is used to choose the appropriate places for the installation of energy conversion technologies and devices.

The second step has been effective in calculating the number of users in a practical way. It was determined in the study that the effective number of users can be obtained by collecting data regarding

the actual users with respect to their category (for example, they can be students, faculty members, or staff) and then matched with the activity schedule of these users. Furthermore, space analysis was used to determine the percentage of the actual potential area occupied by users [18], [19], [20].

The third step is where calculations for electrical load begin. At this point, all of the equipment used in the study is compiled. This includes tools such as air conditioning systems, LED lights, computers, water dispensers, and projectors. The next step is to determine the wattage of each item, as well as the amount of time that it runs on a weekly basis. Then, weekly energy consumption is determined. At this time, the energy requirements for the building can be determined. The electricity bill of the faculty must also be checked in order to ensure that calculations of electrical usage correspond to the actual amounts used.

Fourthly, there is measuring the frequency of steps [9], [21], [22]. The data is collected through observations done with a step counter available on the smartphone during the operation hours of the university. The observations are conducted along the representative paths located on the ground floor as those have a similar approach to the paths of other floors thus they will be used as the reference measures. According to the results of the measurement, the average step size is about 0.78 meters, and the number of steps varies from 270 to 350 per day thus the average measure of 300 steps per user per day has been taken. For stair climbing, the observations of the route from the ground floor to the fourth floor reveal 89 stairways used as the average number of steps per user.

The fifth step is the characterization of piezoelectric output [23], [24], [25]. Laboratory test results showed that the piezoelectric prototype produced a peak power of 1.2 W at an average user load of ± 70 kg. Taking into account the contact time of 0.4–0.5 seconds in walking and 0.8–0.9 seconds in climbing stairs, a more representative average power value is used to calculate energy per step. Based on these calculations, walking activities generate about 0.48–0.60 joules per step, while climbing stairs generates 0.96–1.08 joules per step. The energy value per step is used in estimating the energy contribution of buildings, because it is more relevant than the peak power value which is only momentary.

2.3 Sampling Design

An effective sampling plan needs to take into account the general tendencies of movement of people around different regions of the building. The first step in this regard will involve the selection of the locations of observation basing on the examinations of the ground floor's main hallways and stairs. These locations are highly utilized and inform about how people are used to moving about the building. The next step would be choosing the time of observation. For example, it can be set at hours of operation of the institution, from 8 a.m. to 5 p.m., during which periods people are most active. The observations would be conducted for five working days to avoid fluctuations in movements from day to day. The level of occupancy of the building was determined according to the categories of people who resided there, including students, teachers, and employees.

2.4 Data Processing and Energy Conversion

The estimated total daily energy is calculated using the formula:

$$E = V \times I \times t \times N \quad (1)$$

E signifies the total energy conversion expressed in joules. V denotes the output voltage in volts from the sensor. I represents the output current from the sensor in amperes. t refers to the time of contact per step in seconds. N represents the number of active user steps per zone within a day. The study therefore applies the same concept to measure the potential energy from walking and climbing stairs through each zone. The concept also explains the basis for establishing the link between the measured energy and actual energy consumption in their area. This concept is applicable in determining the efficiency of circulation areas. Thus, this idea can serve as assistance for the development of renewable energy systems that rely on human activity.

2.5 Control Variables

The study also examined various influences such as temperature outside and solar radiation. The research noted the process where the fresh air comes inside the premises both naturally and through mechanical means. Besides, data on electricity usage and heating and air conditioning system operations were collected. These parameters were necessary in order to take into account outdoor environmental conditionals and everyday operations to eliminate bias.

2.6 Analytical Framework

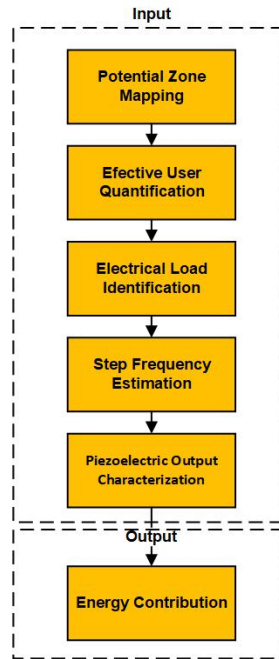


Figure 1. Framework for Measuring Human Activity Energy Measurement Methods

This framework consists of five stages that can be used multiple times. However, additional studies need to modify the template to buildings used in research. Buildings are all unique in terms of configuration. The way rooms are designed can have an influence on the way a crowd moves inside the building. Also, the users of a building have different preferences and habits. The hours during which people use a building influence their behavior inside of it.

The electricity consumption also differs for various types of buildings. Some buildings are equipped for a high load but others are different. Due to these differences in buildings, the framework will provide different levels of activities and electricity consumption for each building. Nevertheless, this approach can be applied to different buildings.

2.7 Validation

The validation process involved building energy simulation tools EnergyPlus or DesignBuilder, as well as comparing the results with real building energy consumption information. This validation method guarantees the validity and accuracy of the suggested method for measuring energy contributions attributable to human activity in total building energy performance.

3. Results and Discussion

Spatial analysis with the Space Syntax approach (connectivity and visual integration parameters) showed that only 34.45% of the corridor area was included in the category of zones with high potential for users to pass, while the remaining 65.55% was classified as low. The area of this potential zone averaged 153.5 m² out of a total horizontal circulation area of 442 m². This proportion is the basis for

determining the distribution of effective users, i.e. individuals who are actually active in strategic zones and contribute to energy conversion through footrests. Out of a total of 840 building users, calculations show that only about 290 people can be categorized as effective users. This distribution also takes into account the use of stairs, where the main staircase (high zone) is used by about 70% of users due to its strategic access to the classroom, while the right-side staircase is used by 20% and the left-side staircase is used by 10% of users.

Table 1. Potential Zones and Effective Users

Parameters	High Zone (m ²)	Medium Zone (m ²)	Total Area (m ²)	Potential Zone %	Total Users	Effective Users
Connectivity	68	111	179	40.0		
Visual Integration	30	98	128	28.9		
Average Potential zone %				34.45 %		
Regular Class					336	116
Evening Staff Class					252	87
Morning Staff Class					252	87
Total					840	290

This table presents the results of the spatial study and the method used to process user count data. It also shows a clear relationship between the area of potential zones and user locations. Therefore, these figures can be used to calculate how much energy is generated from walking and climbing stairs.

The energy consumption of such entities depends on the number and type of devices in them, such as air conditioning systems, LED lamps, computers, water coolers, and projectors. According to calculations, the highest weekly consumption of energy belongs to the regular classes - 2,488 kWh. The employees of the evening shift rank second with the consumption of 197.76 kWh, followed by those of the morning shift with the consumption of 191.36 kWh. The total for these three groups is 2,877.12 kWh. After accounting for the breaks of lessons and energy-saving measures, the effective weekly consumption is roughly 2,013.98 kWh, which aligns with the number on the monthly bill. Thus, this number can be taken as a benchmark for gauging the impact of energy consumption.

Table 2. Quantification of Electricity Demand

Class Type	Operational			AC 60/1400 W (Units)	Lamp 240/40 W (Units)	Computer 15/300 W (Units)	Dispenser 15/500 W (Units)	Projector 12/300 W (Units)	Energy Consumption KWH
	Days (Per Week)	Hours (Per Day)	Hours (per week)						
Regular	5	8	40	31	80	15	15	12	2.488
Evening Staff	2	4	8	12	48	3	3	12	197,76
Morning Staff	1	8	8	12	28	3	3	12	191,36

The table shows how much energy is used each week in campus buildings. It compares three types of classes. The number of steps was calculated by observing a person walking during a trial. A step-counting app was used on individual phones.

On the hallway route, the average stride length was 0.78 m. The step frequency was 1.33 Hz. Each step took about 0.75 seconds. Three route lengths were used to estimate movement. For a distance of 40 m, there were 55 steps. For a distance of 70 m, there were 80 steps. For a distance of 20 m, there were 41 steps. This resulted in a daily total of approximately 270 to 350 steps. Therefore, this study used 300 steps per person per day as a substitute for running activity.

Regarding stair use, the main staircase was observed from the ground floor to the fourth floor. Each trip involved 89 active steps. This study only counted the activity of climbing stairs. The reason given was that the ground reaction force is higher and more stable when climbing stairs than when descending them. For this component, the total daily steps per person were set at 89 steps per day.

The daily number of steps for walking activity is derived from a combination of realistic trajectory frequencies in a single day of operation. The model is written as:

$$L_{\text{walk}} = 55 f_{\text{A}} + 80 f_{\text{B}} + 41 f_{\text{C}} \quad (2)$$

With f_{A} , f_{B} , f_{C} , is the frequency of the A/B/C route per day. With a moderate pattern reflecting arrivals - transfers between rooms - facility visits ($f_{\text{A}} = 2$, $f_{\text{B}} = 2$, $f_{\text{C}} = 1$) are obtained:

$$L_{\text{walk}} = 2(55) + 2(80) + 1(41) = 311 \text{ steps/day} \quad (3)$$



Figure 2. Step Frequency Quantification

The results of walking tests in the corridors of the Engineering Faculty are illustrated in Figure 2. The graph represents three normal paths. The map marks the starting and ending points of every trip. It also indicates the values like the total distance, the number of steps, and the duration of the trip. The remaining values include the length of a stride, the step frequency, and the time to take a step. The mentioned paths are the same for all measurements. In general, one person walks around 300 steps a day. This information helps make an estimation of the energy consumption of the steps in the future.

The trial of the piezoelectric prototype showed a maximum power output of 1.2 W. This value translates into about 0.48 to 0.60 J per step while walking. The number doubles when the process of climbing the stairs comes into play and equals approximately 0.96 to 1.08 J per step. Other variants of the system have shown the results of 5 to 10 W per step. Compared to other configurations, this output is significantly lower. It means that the present system works on a smaller scale. However, this paper does not trace the possibilities of implementing this idea in practice.

Based on estimates of how many active users there are at one time, as well as the rate at which people make use of steps at the same time, it was discovered that energy generation per week is 0.0529 kWh,

which accounts for just 0.0018% of the building's consumption of energy amounting to 2,877 kWh. This value also corresponds to the 0.0026% of the effective energy consumption amounting to 2,014 kWh. Speaking of the area, this value is about 0.00002 to 0.00003 kWh per square meter per week, which is quite a small amount that does not greatly affect the overall demand for energy. Nevertheless, it is to be noted that the users still have an impact on comfort conditions in the indoor environment.

Further assessment has shown a clear positive correlation between occupancy level in any given room and some internal conditions. The relationship is particularly well established as far as air temperature and carbon dioxide concentration in the air are concerned. So, when a room experiences its peak occupancy level, the amount of the air temperature goes up along with CO₂ concentration. With more people in the room, the need for ventilation rises. An hourly evaluation of the results shows that the most important impacts as far as energy consumption and heat produced by human bodies is concerned, happen around the mid-day, from 10:00 a.m. to 2:00 p.m.. It is also the time when the building is being used the most vigorously. Therefore, it can be concluded that the level of crowding in any of the examined locations has a huge influence on the shifts in energy consumption. However, the results obtained in this case cannot actually be used to support the oversimplified idea that energy requirements can simply be replaced by energy inputs.

The study reveals that the organization of a space impacts energy levels. When the paths of circulation are effectively bridged, people tend to travel more often through those spaces providing ample opportunities to recover energy. The design of the building is important. The position of windows determines the amount of sunlight that comes into the space. The paths of airflow in ventilating space help to circulate heat in the room. The materials of walls and floors that accumulate heat can make the warming process faster or slower.

Table 3. Weekly Energy Contribution and Consumption (Actual and Effective)

Class Type	Walking Contribution (kWh)	Stair Contribution (kWh)	Total Contribution (kWh)	Energy Consumption (kWh)	Effective Consumption (kWh)	Current Comparison (%)	Comparison on Effective (%)
Regular Class	0.023	0.013	0.036	2,488.00	1,741.60	0.0014 %	0.0021 %
Evening Staff Class	0.007	0.004	0.011	197.76	138.43	0.0056 %	0.0079 %
Morning Staff Class	0.0035	0.002	197.76	138.43	0.0056 %	0.0029 %	0.0041 %
Total	0.034	0.019	0.053	2,877.12	2,013.98	0.0018 %	0.0026 %

While electricity performance makes up only a minor portion of total energy consumption, the integration of human conduct in energy models can facilitate more accurate assessments of buildings. With the emission factor of around 0.85 kg of CO₂/kWh, current electricity production would lead to a very slight decrease in emissions. However, with the application of this method in buildings with high floors or excessive occupancy, results can become more considerable.

The results of scientific research show that by using piezoelectric energy only, the output would still be small in micro scale. However, this method creates a link between the behavior of inhabitants, the layout of premises, and the quality of energy generation by a building. This may support further projects, where design choices and concepts of using energy in conjunction with realistic behavior models will create prominent effects in practice.

4. Conclusion

The findings of the study indicate that human activity can play a significant role in an edifice's electricity consumption, even at a micro level. It also demonstrates the importance of considering human activity

in assessing energy performance because this will lead to more comprehensive results regarding energy performance in buildings. In addition, occupancy and load models should give better results if data can be gathered regarding the layout of rooms in the building and data on behavior and activities occurring in the building. Proper use of these parameters can lead to more accurate predictions regarding the use of energy. Moreover, they can help in making design solutions more environmentally friendly on campus. This study aims at linking engineering and architecture horizons. To make this possible the study incorporates human activity data into different stages of development of an energy model. Besides, it is important to note that the research showcases the influence of spatial design on passive energy advantages, especially in circulation zones.

There were limitations to this study. Data were collected over a short period. It considered only one climate; hence, results may not be generalizable. More research is needed. Research should be done to test these concepts with an active sensor network. More exploration in future research should be focused on predictive models based upon machine learning. Validation should involve other buildings and be done across more than one climate region. These steps can facilitate human activity energy modeling in diverse types of building environments.

Declaration of AI and AI-assisted technologies in the writing process

In writing this text, the authors utilized ChatGPT to improve language accuracy. Moreover, the authors used ChatGPT to check and improve grammar, syntax and writing clarity. They then reviewed the work carefully and made necessary changes to it. Any responsibility for the text lies with the authors.

Declaration of Competing Interest

The article was then reviewed meticulously enough to accommodate all relevant changes to it. The authors take responsibility for the content of the article.

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