Correlations between energy, water, and waste consumption of residential buildings for community demand understanding and management of Smart Village

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Abstract

This research study aims to investigate the Correlations between energy and water consumption data in residential buildings and waste generation. The objective is to gain valuable insights that can contribute to sustainable community demand management practices. Data analysis was conducted on a selection of six residential buildings to identify patterns in energy and water usage, as well as waste generation, and to explore the correlations between these three variables. The findings indicate that buildings of the same type exhibit similarities in energy and water consumption patterns, as well as waste generation. However, variations exist due to individual building demands, user behavior, and occupant characteristics. The analysis further reveals a strong correlation between energy and water usage, while the association between waste generation and energy or water consumption shows less consistency. It was observed that activities requiring long-duration energy consumption have a positive correlation with waste generation, whereas the relationship between shorter activities and waste generation exhibits variability. Additionally, the analysis of the data reveals significant correlations between some activities and energy, water, and waste, while others do not show such correlations. This research provides valuable insights into the interrelationships among energy and water consumption data in residential buildings and waste generation, enabling individuals to make informed decisions aimed at reducing their environmental impact and promoting sustainability. Moreover, the findings contribute to the development of sustainable community demand management practices that address the challenges associated with urbanization and population growth.

Keywords:

Community Smart Village; Energy-Water-Waste Correlations; Behavioral Demand

1. Introduction

Residential buildings are major contributors to the consumption of energy and water and the generation of waste. As the population grows and urbanization continues, the demand for energy, water, and waste management increases. Therefore, it is crucial to study the correlations between these three elements to manage the community's demand effectively.

The interdependence between energy, water, and waste factor in residential buildings is a complex and crucial issue. Studies have shown that there is a strong correlation between energy & water consumption and waste generation in residential buildings. The amount of energy used in a building is highly correlated with water consumption and waste generation. Water is a crucial resource for human survival, and its availability is rapidly decreasing. The excessive consumption of water in residential buildings not only affects the availability of this resource but also has a significant impact on energy consumption. Additionally, waste generation is highly correlated with energy and water consumption in buildings. In residential buildings, household energy savings activities are related to human life activity, and energy & water consumption, and waste generation data [1], [2]. The correlations between the energy, water, and waste data are affected from the building activity such as water heaters for bathing [3] – [7], energy and water consumption for cooking and eating in addition to waste generation [8] – [10]. A reduction in water usage can lead to a decrease in energy consumption as it reduces the amount of energy needed for water heating and treatment. Additionally, the implementation of waste reduction strategies such as recycling can lead to a decrease in the volume of waste generated and hence, a reduction in the energy required for waste disposal.

Understanding the correlations between energy, water, and waste factors in residential buildings can enable more effective management of community demand. By identifying areas where consumption is high, building owners and managers can implement energy-efficient technologies and sustainable practices to reduce consumption and minimize environmental impact. These efforts can also lead to cost savings and contribute to the overall sustainability of the community. Hence, this study aims to study the correlations of resident building energy, water, and waste factors for understanding resource demand and managing them appropriately to provide insights into sustainable management practices for the Smart Villages.

2. Experimental detail

To investigate and analyze the intercorrelations between the three data sectors (energy, water, and waste), comprehensive data from the buildings is required, encompassing both the frequency and time dimensions of its occurrence. Such an understanding is imperative as the frequency and timing of data events reflect the activities within the building. The investigation of data correlations is divided into two phases. The first phase involves gathering data from each building through the installation of smart meters, while the second phase involves the analysis of the collected data to determine the intercorrelations between them.

In this study, 6 residential buildings are considered as the sample buildings of the residents in the community. The buildings are separated into three sub-groups: 2 general public houses, 2 schoolhouses, and 2 community hospital houses. For the general public houses, the first home (1st general public house: GH1) has three residents, two females, and one male, ranging in age from 21 to 60 years. The second home (2nd general public house: GH2) has one male and one female resident aged 51 to 70. For the school houses, the first home (1st school house: SH1) has three residents, one female and two males, ranging in age from 31 to 60 years, while the second home (2nd school house: SH2) has four female residents, ages 21 to 30 and 41 to 50 years old. For the community hospital houses, house 1 (1st community hospital house: HH1) has two female residents aged between 21 to 30 years old, and 2nd community hospital house (HH2) has two male residents aged from 21 to 40 years old. Smart meters (SM) are installed to collect the amount of energy & water usage and waste generated within the buildings to create the building activity profile. SM is used to measure and record the data every 15 minutes from the sample houses. SM for collecting energy consumption per time in kWh units, water consumption in liter units, and waste disposal in kilogram units. The data was collected for a total of 6 months (September 2022 – February 2023).

Data on activity behavior in household consumption patterns was collected through the use of a questionnaire structured into four sections. The first section pertained to the personal data of consumers, to group consumers, and to analyze how personal factors affect household consumption. Multiple-choice questions in this section included gender, age, education level, occupation, and average monthly income, and respondents were required to select from various options in each category. The objective of this section was to collect basic demographic information about participants to help categorize their consumption patterns.

The second section of the questionnaire focused on appliances within the household and collected data through a series of multiple-choice and open-ended questions that provided a list of household appliances such as light bulbs, fans, air conditioners, washing machines, irons, and televisions. This section aimed to collect information on the size, number, and usage patterns of household appliances. Respondents were also asked to provide information about the frequency and timing of household activities, such as turning on lights, taking showers, and washing dishes.

The third section of the questionnaire was concerned with collecting information on the time period of each activity. Respondents were required to complete a table checklist question on activity by time to obtain activity interval data from 0:00 – 23:30 hrs. with an activity interval frequency of 30 minutes. The activity in the table checklist question corresponded to questionnaire section 2 (II.III The frequency of household activities) and was used to identify the time and duration of each activity. Data collection was divided into two periods: activities that occurred on weekdays and those that occurred on weekends.

The data from the two sections were analyzed to determine the amount of energy, water, and waste generated during each activity. This involved comparing the peak load data for each time period with the building activities during the same time period. The usage quantity was then separated based on the data obtained from the questionnaire completed by each user in the building. Statistical methods were used in the process of analyzing the building activity profile, which entailed comparing various data formats related to energy, water, and waste. These data formats included the correlations between energy and water, energy and waste, water and waste, and energy, water, and waste. The objective of the analysis was to identify significant connections among these variables. The activity behavior in the building, which may affect the correlations between energy, water, and waste, was analyzed to understand the community's resource use during each activity, predict overall community demand, and analyze each building's activity behavior. The process of analyzing the activity behavior involved collecting data from surveys, energy and water usage, and waste generation to determine the timing and frequency of actual events in each activity. This was done by comparing actual maximum energy usage data for each day and determining the frequency of repeated events in each time period of the day from all data. The correlations among all three aspects of data are the Pearson correlation coefficient as a method that indicates the correlations and direction between two variables. The Pearson correlation coefficient ranges from -1 to +1, with values approaching ±1 indicating a strong correlation between the two variables. If the correlation coefficient is close to 0, it means that the two variables have weak or no correlations. The plus-minus sign (±) indicates the direction of the correlations. If the correlation coefficient is positive (+), it means that the two variables correlate in the same direction. If the correlation coefficient is negative (-), it means that the two variables correlate in the opposite direction [11], [12]. This research is divided into two parts: correlations between each component and the period of usage, and correlations between the quantities of resources used in all three aspects of the building and each activity.

3. Results and Discussion

Based on the analysis of community data, the data analysis model is divided into three components, which include data on community consumption and generation, the intercorrelations between each aspect and its usage period, and the correlation of resource utilization quantities across all three aspects over time.

3.1. Community Consumption and generation data

In terms of the energy sector, it collects data on the quantity of power utilized in each building. The total quantity of power consumed in the building every 15 minutes is what will be utilized to calculate how much electricity was used all day. Figure 1 shows the average energy consumption data profile collected at a 15-minute frequency within the GH1 with a smart meter. Overall, there are 2 significant periods of energy usage where 2 peak power consumption were observed. For the first period, it was found that the indoor energy consumption was low 0.10–0.12 kWh until about 6:00 when the energy consumption increased rapidly and decreased slightly until around 13:30. The energy consumption rate increased for the second period at 17:30 until the maximum daily energy consumption is reached. The daily average maximum used was 0.19 kWh at 19:00. The standard deviation (SD) average of period energy consumption is 0.11. The SD of the average household energy consumption data, on the other hand, is directly proportional to the amount of energy consumed in each period.

The energy usage characteristics within all buildings are similar to those in GH1, but the quantity of energy used differs. However, the benchmark values show a corresponding variation in energy usage. Data from Table 1 shows that the peak energy consumption occurred during the first period, with HH2 using the most energy at 8:00 AM with a usage of 182.01 Wh and an SD of 141.27, which is the highest value among all buildings. GH2 had the peak usage during the first period at 5:00, with a usage of 29.38 Wh and an SD of 45.50. In the second period, HH2 still had the highest energy usage at 19:30 with a usage of 137.12 Wh. When considering the minimum energy usage for each building, it was found that Building GH2 had the lowest average energy usage at 8.03 Wh and is also the building with the lowest average energy usage among all buildings, with an average usage of 14.01 Wh.

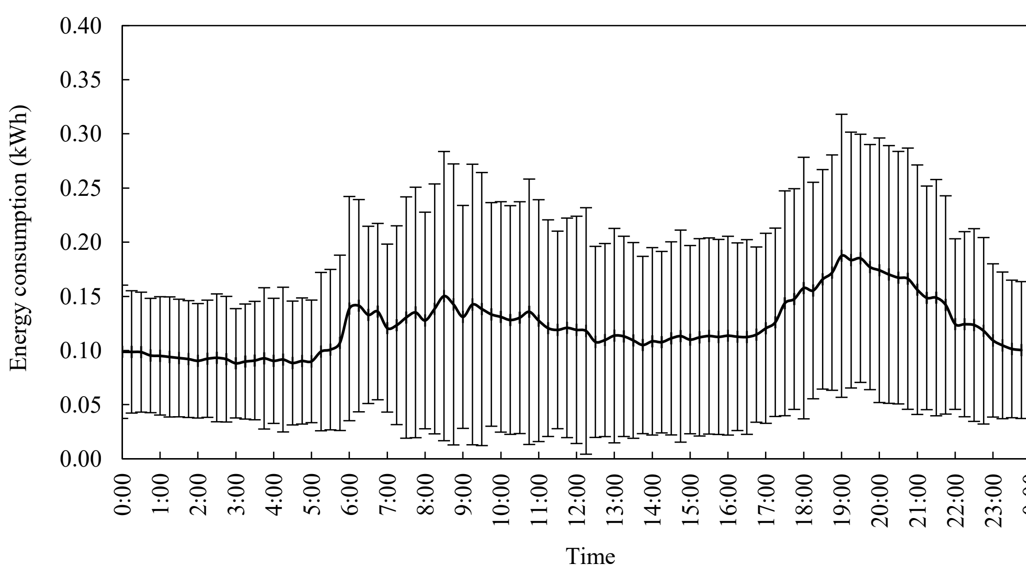


Fig. 1 The average data of the energy consumption profile of GH1 (6 months).

Table 1 Peak period for the community energy consumption data.

Building	1st peak period			2nd peak period			Min (Wh)	SD	Average (kWh)	SD
	Time	Max (Wh)	SD	Time	Max (Wh)	SD				
GH1	08:30	150.24	133.53	19:30	185.11	114.57	88.18	50.47	122.58	89.45
GH2	05:00	29.38	45.50	18:30	37.27	55.46	8.03	12.41	14.01	21.61
SH1	06:45	48.84	77.59	19:00	53.54	78.92	10.39	16.14	22.98	31.12
SH2	06:30	73.21	87.12	19:45	76.41	85.79	23.47	27.70	43.64	53.02
HH1	01:30	67.49	106.41	22:45	64.45	96.31	20.73	27.16	35.61	50.03
HH2	08:00	182.01	141.27	19:30	137.12	113.02	30.43	18.86	66.56	51.32

Water consumption within buildings has profile characteristics similar to the energy consumption profile within buildings in that there is a maximum amount of usage or a peak frequency of water usage in two time periods (Figure 2). The first period has high water usage between 6:00 and 8:00, and the second period is between 17:00 and 22:00. Building HH1 has the highest average water usage within the building. The highest average amount of water usage within the building is during the first time period at 7:45, with an average water usage of 84.47 l, and during the second time period at 19:15 with a water usage of 66.67 l, with an SD value of 66.51 and 50.42, respectively. The lowest average water usage within this building is still higher than the lowest average water usage in other buildings, which is 35.07 l, resulting in an average water usage of 49.41 l for this building. The standard deviation value is 34.69. GH1 is the second-highest building in terms of average water usage during time period one, with a water usage of 66.57 l and an SD value of 58.05, and SH2 has an average water usage of 51.57 l and an SD value of 53.30 during the second time period. When considering the water usage of all six buildings, during the first time period, buildings GH2, SH1, SH2, and HH2 have very similar high average water usage values of 39.28, 38.76, 37.42, and 33.39 l, respectively. However, during the second time period, the buildings have different maximum average water usage values, with building SH1 having a water usage of only 16.84 liters and the lowest average water usage of 7.96 l per 15 minutes with an SD value of 8.12. The peak water usage data for all six buildings are detailed in Table 2.

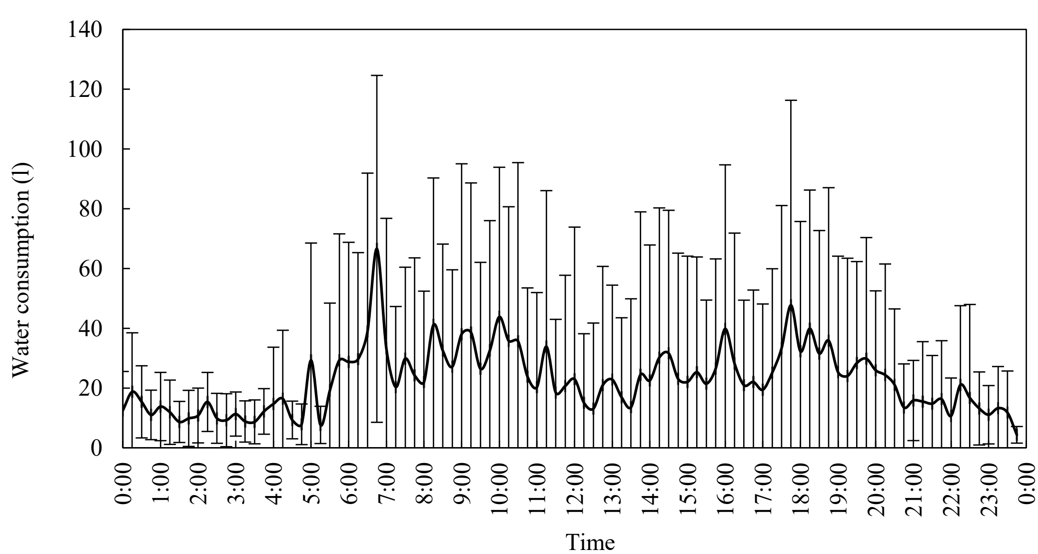


Fig. 2 The average data of the water consumption profile of GH1 (6 months).

Table 2 Peak period for the community water consumption data.

Building	1st period			2nd period			Min (l)	SD	Average (l)	SD
	Time	Max (l)	SD	Time	Max (l)	SD				
GH1	06:45	66.57	58.05	17:45	47.69	68.60	4.33	2.78	22.59	30.32
GH2	05:45	39.28	56.60	20:30	25.32	21.57	0.08	0.02	9.18	7.05
SH1	07:00	38.76	27.50	20:30	16.84	17.66	3.06	2.46	7.96	8.12
SH2	06:45	37.42	35.86	21:00	51.57	53.30	6.15	6.26	15.30	18.48
HH1	07:45	84.47	66.51	19:15	66.67	50.42	35.07	21.20	49.41	34.69
HH2	08:00	33.39	45.53	19:45	32.95	35.55	5.77	3.79	15.58	14.94

The characteristics of waste generation for each type of waste within a building are shaped by the patterns of disposal and the average quantity, which are somewhat correlated with the energy and water usage within the building. The occurrence of waste generated within a building can result from various behaviors that affect waste disposal patterns. The frequency of waste generation within a building is highest during two periods of the day, which are the morning and evening, as these are the times when occupants are engaged in activities inside the building, and it reduces during midday when there are fewer people inside. Additionally, the differences in waste generation among buildings are dependent on the characteristics of the occupants within those buildings. Moreover, the frequency of waste generation is variable and has a direct impact on the quantity of waste generated. In other words, the high frequency of waste generation during a particular period resulted in a relatively low quantity of waste generation. From Figure 3, which illustrates the accumulated waste generation within GH1 at a frequency of 15 minutes, it can be observed that general waste has a high quantity of waste generation but a lower frequency than the other two types of waste. Additionally, organic waste has a high frequency of waste generation but a low quantity, whereas recyclable waste has a high quantity of waste generated during a specific period, approximately from 19:30 to 23:30.

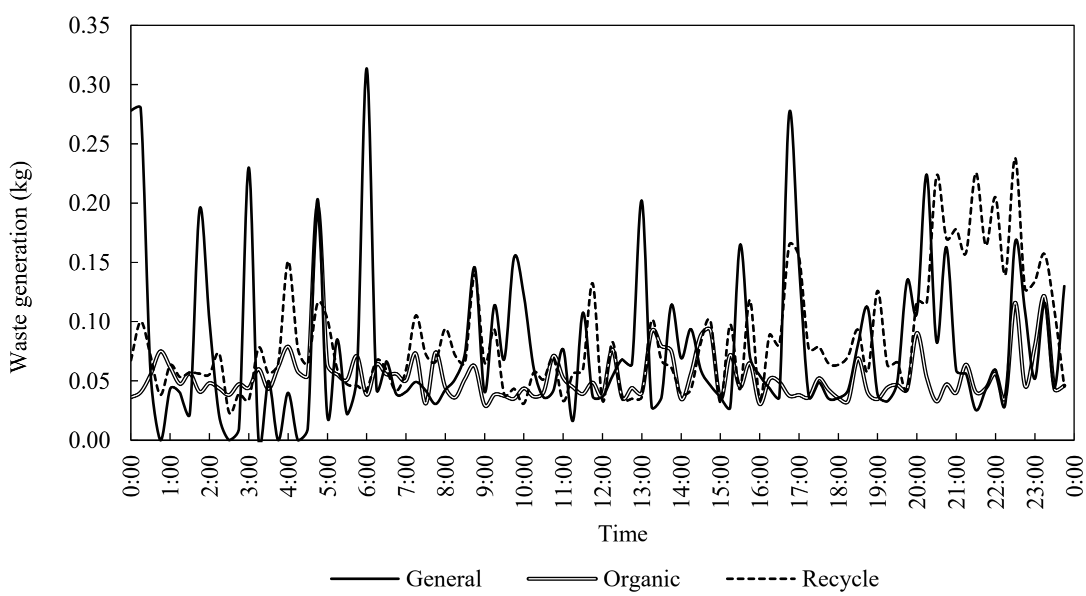


Fig. 3 The average data of Waste generation in GH1.

When considering the amount of waste generated within the 6 buildings as shown in Table 3, it was found that the average quantity of general waste for each building is approximately 0.4-0.5 kg, and the amount of general waste accumulated per 15 minute is around 0.72-0.74 kg. The average SD value is 0.02, except for the residential buildings for doctors, which have an average general waste quantity of 0.09 kg/ 15 minute for HH1 and 0.14 kg/15 minute for HH2, and an accumulation of general waste quantity of 15 minutes approximately 1.01 kg for HH1 and 1.70 kg for HH2, with an average SD value of 0.06. Additionally, the organic waste quantity for HH1 and HH2 is still higher than that of other buildings, with an average accumulated organic waste of 0.10 and 0.11 kg, and a maximum amount of 1.74 and 1.43 kg, respectively. Both buildings have an SD value of 0.04 for organic waste, and the average quantity of organic waste ranges from 0.01-0.03 kg. The maximum amount of organic waste per occasion is approximately 0.30 kg, with an SD value of approximately 0.00. Furthermore, when considering the estimated quantity of recyclable waste, only building HH1 has a higher quantity than the other buildings, with a waste quantity of 0.04 kg, which is higher than the other buildings with an average waste quantity of approximately 0.01-0.02 kg. The maximum accumulated waste quantity is 1.63 kg.

Table 3 Waste generation data for the community.

Building	General				Organic				Recycle			
	Avg	Max	Min	SD	Avg	Max	Min	SD	Avg	Max	Min	SD
Unit	(kg/15 min)				(kg/15 min)				(kg/15 min)			
GH1	0.04	0.72	0.01	0.01	0.01	0.20	0.01	0.00	0.01	0.15	0.01	0.00
GH2	0.05	0.74	0.01	0.03	0.03	0.60	0.01	0.00	0.02	0.44	0.01	0.01
SH1	0.04	0.72	0.01	0.01	0.01	0.20	0.01	0.00	0.01	0.15	0.01	0.00
SH2	0.04	0.72	0.01	0.01	0.01	0.20	0.01	0.00	0.01	0.15	0.01	0.00
HH1	0.09	1.01	0.01	0.06	0.10	1.74	0.01	0.05	0.04	1.63	0.01	0.00
HH2	0.14	1.70	0.01	0.07	0.11	1.43	0.01	0.04	0.01	0.27	0.01	0.00

Based on the data regarding energy, water, and waste in residential buildings, it was discovered that the utilization patterns of energy and water, as well as the generation of waste, are similar among buildings of the same type. Notably, the data for all three factors were divided into two time periods because the occupants of the six buildings all had outside occupations. GH1 and GH2, however, differed from the other four buildings as they did not have fixed work hours, resulting in wider peak load time frames. In contrast, the buildings SH and HH were occupied by individuals with fixed work hours from 8:00 to 16:30, which resulted in peak load time frames that were closer together. It should be noted that the quantities of energy, water, and waste varied depending on the specific demands of each individual building, as well as user behavior and the characteristics of the occupants residing in each building [13]–[15].

3.2. Analysis of the behavior of individual consumers in the building

The investigation of activities conducted within a range of buildings was accomplished via the utilization of data collected via questionnaires administered to residents who were situated in buildings equipped with smart meters. Data acquisition involved the recording of all activities transpiring within the buildings and outlining their defining characteristics. The analysis of building activities was separated into two key components, the first being the frequency analysis of every activity happening within the building, and the second being the time analysis of each activity as it occurred. Additionally, the activities were sorted into categories based on individual consumer characteristics to identify trends and patterns in activity behavior within the building. This classification process necessitated the identification and analysis of consumer characteristics in conjunction with their activities within the building.

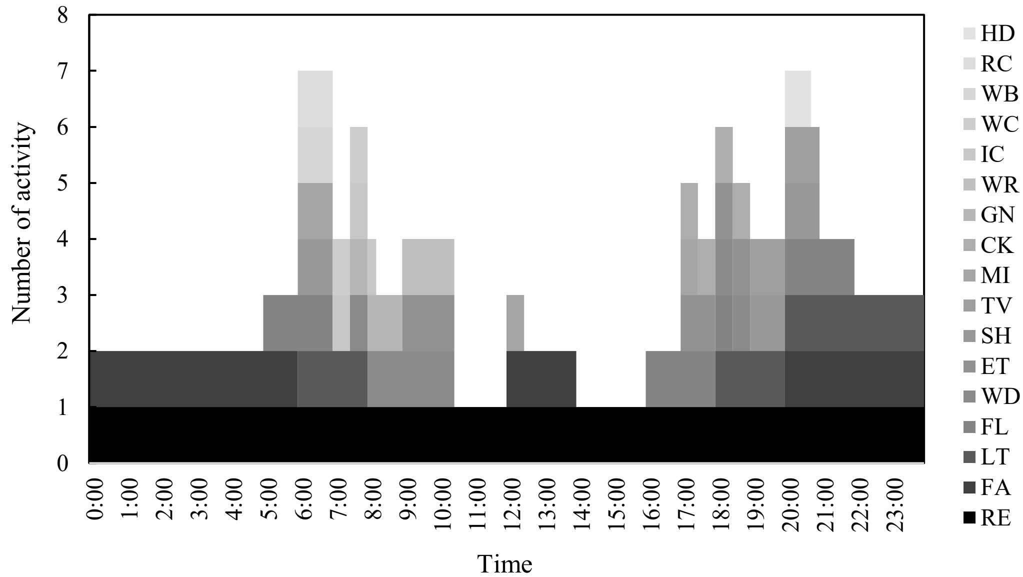


Fig. 4 The example of activity in GH1 by the 1st consumer.

The data on activities conducted within each individual's dwelling within a residential building reveal that, for the most part, behavioral patterns are consistent and align with one another. For instance, the occupants of General Public House 1 (GH1) exhibit similar behavioral patterns, with activities occurring twice a day during the morning and evening shown in Figure 4. In total, occupants engaged in 16 activities per day, which included utilizing a refrigerator (RE), a fan (FA), turning on lights (LT), entering the restroom (TL), washing dishes (WD), eating (ET), bathing (BA), watching television (TV), using a microwave (MI), cooking (CK), watering plants (GN), washing a car (WR), ironing clothes (IC), washing clothes (WC), boiling water (WB), rice cooking (RC), and a hair dryer (HD).

Notably, the RE activity was continuously executed throughout the day due to its necessity as an electrical appliance. Furthermore, all activities were characterized by specific details. For instance, the FA activity was divided into three-time intervals per day, with an average usage time of approximately 11 h/day. The LT activity occurred twice per day, with an average duration of approximately 420 min/day. The frequency of TL activities is six times per day, in three-time slots, with an average duration of approximately one minute per occurrence. The frequency of occurrence of activities for WD is twice per day, in two-time slots, with an average duration of approximately 15 min/times. The frequency of occurrence of activities for ET is 2 times/day, in two-time slots, with an average duration of approximately 25 min/times. The frequency of occurrence of activities for BA is twice per day, in two-time slots, with an average duration of approximately 10 min/times. The frequency of occurrence of activities for TV is approximately three times per week, during the time slot of approximately 19:00-20:45, with an average duration of approximately 60 min/times. The MI has an average frequency of approximately 5 activities per week, divided into three-time slots, with an average activity duration of approximately 2 minutes per occurrence. The CK has an average frequency of 1 time/day during the time slot of 17:00-18:45, with an average activity duration of approximately 45 min/times. The GN group has an average frequency of 4 activities per week during the time slot of 7:30-8:45, with an average activity duration of approximately 30 min/times. The WR group has an average frequency of 1 activity per month during the time slot of 9:00-10:30, with an average activity duration of approximately 30 min/times. The IC group has an average frequency of 2 activities per week during the time slot of 7:00-8:00, with an average activity duration of approximately 60 min/times. The WC group has an average frequency of 2 activities per week during the time slot of 7:00-7:45, with an average activity duration of approximately 60 min/times. The WB and RC groups have an average frequency of approximately 1 activity per day during the time slot of 6:00-6:45, with an average activity duration of approximately 15 min/times for WB and 20 minutes per occurrence for RC. Finally, the HD has an average frequency of 4 activities per week during the time slot of 20:00-20:30, with an average activity duration of approximately 5 min/times. Thus, while occupants of buildings of the same type exhibit similar behavioral patterns, there may be differences in the frequency and quantity of activities conducted within the building.

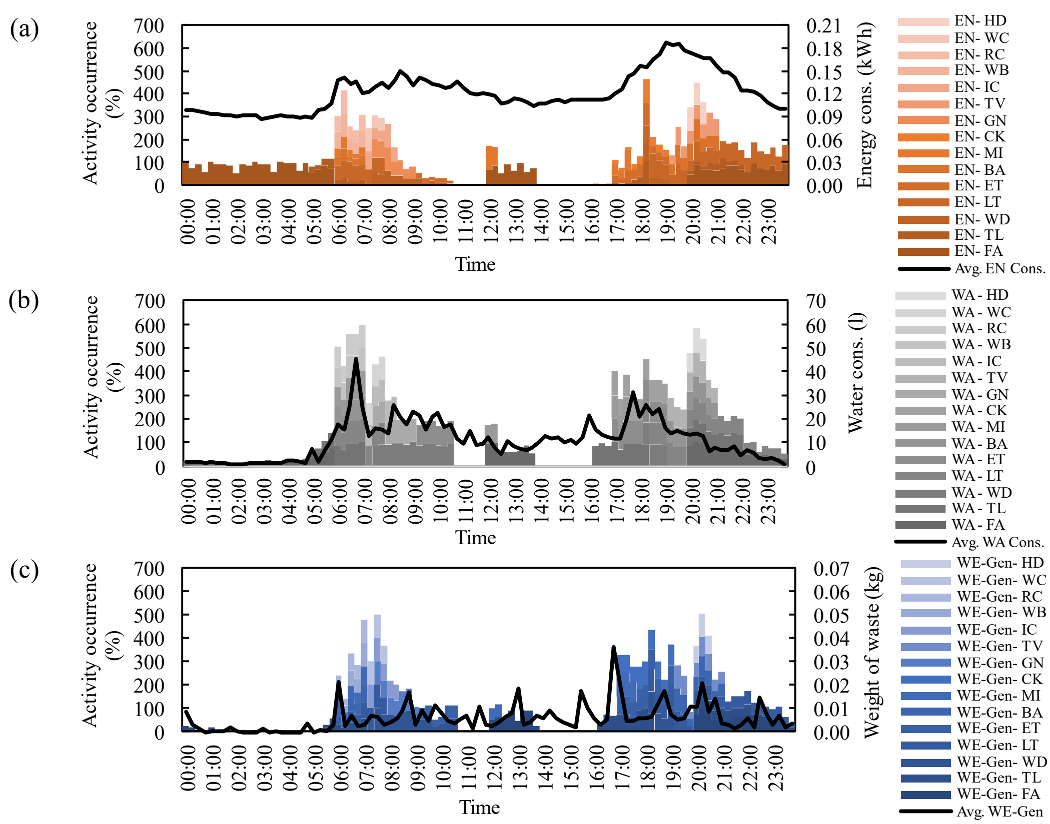
3.3. Analysis of energy consumption, water, and waste generation of each activity

This study offers an in-depth analysis of the frequency of activities and energy consumption patterns within individual buildings across various sectors. By categorizing energy-related data into activities or electrical appliances that require continuous energy usage and activities that consume energy over extended periods, we can better understand the diverse nature of resource consumption. By examining peak loads for each sector, we identify patterns or behaviors of normal usage, as well as activities that utilize resources in a coordinated manner.

The process of activity identification employs data on energy consumption, water usage, and waste generation from smart meters, enabling the confirmation of peak load periods for each activity. Questionnaires help determine the timing of activities, and the analysis is stratified based on consumer profiles, as demonstrated in consumer profiles by age and gender. By comparing the data between groups, the behavior of each consumer profile is ascertained. The data on the quantity of energy consumption, water usage, and waste generation for each activity occurring in individual buildings, as this represents an aggregate of data for all consumers within the building. This separation allows for the identification of individual consumers, enabling a more nuanced understanding of resource utilization patterns. The insights gleaned from this study can be instrumental in designing targeted, efficient, and sustainable resource management strategies that cater to the unique needs of diverse consumer groups, thereby promoting responsible energy consumption and sustainable urban living.

The correlations between behavioral characteristics of energy usage, water consumption, and waste generation within a building, and the frequency of activities by individual consumers. The analysis, which included the example of the first consumer in building GH1, as depicted in Figure 5, illustrated the behaviors of energy, water consumption, and waste generation. The symbols "EN," "WA," "WE-Gen," "WE-Org," and "WE-Rec" represented the quantities of energy consumption, water consumption, general waste generation, organic waste, and recyclable waste, respectively, associated with various activities occurring within the building. The activities were denoted by the symbols HD (hair drying), WC (clothes washing), RC (rice cooking), WB (boiling water), IC (clothes ironing), TV (television viewing), GN (gardening), CK (cooking), MI (microwave food heating), BA (bathing), ET (eating), LT (lighting), WD (dishwashing), TL (toilet usage and personal activities), and FA (fan usage). Additionally, "Avg." represented the average value of each dataset generated within the building. For instance, EN-HD indicated the quantity of energy consumption during the hair-drying activity, WE-Gen-HD represented the amount of general waste generated during the hair-drying activity, and Avg.Wa Cons. denoted the average cumulative water consumption every 15 minutes within the entire building.

The data obtained from the study revealed that, firstly, a direct proportionality was demonstrated between the energy consumption quantity and the amount of activity occurring during each time interval, as depicted in Figure 5 (a), which illustrates the average daily energy consumption over different time intervals. This finding was in line with the results obtained from the analysis of water consumption, as presented in Figure 5 (b). It was observed that higher frequencies of activities during specific time intervals resulted in greater quantities of water consumption, with variations depending on the individual usage patterns of the consumers. Secondly, contrary to common expectations, the occurrence of waste generation for each activity during different time periods was not significantly influenced by the quantity of waste generated within the building. However, the importance of the amount of waste generated was identified. This was exemplified through the examination of the average daily amount of waste disposed of for General, Organic, and Recyclable waste by Consumer 1 in house GH1, as illustrated in Figure 5 (c) – (e). Notably, the time periods with the highest average amount of waste disposed of did not align with the time periods featuring the highest occurrence of activities within the building.



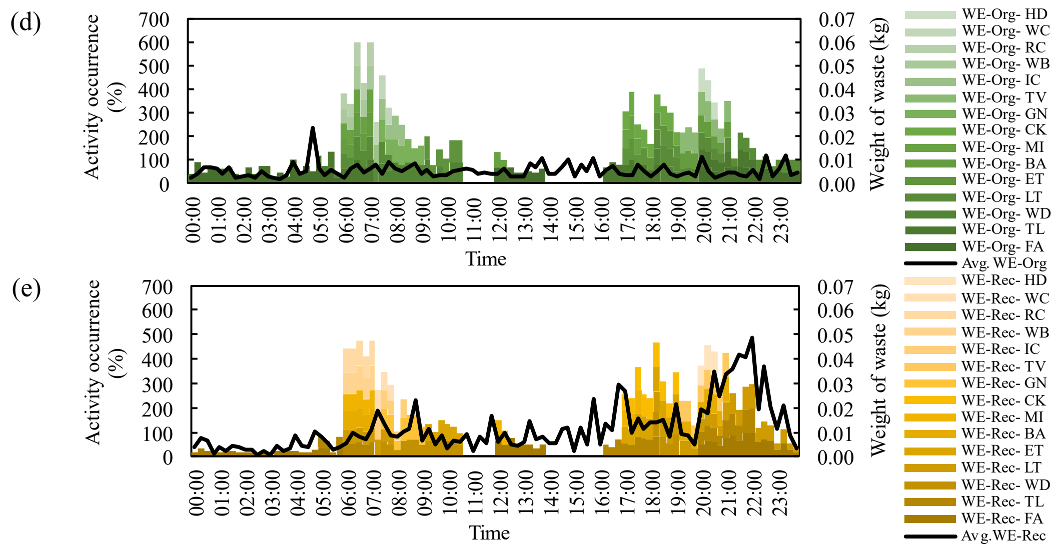


Fig. 5 The activity occurrence in GH1 of 1st consumer with consumption of (a) Energy (b) Water and creation of (c) General (d) Organic and (e) Recycle Waste.

An investigation was conducted that focused on energy usage, water consumption, and waste creation for each consumer within a building to discover usage trends and generate customer profiles for buildings regarding their resource consumption. To accomplish this analysis, data was collected on activity and device usage for each consumer at the time of measurement. The variables considered included the size, number, proportion, and total consumption of appliances in each sample building, as well as the activity time, frequency, and period of each consumer and building. Subsequently, the percentage of energy usage and waste generation was calculated and adjusted for each consumer.

The sample study of the energy consumption patterns of a residential building by examining the activities of its first and second consumers. The primary focus of this analysis is on the energy usage of consumers 1. The results show that the refrigerator is the activity with the highest and most persistent energy consumption, with an average consumption of 32.75 Wh (SD = 5.99) throughout the day. The next activity with the highest energy consumption is the use of electric lighting, which occurs during specific time periods and has an average electricity consumption of 10.19 Wh (SD = 4.98). The use of a fan is also examined, and it is divided into three time periods with an average energy consumption of 4.02 Wh (SD = 2.12) during each period. Other activities, such as bathing, cooking rice, laundry, washing clothes, hair drying, TV viewing, and using a microwave, have lower energy consumption levels. Furthermore, the study notes that the energy consumption of consumer 1 is generally higher than that of consumer 2, except for the usage of refrigerators. This is due to the presence of an additional cake refrigerator, which operates continuously and has a relatively high power consumption rate. The average energy consumption for the cake refrigerator throughout the day is 52.15 Wh with an SD of 9.53, whereas the regular refrigerator consumes an average of 26.12 Wh with a standard deviation (SD) of 4.77. The energy consumption for other activities throughout the day is 9.53, 4.15, 1.00, 0.83, 0.71, 0.31, 0.30, and 0.24 Wh, with SDs of 4.73, 0.95, 0.15, 0.15, 0.21, 0.06, 0.08, and 0.02, respectively. These activities include turning on lights, taking a shower, washing clothes, doing laundry, cooking rice, blow-drying hair, using a microwave, and boiling water.

After analyzing the water consumption patterns of the first and second consumers, it was observed that water was utilized during activity periods within the buildings by both users. The study examined the average water usage of the first user for each of the 10 activities, which include watering and caring for plants, boiling water, cooking rice, bathing, cooking, dishwashing, eating, using the bathroom, doing laundry, and washing the car. The results indicate that the water usage for these activities ranges from 2.86 to 6.05 liters, with standard deviations ranging from 0.57 to 2.01. For the second user, water was used in all 6 activities within the buildings, namely using the bathroom, cooking rice, eating, doing laundry, bathing, and cooking, with an average water usage ranging from 0.49 to 3.71 liters, and standard deviations ranging from 0.12 to 1.22. Upon comparing the water usage quantities of the same activity by both users, it was found that the first user used slightly more water than the second user. It should be noted that the water usage quantity for each activity varied depending on the activity duration. Overall, the study provides insights into the water consumption patterns of different activities by different consumers in a residential building, which can inform the development of strategies for water conservation and management.

The study conducted an analysis of the quantity of waste generated within the building by each user, categorized by waste type as shown in the figure General waste generation of each activity. The average general waste generated by user 1 and user 2 was found to be 0.01 kg and 0.006 kg, respectively. The Organic waste generation of each activity displays the amount of organic waste generated, while the Recycle waste generation of each activity shows the amount of recyclable waste generated. The quantity of waste generated fluctuates considerably and varies according to the timing of different activities carried out within the building. The average organic waste generation for both users was found to be 0.001 kg, and the average recyclable waste generation was 0.002 kg. Both organic and recyclable waste generation displayed similar patterns of variability in waste generation. The study's findings provide valuable information on the waste generation patterns of different activities by different users in a residential building, which can inform waste management strategies and policies aimed at reducing waste generation and promoting recycling.

The data presented in this study highlights the quantities of energy consumption, water usage, and waste generation that arise from the activities of each individual user residing in each building. These quantities are calculated based on the usage behaviors of both energy and water, as indicated by the trends of the data sets that point in the same direction within each group of buildings. It is important to note that the amount of energy consumed by users residing in the same building and engaging in similar activities is likely to be similar due to the shared use of certain types of electrical appliances. However, there may be variations among users due to differences in the duration of their activities. This study's findings provide valuable insights into the energy consumption, water usage, and waste generation patterns of different activities by different users in residential buildings, which can inform the development of strategies and policies aimed at promoting sustainable living and reducing environmental impact.

3.4. The correlations between each aspect and the period of usage

This section shows the building's energy, water, and waste patterns. The consumption data assessment is separated into three characteristics: the building's general average energy consumption, energy consumption characteristics by weekday and weekend, and energy consumption characteristics by days of the week.

The analysis of energy usage data in all buildings shows that the energy usage data at a frequency of 15 minutes, backward 3 months, is positively correlated with time in the following buildings: GH1 (correlation value of 0.151), GH2 (correlation value of 0.100), SH1 (correlation value of 0.019), SH2 (correlation value of 0.114), and HH2 (correlation value of 0.163), all of which are significant at the level of 0.01, except for building HH1. Building HH1 is negatively correlated but not significant. When analyzing the energy usage data by day of the week, only three buildings show a correlation with each other. Building GH1 has a significant negative correlation at the level of 0.01 (correlation value of 0.033), and buildings HH1 and HH2 have significant positive correlations at the level of 0.01 (correlation values of 0.048 and 0.040, respectively). Similarly, when analyzing the energy usage data by weekday and weekend, a total of five buildings are positively correlated with each other and significant at the level of 0.01, including GH1 (correlation value of 0.093), GH2 (correlation value of 0.063), SH1 (correlation value of 0.047), SH2 (correlation value of 0.040), and HH2 (correlation value of 0.091). From the data, it can be concluded that energy usage in residential buildings is positively correlated with time in a significant way.

The water sector shows a correlation between water usage data within buildings over time, with estimates of water usage having significant correlations over time for five buildings: GH1, SH1, SH2, HH1, and HH2, with correlation coefficients of 0.050, 0.020, 0.064, 0.065, and 0.041, respectively, all significant at the 0.01 level. Only GH2 had a negative correlation coefficient, which was not statistically significant. When analyzing energy usage within the buildings separated by each day of the week, only GH1 and HH2 had correlations, with GH1 having a positive correlation coefficient of 0.021 and HH2 having a negative correlation coefficient of 0.027, both significant at the 0.05 level. Additionally, when further analyzing the data for weekdays and weekends, only three buildings had correlations between water usage and time for each day: GH1 had a positive correlation coefficient of 0.047, while SH1 and HH2 had negative correlations with coefficients of 0.059 and 0.036, respectively, all significant at the 0.05 level.

The study of the correlations between the quantities of the three types of waste generated within a building in the waste sector found that the characteristics of the three types of waste are statistically significantly related to each other. Therefore, the total amount of waste from all three types was used for analyzing the correlations over time. It was found that only two buildings, GH1 with a correlation coefficient of 0.016 significant at the 0.05 level, and SH2 with a correlation coefficient of 0.023 significant at the 0.01 level, had a positive correlation between the quantities of waste over time. When the quantities of waste were analyzed separately by day of the week, it was found that only two buildings, GH1 with a correlation coefficient of 0.026 and SH2 with a correlation coefficient of 0.028, had a positive correlation between the quantities of waste on each day, both significant at the 0.01 level. However, when analyzed by working days and days off, it was found that buildings GH1, GH2, and SH2 had positive correlations with correlation coefficients of 0.028, 0.025, and 0.016, respectively, all significant at the 0.01 level.

The correlations between energy, water, and waste over time indicate a positive correlation between these variables. As time increases each day, the quantity of energy, water, and waste also increases. However, on average, the level of correlation among all the data does not approach 1, which would indicate a high level of correlation that is closely represented by a linear equation. Nevertheless, there is still a possibility of a correlation based on the trend of energy data for each building. During the period from 00:00, the quantity of load within the building is low because it is the time when most residents are sleeping. The quantity of energy usage increases when they wake up at around 7:00, which is higher than the average amount during midnight. However, the quantity of energy usage in the morning is still lower than in the evening period because it is a short time period each day. As a result, the average value of energy usage in the evening period for all buildings is slightly higher than in the morning period. This leads to a positive correlation between energy usage and time.

Table 4 The correlations between energy, water, and waste per time.

Building	Energy			Water			Waste*		
	Time	Day of week	Weekday/ weekend	Time	Day of week	Weekday/ weekend	Time	Day of week	Weekday/ weekend
GH1	✓	✓	✓	✓	✓	✓	✓	✓	✓
GH2	✓	-	✓	-	-	-	-	-	✓
SH1	✓	-	✓	✓	-	✓	-	-	-
SH2	✓	-	✓	✓	-	-	✓	✓	✓
HH1	-	✓	-	✓	-	-	-	-	-
HH2	✓	✓	✓	✓	✓	✓	-	-	-

* This statement suggests that there is a significant positive correlation between all three types of waste data, which are measured at a frequency of 15 minutes. The Correlation is significant at the 0.05 level.

Based on the summary information in Table 4, the time spent analyzing the correlations between energy use, water use, and internal building waste has an impact on the level of correlations observed in the data. The analysis was divided into two groups: weekday data, which occurred from Monday to Friday, and weekend data, which occurred on Saturdays and Sundays. The study found that the level of correlations decreased due to the fact that all residents within the building do not have the same work and lifestyle patterns during the week, in other words, the behavioral patterns within the building are not the same every day. This results in energy use, water use, and internal building waste data not being correlated with each other on a weekly group level. Data continuously used in line with the behavior of residents within the building will have a high level of correlations over almost the entire analysis period, such as data on energy use and water use. This is because residential buildings are closely linked to the behavior of residents that aligns with user characteristics such as age, occupation, and interests. However, data on the amount of waste generated tends to not be consistent with other data within the building. This is due to the fact that waste generation behavior, or activities that lead to waste generation, may not necessarily involve the use of energy or water.

3.5. The correlations between resource usage quantities in all three aspects over time

Analysis of the correlations between energy, water, and waste data is a study of the patterns of correlations based on the time the data is generated. When comparing data within all six buildings, it was found that GH1 correlated only between energy and water at a correlation level of 0.109. GH2 correlated with energy and waste in a negative direction at a correlation level of 0.028. SH1 had two positive correlations between energy and water and water and waste at correlation levels of 0.022 and 0.023, respectively. Similarly, SH2 had three correlations within the building, which were energy to water, energy to waste quantity, and water to waste quantity, at correlation levels of 0.082, 0.037, and 0.023, respectively. HH1 and HH2 had two positive correlations within each building between energy and water and water to waste quantity, with a correlation coefficient of 0.102 and 0.090 for HH1 and 0.300 and 0.018 for HH2, respectively.

It should be noted that the correlations between all three variables in each building also have external correlations with each other. It was found that most of the energy factors in each building correlate with the energy of other buildings, which differs from the water usage data, which has a lower correlation with the water usage of other buildings. When considering the correlation pairs of all six buildings, it was found that all three variables had a statistically significant correlation, which comprises a complex web of interrelated factors. The data and correlations details are shown in Table 5.

Table 5 The correlations between energy, water, and waste factor between sector.

	EN-GH1	WA-GH1	WE-GH1	EN-GH2	WA-GH2	WE-GH2	EN-SH1	WA-SH1	WE-SH1	EN-SH2	WA-SH2	WE-SH2	EN-HH1	WA-HH1	WE-HH1	EN-HH2	WA-HH2	WE-HH2
EN-GH1	1.000	0.109 **	-0.003	-0.037 *	-0.003	0.003	0.074 **	0.052 **	-0.014	0.091 **	0.017	-0.001	-0.369 **	0.143 **	0.032 *	0.071	0.062 **	0.004
WA-GH1	0.109 **	1.000	-0.007	-0.064 **	0.011	-0.012	0.117 **	0.004	-0.004	0.067 **	0.026 **	-0.001	-0.058 **	0.108 **	0.022 **	-0.008	0.028 **	0.038 **
WE-GH1	-0.003	-0.007	1.000	0.094 **	-0.001	0.003	-0.024 *	0.001	0.004	0.005	-0.005	-0.002	N/A	-0.016 *	-0.002	N/A	-0.003	-0.002
EN-GH2	-0.037 *	-0.064 **	0.094 **	1.000	-0.013	0.028 **	-0.185 **	0.068 **	0.070 **	0.019 *	-0.060 **	-0.021 *	N/A	-0.194 **	-0.021 *	N/A	-0.035 **	-0.023 *
WA-GH2	-0.003	0.011	-0.001	-0.013	1.000	-0.002	0.037 **	0.007	-0.001	0.015	0.029 **	0.001	-0.002	0.054 **	0.006	0.002	-0.001	0.001
WE-GH2	0.003	-0.012	0.003	0.028 **	-0.002	1.000	-0.030 **	0.008	0.000	-0.008	-0.008	-0.003	N/Ac	-0.025 **	-0.003	N/A	-0.005	-0.003
EN-SH1	0.074 **	0.117 **	-0.024 *	-0.185 **	0.037 **	-0.030 **	1.000	0.022 *	-0.013	0.154 **	0.179 **	0.060 **	0.024	0.351 **	0.029 **	0.140 **	0.108 **	0.043 **
WA-SH1	0.052 **	0.004	0.001	0.068 **	0.007	0.008	0.022 *	1.000	0.023 **	0.069 **	0.013	-0.006	-0.008	0.008	-0.003	0.000	0.009	0.015
WE-SH1	-0.014	-0.004	0.004	0.070 **	-0.001	0.000	-0.013	0.023 **	1.000	0.000	-0.003	-0.001	N/A	-0.009	-0.001	N/A	-0.002	-0.001
EN-SH2	0.091 **	0.067 **	0.005	0.019 *	0.015	-0.008	0.154 **	0.069 **	0.000	1.000	0.082 **	0.037 **	0.038 **	0.107 **	0.007	0.118 **	0.034 **	0.014
WA-SH2	0.017	0.026 **	-0.005	-0.060 **	0.029 **	-0.008	0.179 **	0.013	-0.003	0.082 **	1.000	0.023 **	-0.018	0.228 **	0.011	-0.033	0.069 **	0.041 **
WE-SH2	-0.001	-0.001	-0.002	-0.021 *	0.001	-0.003	0.060 **	-0.006	-0.001	0.037 **	0.023 **	1.000	0.005	0.051 **	-0.003	-0.015	0.012	-0.003
EN-HH1	-0.369 **	-0.058 **	N/A	N/A	-0.002	N/A	0.024	-0.008	N/A	0.038 **	-0.018	0.005	1.000	0.102 **	-0.024	0.067 *	0.041 **	0.020
WA-HH1	0.143 **	0.108 **	-0.016 *	-0.194 **	0.054 **	-0.025 **	0.351 **	0.008	-0.009	0.107 **	0.228 **	0.051 **	0.102 **	1.000	0.090 **	0.116 **	0.368 **	0.097 **
WE-HH1	0.032 *	0.022 **	-0.002	-0.021 *	0.006	-0.003	0.029 **	-0.003	-0.001	0.007	0.011	-0.003	-0.024	0.090 **	1.000	0.038	0.038 **	0.016 *
EN-HH2	0.071	-0.008	N/A	N/A	0.002	N/A	0.140 **	0.000	N/A	0.118 **	-0.033	-0.015	0.067 *	0.116 **	0.038	1.000	0.300 **	-0.012
WA-HH2	0.062 **	0.028 **	-0.003	-0.035 **	-0.001	-0.005	0.108 **	0.009	-0.002	0.034 **	0.069 **	0.012	0.041 **	0.368 **	0.038 **	0.300 **	1.000	0.018 *
WE-HH2	0.004	0.038 **	-0.002	-0.023 *	0.001	-0.003	0.043 **	0.015	-0.001	0.014	0.041 **	-0.003	0.020	0.097 **	0.016 *	-0.012	0.018 *	1.000

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

3.6. The correlations based on the activities

The behavior of activities within the building can be divided into two groups: activities with long durations that use electricity exclusively and activities that occur at certain intervals. The three types of activities have a statistically significant correlation with each other since they involve the use of water and waste disposal. Energy usage within the building has a statistically significant correlation with waste generation from activities such as using a refrigerator, turning on a fan, and turning on lights, with a mostly positive correlation. Additionally, all three activities have a statistically significant correlation with waste generation for all three types of waste.

Activities in the second group have different correlations between energy, water, and waste due to individual characteristics such as housing, occupation, and age. Bathroom and showering activities have a statistically significant positive correlation in all directions. Cooking activities correlate only in terms of water and waste, with a positive correlation between each type of waste. Cooking affects the correlation level between water and waste. Still, rice cooking activities that require energy, water, and generate waste have a significant impact on the correlations between energy, water, and waste due to lifestyle behavior. The activities of boiling water and using a microwave were found to have a significant correlation with energy, water, and waste, and there was also a correlation between the different types of waste generated during each activity. Eating and dishwashing activities had a significant positive correlation with water and waste, but little correlation with energy. The activities were conducted only with the presence of water and waste, and the low correlation to energy is because the activities do not require much energy, except for the use of light in the building. Both eating and dishwashing activities typically occur in conjunction with turning on the lights. The activity of laundry washing uses water and electricity-powered washing machines and has a positive correlation between energy and water, but no correlation to waste generation. Clothes ironing activity generates waste due to energy usage, but the different types of waste generated during the activity are not correlated with each other. The activity of gardening has a positive correlation between energy and waste, water and waste, and each type of waste. This is because plant care activities use a large and continuous amount of water, which affects the amount of water used during the activity period, and also involves trimming, weed removal, rice collection, or house cleaning, leading to waste generation in all three categories. However, the use of water does not require a water pump that requires energy, so the impact on energy usage is not significant. The analysis shows no significant correlation between energy, water, and waste in hair blow-drying and dishwashing activities. These activities consume resources, but they do not affect each other significantly.

The correlations between energy, water, and waste in activities within a building depend on the duration and characteristics of the activities. Long-duration activities that use electricity exclusively have a significant positive correlation with waste generation, while activities with shorter durations have varying correlations between energy, water, and waste depending on individual characteristics. Some activities have a significant correlation with energy, water, and waste, while others do not. The analysis also shows that different types of waste generated during an activity may have their level of correlation and may not be correlated with each other. Understanding the correlations between energy, water, and waste in activities within a building is crucial in promoting sustainable living practices and reducing the overall environmental impact of human behavior.

4. Conclusion

This research describes the community data on the energy, water, and waste characteristics within the residential buildings. In terms of energy consumption, the data collected from smart meters show that indoor energy consumption increased from normal consumption at 6:00 and was constantly used at high consumption until around 13:30. The energy consumption rate increased again for the second period at 17:30 until the maximum daily energy consumption is reached at 19:00. The highest energy consumption occurred during the first period, and HH2 used the most energy at 8:00 AM. In terms of water consumption, the highest average amount of water usage within a building was during the first time period at 7:45, and during the second time period at 19:15. Building HH1 has the highest average water usage, and the lowest average water usage in all six buildings was 7.96 l per 15 minutes with an SD value of 8.12. Waste generation is highest during two periods of the day, which are the morning and evening, and the frequency of waste generation within a building is variable and has a direct impact on the quantity of waste generated. The average quantity of general waste for each building is approximately 0.4-0.5 kg, and the amount of general waste accumulated per occasion is around 0.05 kg. Organic waste has a high frequency of waste generation but a low quantity, whereas recyclable waste has a high quantity of waste generated during a specific period, approximately from 19:30 to 23:30.

The study analyzed the energy, water, and waste consumption patterns in various residential buildings. The analysis showed that energy usage in residential buildings is positively correlated with time in a significant way. Water usage also had significant correlations over time for several buildings. Only a few buildings showed a positive correlation between the quantities of waste over time. The analysis of consumption data was further separated into characteristics like weekdays, weekends, and days of the week. Different buildings showed correlations between consumption patterns and time, depending on the characteristic analyzed. Analysis of the correlations between energy, water, and waste data in six different buildings. The study found various correlations between these variables in each building, and most energy factors in each building correlate with the energy of other buildings. Additionally, all three variables had statistically significant correlations, which comprise a complex web of interrelated factors.

The correlations between energy, water, and waste in activities within a building are complex and depend on various factors such as the duration, type, and individual characteristics of the activities.

Long-duration activities that use electricity exclusively have a significant positive correlation with waste generation, while activities with shorter durations have varying correlations between energy, water, and waste. Some activities have a significant correlation with energy, water, and waste, while others do not. Understanding these correlations is crucial in promoting sustainable living practices and reducing the overall environmental impact of human behavior. By considering these factors, individuals can make informed decisions about their energy, water, and waste usage to reduce their environmental impact and contribute to a sustainable future.

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