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# Analysing Passenger and Climate Impacts on Bus Station Cooling Energy Consumption in Kuwait

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***Abstract*** **-** Public transportation significantly helps to reduce traffic congestion, lower greenhouse gas emissions, and promote economic and social development. This study aimed to design a sustainable and comfortable bus stop equipped with air conditioners to serve against Kuwait's extreme summer temperatures in alignment with Kuwait's Net-Zero emissions Vision 2060. The experiment was to establish whether the air conditioning system will keep the place cool so that there is an internal temperature below 27°C. This is crucial, especially with external temperatures rising towards 40-50°C in summertime in Kuwait. Five 100-watt heaters were placed inside the bus stop in distributed positions to simulate the heat generated by passengers. These were made to run on a set timetable to mimic the heat generated by human bodies in the bus stop. The tests were carried out over two weeks, one with heaters were turned on using a specific pattern to simulate human bodies heat and the next week were turned off. The results imply that the air conditioner failed to maintain the comfort level and indoor temperature reached to 35° C during the day when heaters were on. Once the heaters were off, the indoor temperature reached 33 °C indicating that the simulated human heat has contributed to overheating of the bus stop. This shows that the 1-ton air conditioner currently implemented in the bus stop does not provide enough cooling capacity particularly at peak hot hours of the day leading to excessive energy consumptions and human discomfort. Research will continue by replacing the AC system with a higher capacity air conditioning to improve energy consumption and effective cooling to ASHRAE standards. This study reinstates the importance of inculcating environmental and human factors in designing public infrastructure.

***Keywords*****:** Cooling Systems, Human Thermal Load, Kuwait Net-Zero emissions Vision 2060, Sustainable Infrastructure.

## 1. Introduction

There are global efforts to mitigate climate crisis due to the global warming by decreasing $CO_2$ emissions in many public and governmental sectors. The urban transport is one of the key influential factors to achieve climate neutrality by its significant role in reducing greenhouse gas emissions. Moreover, Christidis et al. [1] provided the heat map of European countries in 362 cities due to transportation and highlighted the urgent need to promote public transport and active mobility to reduce utilisation of private cars. The role of stakeholders such as energy providers and public transport operators are crucial to overcome complexity of urban transportation policies to mitigate environmental issues. Similarly, Fattah et al. [2] indicated that traffic congestion is one of the major barriers for economic development in Bangladesh and developing countries. They investigated various influential factors in well-being of transportation in a port city by variety of traffic measurement and statistical based questioners, blaming ineffective public transportation along with several other factors as the main factors for traffic congestion. These had contributed to $2.0 million economic loss per day. Furthermore, Elassy et al. [3] highlighted the importance of smart transportation in well-being and suitability of public transport system. They addressed various intelligence factors for improving transportation such as traffic forecasting and intelligence traffic lights. However, security matters remain challenging in smart transportation like privacy concerns, according to the authors. In addition, Richter et al. [4] discussed importance of developing urban mobility solutions in smart cities particularly with respect to autonomous vehicles (AV). They recommended non-AV public transportation to replace private cars as a smart solution. Salas et al. [5] explored two states in France on finding relation between air pollution with transport system and population in urban environment. They found the activity emission model OLYMPUS provided insightful information on mobility patterns and road pollutions and suggested strategies to improve these.

In another recent stud, Mokhles and Acuto [6] reviewed over 3700 actions by 800 local governments mainly in building energy and transportation to disclose carbon emission mitigations. No correlations were found between the size and economy of cities on carbon production. Furthermore, Aboagye and Sharifi [7] reviewed critically the current existing governmental action plans to mitigate environmental impacts of carbon emissions. They highlighted shortage of the existing action plans, and proposed a framework based on globally accepted standards and verified it over 257 urban climates using 43 criteria. They recommended more recent action plans since 2018 to 2022 that best fitted with their proposed methodology.

Xing et al. [8] investigated massively populated cities correlated urban form with carbon emissions studying emission data for over 260 cities in China. Their results indicated compactness in large to mega cities showed increasing trends in carbon emissions.

Zhao et al. [9] evaluated smart transportation impacts on a green productivity factor in China indicating positive effects. The green factor was also positively correlated to energy efficiency within industrial sectors. Smart transportation involves real-time management of traffic, tracking mechanisms of driving vehicles, road traffic assessment, intelligent control of traffic lights, autonomous vehicles and so on. Muñiz and Sánchez [10] indicated a large portion of greenhouse gases (GHG) production were associated with transport system in Mexico. They correlated the method of compact city with the built environment and mobility and indicated urban land regulations to reduce emissions were crucial. Brenner et al. [11] investigated the impact of super-blocks in Austria to mitigate impact of carbon emission on well-being and public health. Their results showed that the effects of super-blocks areas were 2 to 3 times more than urban areas. A superblock is usually defined as a planning concept in urban blocks to prioritise pedestrians and bicycles over cars.

Kozera et al. [12] highlighted a European funded pilot study in Poland on utilization of low GHG emissions and green energy in public transport system. More than 778 projects integrating renewable energy were conducted with the total budget of 7.4 billion euros provided by the government. Some cities were enjoyed more from the European fund on the green transport development. Many of these projects were related to electric transportation, electro-mobility, cycling, and purifying air. Bernacki and Lis [13] investigated impacts of investments on transport sustainability at port-cities in Poland by improving waterway and railway developments. The improvements on social and environmental factors such as congestion, traffic noise and pollution, accidents, and reduction in GHG emissions were highlighted. Almatar [14] showcased the future of Saudi Arabia with green mobility and increasing use of renewable energies.

The research highlighted viability and advantageous of green transport using statistical approach particularly the environmental benefits and improved quality of life, although, a clear policy by the government would accelerate such developments. Also, This paper outlines the efforts towards development of a green bus stop in Kuwait focusing on cooling by an air conditioning and human heat simulations. Experiments were conducted by measuring indoor and outdoor weather condition and assessing power consumption and ability of the air-conditioning system to cope with extreme heat in the summertime of Kuwait. Section 1 reported an introduction on recent literature on green mobility and GHG emission reduction remedies in transport system across the globe. Section 2 presents the developed bus stop container and its features, also provide technical specification of instruments used for measurements. Section 3 gives results and findings of the present work and highlights the required steps forward for creating a sustainable green bus stop container. Section 4 concludes the findings, recommends the practical and policy implications, limitations and future directions.

## 2. Methodology

A contemporary bus stop with interior dimensions of L = 5898 mm, W = 2352 mm, H = 2390 mm, and external dimensions of L = 6058 mm, W = 2438 mm, H = 2591 mm, with a tare weight of 2120 kg (before conversion) is created by converting a typical SCF 20 ft shipping container. The shipping container's walls are made of 14-gauge corrugated steel plates and have a thickness of 0.075 in (1.905 mm). The 7-gauge tubular steel with a thickness of 0.187 in (4.7498 mm) is used to construct the frame, pillars, and rails. 20 cm wide and 8 mm thick weathering carbon steel H-beams make up the structural base. Eight-millimetre steel plates support eighteen cross-braced wooden bars that make up the pillars. Steel apertures for windows and doors were expertly carved. The door's 2.1 m height and 1 m width allowed for a 2.1 m$^2$ entry area. It was constructed out of clear security glass with a 10 mm thick layer. To improve outdoor vision, two aluminium-framed windows measuring H=1.5 m and W=1.25 m each had double glazing of transparent glasses installed. The double glaze thickness was 3/4 in (19.05 mm), and the thickness of each glass was 1/8 in (3.175 mm). Together, these two windows provided 1.875 m$^2$ of double glazing, making the total amount of double-glazed windows 3.75 m$^2$. 50 mm thick thermal and acoustic insulation panels of the type extruded melamine foam covering all the interior walls were installed (see Fig. 1). All the inside walls were covered with 50 mm thick extruded melamine foam thermal and acoustic insulation materials. The 12.5 mm waterproof gypsum boards were put on top of the wall insulation. 12.5 mm gypsum boards were put on top of a 50 mm polyurethane foam sheet and a steel support frame. 18 mm MDF wood, 50 mm of foam installation, and 8 mm thick pine wood flooring were all installed on the container's floor. Using 4 mm Gulf cable wiring, two air conditioning connections were placed on the west wall to allow for the installation of optional DC and AC air conditioning systems. Electrical connections to four wall plugs, lights, and breakers for the container's power source were all connected to internal wall conductors. Within the container, four 40 W long-duty LED lights were placed. A white melamine wood counter and temporary wooden sitting seats were erected.

The installation of a Smart Weather Station [15] allowed for the monitoring of solar radiation, rain, wind direction, wind speed, and indoor and outdoor temperature and humidity. This makes it possible for the weather station to wirelessly send data to the biggest personal weather station network in the world. The Emporia Smart Home Energy Monitor system [16] was installed to track energy generation and usage. Eight 50A sensors are included with the system to precisely track the bus stop air conditioner, lamp usage, and other functions. Up to eight more sensors can be added to the system. Human occupancy was simulated by using Ceramic Reptile Heat Lamp Bulbs, 100W each [17]. Those heaters were turned ON and OFF by using programmable Wi-Fi sockets, as seen in Fig. 2.


Fig. 1: The constructed bus stop with indoor and outdoor weather monitoring devices and heaters 'stands in selected locations.

## 3. Results and Discussion

Figure 3 compares temperature variations for both indoor and outdoor environments during two periods (22-24 June and 25-27 June) to the corresponding indoor heaters were on or off, simulating human heats in the bus stop container. The outdoor temperature corresponds to very hot days in Kuwait, follows a similar diurnal pattern in both periods, peaking to 48 °C around midday and dropping to 35 °C at night, but temperatures on 26 June afternoon stay hotter compared with those hours on 23 June. When the five 100 W heaters were on according to the preset schedule to simulate busy or less busy hours of the day, the indoor temperature has higher peaks compared with the days when the heaters were turned off, indicating that the human heat can noticeably contribute to indoor temperature on hot hours of the days. These indoor temperatures, however, indicates the indoor environment are far away from the human comfort temperature zone of 24 to 26 °C according to ASHRAE standards. These measurements clearly indicated the indoor temperature can be uncomfortably high during hot months in Kuwait. Hence, the current AC system with the capacity of 1-ton is not suitable and most be replaced with higher cooling capacity air conditioning systems.

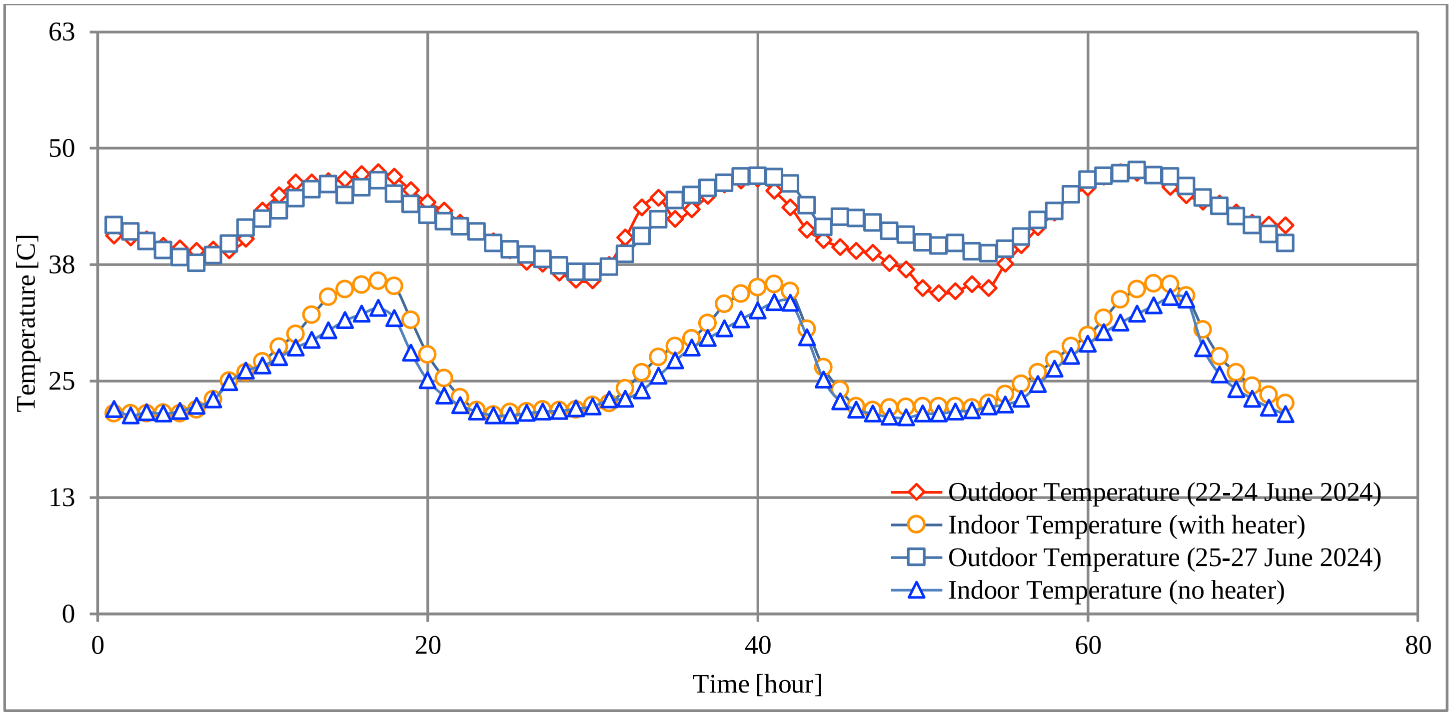


Fig. 3: Indoor and outdoor temperature variations from June 22 to 27, 2024.

Figure 4 shows the scheduled heater patterns and the AC power consumption over the two discussed periods. The programmed heaters worked according to the scheduled patterns indicated in Table 1. As observed in Fig. 4, the heaters have correctly operated to the scheduled plan. The amount and timing of the heaters can be flexibly adopted to different scenarios including randomly applied heating or based on weekly forecasting based on situations that the bus stop will be affected due to public holiday, rush overs, and traffic situation so that these aspects can be integrated with an AI predicting tool to simulate more accurately the number of people getting into and out of the bus stop. Figure 4 also shows that once the heaters are on, the AC power consumption was increased particularly during hot time of the day. The maximum AC power consumption of 1.2038 kW was observed when the heaters were on, in comparison with 1.1675 kW when the heaters were off. However, since the hotter hours was longer on 25 June, the average AC power consumption was higher in overall with values of 0.9866 kW (with heaters) and 1.0154 kW (no heaters). The AC's power consumption in Fig. 3 also indicate that the AC system compressor had never stopped working that indicating not healthy operation of the AC system. A higher capacity AC system with effective strategies must be implemented to maintain indoor environment to human comfort levels, and its energy consumption and operation hours are properly supervised and monitored for saving energy and protecting the AC system against overloading and overheating. Such a monitoring devices can improve the operation of AC system in smart fashion using AI interactions.

Table 1: Scheduled heating to simulate human heats.

| **Time of the day** | 6:00AM-8:00 AM &<br>12:00 PM-2:00 PM &<br>6:00 PM- 8:00 PM | 8:00AM-10:00 AM &<br>2:00 PM- 4:00 PM &<br>8:00 PM- 10:00 PM | 10:00AM-12:00 PM &<br>4:00 PM- 6:00 PM &<br>10:00 PM- 12:00 AM |
|---|---|---|---|
| **Heating added (W)** | 500 | 300 | 100 |

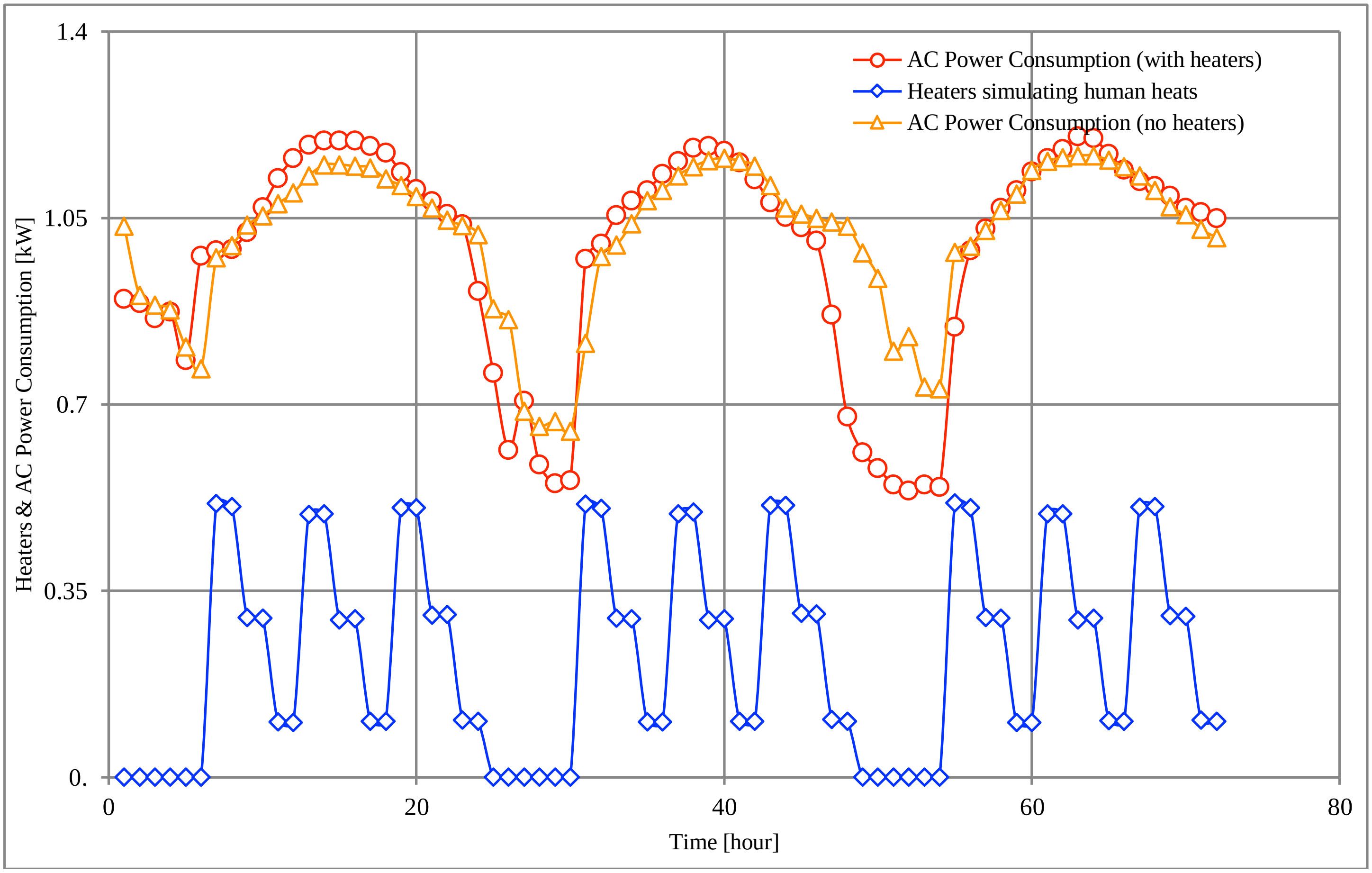

Fig. 4: Heaters & AC Power Consumption (kW) in Power

## 4. Conclusion

The optimisation of the cooling system was studied for a bus stop during hot weather in Kuwait. The impact of human heat, indoor, and outdoor temperatures were considered to examine sustainable indoor temperature for human comfort according to ASHRAE standards within 24-26 °C. The outdoor temperature was recorded at 49 °C at noontime and 35 °C, at nighttime. The indoor temperature was recorded peak value of 33°C during the days when the five 100 W heaters were turned off and the value of 35°C when the heaters were turned on, indicating the level of human body heat effects on indoor air conditions. Studying statistically and monitoring time and number of people waiting for a bus at different routes provides better insight for simulated heat and its frequency to have a broader understanding for improving indoor comfort level and optimise energy consumption by AC systems. Moreover, the measured room temperatures were beyond the typical human comfort temperature, ranging from 24-26°C as per the ASHRAE standards. The one-ton, round-the-clock running of an AC system points to the defectiveness and non-healthy operation. Therefore, a higher capacity AC system with proper monitoring and incorporation of artificial intelligence may improve the effectiveness of AC cooling systems, increase comfort levels and maintain an energy-efficient operation.


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