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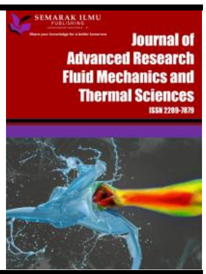

A Study of the Effect on Air Velocity and Temperature by Altering the Shuttle Bus Parameters

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ABSTRACT

The purpose of this research was to assess thermal comfort by analyzing the temperature and air velocity of a shuttle bus while changing factors such as bus speeds and regulator speeds. Data were collected at the front, middle, and back seats using a thermocouple and anemometer mounted to the air conditioning outlets. The goal was to understand how air velocity and temperature behaved to supply cooled air within the bus cabin when the vehicle and regulator speeds were increased. The results revealed that when the regulator speeds increased from minimum to maximum, the air velocity recorded at the front, middle and back seater decreased. When the bus is accelerated from 20 km h^{-1} to 60 km h^{-1}, the air velocity drops from 4.1 m s^{-1} to 1.4 m s^{-1}. The overall temperature was able to decrease when the bus speeds were accelerated from 20 km h^{-1} to 60 km h^{-1}. In all conditions, the lowest temperature was observed mainly at the front seater, which reflected from the evaporator blower location.

1. Introduction

Many localities aim to achieve sustainability while reducing traffic congestion by growing public transportation network utilization. It was expected that with this thinking, the number of people commuting the shuttle bus, train, and cab would grow. The issue in certain nations, particularly in hot climate regions, is to give such a degree of thermal and heat comfort. A bus passenger compartment and other human-occupied spaces require an air-conditioning system [1]. A closed area with improper air circulation can promote suffocation and discomfort, which is particularly troublesome on hot sunny days when it can cause headaches and vomiting [2]. Thermal comfort is the term used to describe the human mind toward the satisfaction feeling of the surrounding temperature whether it is too hot or too cold [3]. It is stated that temperatures between 9 °C and 26 °C show no thermal stress and reflect a comfortable condition, temperatures over 26 °C is related

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with heat stress, while temperatures below 9 °C indicate cold stress [4]. Many studies evaluate thermal comfort level by referring to specific factors such as humidity, airflow, room space, ventilation, heat sources, climate change, the human body and human behavior. Hossam *et al.,* [5] tested several outlets designs and studied the effect of outlet angles by modulating the velocities of the air-conditioning system, whereas Aliahmadipour *et al.,* [6] studied the thermal comfort level by applying temperature and velocity parameters on a heated mannequin. The subject of the thermal comfort study has usually been done to improve those satisfaction levels by designing a better environment such as a workplace air-conditioning and ventilation system design made according to the building structure and human capacity in the room. Those improved designs were reflected in either human behavior studies or field studies to measure some of the common factors in thermal comfort measurements such as ambient temperature, radiant heat, humidity, airspeed, cooling capacity and efficiency. Dzyuban *et al.,* [6] conducted a study to better understand human perceptions of heat and heat-coping behaviour at bus stops. This research examines the characteristics of bus stops that provide thermal comfort and protection from heat that might pose a health risk. They showed that the interrelationship between demographic data and bus stop design attributes affects the level of thermal comfort. The study found that low-income people use public transportation more frequently during peak hours and are more vulnerable to heat exposure. Field data revealed that shade attributes can reduce the bus station temperature to 21°C in the evening, but hourly measurements show that it consistently stays at 45°C, which is higher than the thermal comfort threshold defined by Middel *et al.,* [7].

Due to rapid development in technology and lifestyle, the basic factors to measure the thermal comfort level had to catch up and be modified to suit the new environmental study. In some cases, the humidity factors need to be analyzed together with the changing climate and surroundings. This involved confirming that the weather change during data collection has been constantly monitored and does not affect the humidity. The surroundings like peak hours and normal hours also need to be taken into consideration where human metabolism which generates heat would affect the overall ambient temperature. Dzuban *et al.,* [8] combine the meteorological measurement, surface temperature and field survey to summarise their study outcome. They also used mean radiant temperature and microclimate parameters to evaluate the physiological equivalent temperature (PET). In other cases, thermal comfort was assessed by comparing the heat rejection efficiency of mixing ventilation versus displacement ventilation design. A field study was conducted on the airflow of drafts temperature and vertical temperature from head to ankle [9]. There are yet no standards for measuring the thermal comfort level but somehow the foundation of a research environment for a specific purpose is possibly to be designed. Zhu *et al.,* [10] carried out an experiment to provide better knowledge on optimizing the ventilation system of an air-conditioning bus by designing three different scenarios in their study that may vary the ventilation parameters such as temperature, air outputs, and particulate matter. The parameters were analyzed to assess the airflow quality and level of thermal comfort dissatisfaction.

While there are many public transportation options in the main cities, we are looking at rural areas with high populations of people, such as universities, where shuttle buses are primarily used. Our goal in this research study is to provide the groundwork for analyzing thermal comfort levels by modifying the technical specifications of a college shuttle bus. The study is primarily concerned with the technical aspects that may impact the performance of the air conditioning within the bus cabin. Because the research was conducted in a hot climatic location on an unusually rainy day, the surrounding humidity and temperature were maintained within a constant range before data was collected to ensure a small margin of repeatability. The study's findings will substantially improve passenger comfort and bus cabin air quality design and management.

2. Methodology

The measurement of thermal comfort level is subjective to how satisfied a person is with their situation. The results may differ depending on the different elements involved in data collecting. As a result, the purpose of this study was to begin to comprehend thermal comfort levels by varying technical characteristics such as bus speed, regulator speed, air conditioning outlet location, and outlet depth. The shuttle bus used was a cabin seat with 40 seats and a total length of 1198 cm. The digital thermocouple and anemometer were placed in three locations: the front seater (1st row), middle seater (5th row), and back seater (10th row) of the bus cabin air-conditioning outlets. The same method was used to measure the CO, CO_2, and CH_2O at the air conditioning outlets of a bus campus [11]. The location of digital thermocouple and anemometer was to observe between several different areas in the bus compartment. An area near the door with a larger exposure to solar radiation due to large windscreen in front seater require more energy to cool down the indoor area [12]. Based on Ismail and Che Jamil [13] findings, highest air velocity helps to reduce the average air temperature and hotspot temperature by moving hot air faster which replicates the location at the middle seater near the evaporator. The back seater is the farthest traveling distance from the evaporator where according to Hatif *et al.,* [14], the thermal comfort satisfaction level will not be achieved without good air distribution even with an efficient ventilation system. The outlet temperature and air velocity were measured using a digital thermocouple and an anemometer, respectively. Figure 1 displays the placement of a digital thermocouple device used to measure both temperature and humidity at the air-conditioning outlet while the air velocity was measured inside the air-conditioning ducting at different depths.

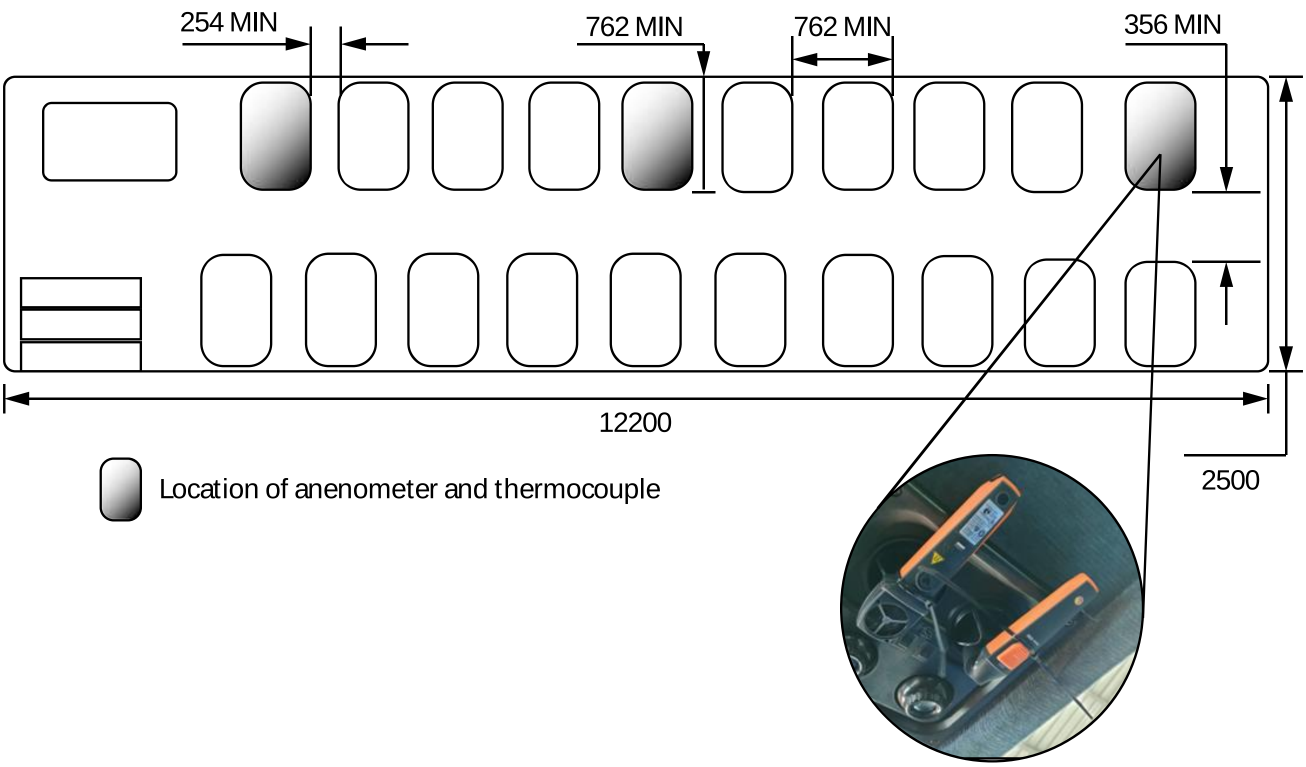


Fig. 1. The setup of the digital thermocouple and anemometer at the air-conditioning outlet

The condition of the shuttle bus has been varied in order to examine the performance of the shuttle bus air-conditioning system under several conditions. The first element was altering the bus speed from 20 km h^{-1} to 40 km h^{-1} to 60 km h^{-1}. It should be noted that the maximum speed that could be accomplished during this investigation is 60 km h^{-1}, which is the speed limit in the locality. The hypothesis was to investigate the effect of bus speed on air-conditioning performance, with higher workload to the engine potentially increasing air-conditioning system performance and improving the interior of the bus compartment more efficiently. The second element was adjusting the air-conditioning speed between low, medium, and high. These characteristics have been examined in order to determine the temperature and air velocity at the previously mentioned measurement location. This arrangement was to reflect the findings of Mohd Fohimi *et al.,* [15] where the air flow from opposite direction can be experienced from turbulence effect. Table 1 is a summary of the parameters that were used in this study.

Table 1
Parameters variation for temperature and air velocity

Parameters			
Bus Speed	20	40	60
Seat Position	Front	Middle	Back
Regulator Speed	Minimum	Medium	Maximum
Depth of Ducting	Bottom	Middle	Top

Only one shuttle bus was used as an experimental subject during the investigation. The bus chosen has been well maintained and is free of any damage or problems with the air conditioning system. According to Danca *et al.,* [16], vehicles require adequate time to acquire a consistent temperature environment; hence, the original setup was to allow the shuttle bus's inner compartment to reach a stable temperature once the engine began. This operation will take roughly 30 minutes before the data is collected. According to Ünal [17], it took roughly 20 minutes to lower the temperature from 50 °C to 25 °C when the air-conditioning system was started from the halted state. This is an important step in ensuring that the interior compartment achieves a steady-state condition prior to recording data. The working hours for collecting data were set between 11 p.m. and 2 p.m. as this would capture the highest surrounding temperature while maintaining the humidity level at a minimum spread. All of this is done to keep the study setting consistent and to prevent unnecessary elements that might influence the data collected. Figure 2 shows the shuttle bus used in the study, with the evaporator displayed on the bus's front side.

Fig. 2. Shuttle bus used in the field study

3. Results

This section discusses the results obtained from the air velocity and temperature measurement study from the effects of bus speed and regulator speed. From the measurement made, it was found that a significant difference can be seen when comparing 20 km h^{-1} and 60 km h^{-1}. Figure 3 and Figure 4 showed the results of temperature measured at three different ducting heights while the air velocity was measured at the air-conditioning outlet at the front, middle and back seater. Figure 3a shows that air velocity was highest at the front seater (4.1 m s^{-1}) with a 20% difference when compared to the middle seater (2.2 m s^{-1}) and back seater (3.1 m s^{-1}). However, when the regulator speed was increased, the air velocity reduced at all seater locations, including the front seater (3.4 m s^{-1}), middle seater (1.57 m s^{-1}) and back seater (2.2 m s^{-1}). As expected, when the regulator speed is increased from minimum to maximum speed, the temperature is reduced. This reduction significantly impacted the temperature reduced especially in the back seat by almost 25% reduction. There is not much of a difference in temperature change at the front and middle seater even though the temperature is still decreased. It is also found that the temperature is reduced the most for the bottom side of the ducting when the regulator turns to the maximum. From the back seater, the temperature drops from (19.97 °C) to (15.33 °C), (19.40 °C) to (16.10 °C) and (18.43 °C) to (16.47 °C) for the top, middle and bottom respectively. At both regulator speeds, the temperature recorded at the front and middle seater are quite similar. When the regulator speed is increased from minimum to maximum, the temperature within the bus cabin is well distributed where the back seater manages to level the temperature value.

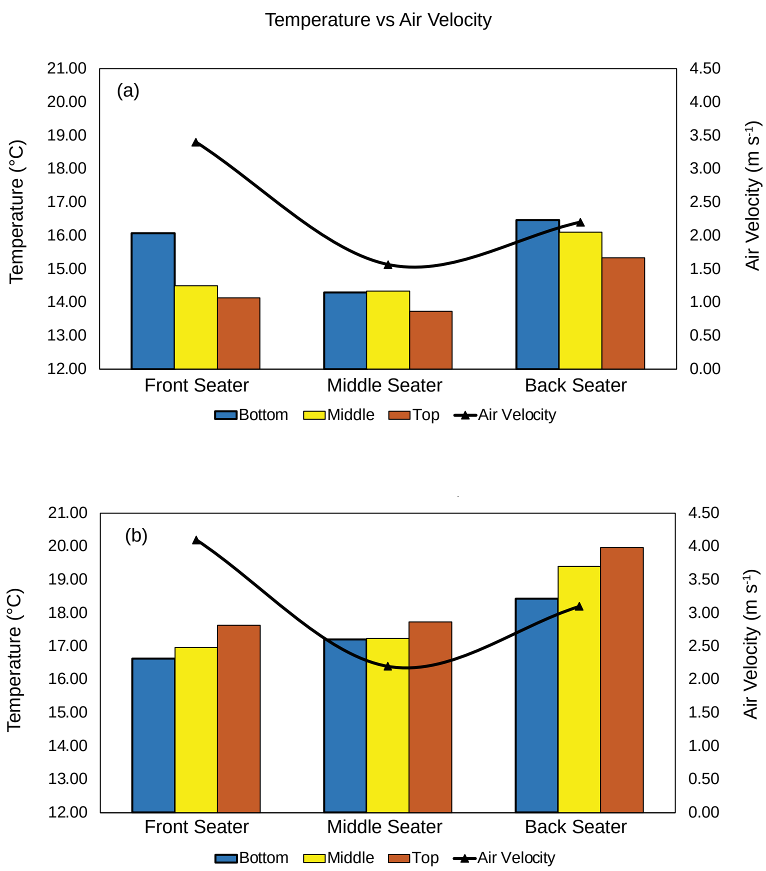
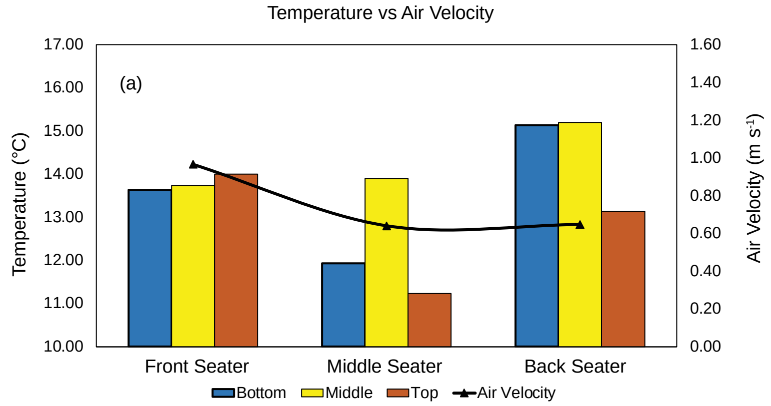


Fig. 3. Comparison of outlet temperature and ducting air velocity at different seat places at 20 km/h moving bus with (a) maximum and (b) minimum regulator speeds



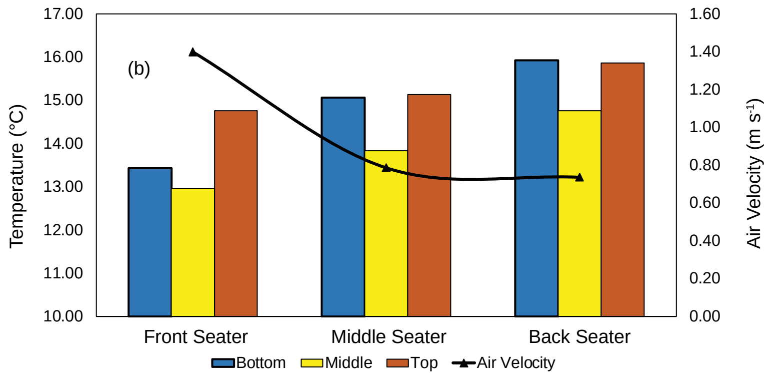


Fig. 4. Comparison of outlet temperature and ducting air velocity at different seat places at 60 km/h moving bus with (a) maximum and (b) minimum regulator speeds

The air velocity result taken at different bus speeds has been depicted in Figure 5. The data shown was for the maximum and minimum regulator speeds. It was clearly seen that increasing the bus speed would eventually decrease the air velocity inside the bus cabin. However, the air distribution throughout the front, middle and back seater is more stable at higher bus speeds where we can see a leaner line at 60 km h^{-1} compared to 20 km h^{-1}. By increasing the bus speed to 60 km h^{-1}, the engine is forced to work hard to deliver more power to push the bus forward. This interrupted and reduced the air velocity performance. It is also found that the air velocity reduced when the regulator speeds were increased from minimum to maximum speed. This situation occurs in both 20 km h^{-1} and 60 km h^{-1}. Results in Figure 3 and Figure 4 also show that the back seater always recorded the highest temperature at all conditions. Despite being disadvantaged with the farthest location from the evaporator blower that receives less cooled air, the bus engine located at the back also contributes to heat generation by radiation. Kilic *et al.,* [18] discovered that the cooling system capacity was exploited in proportions ranging from 18% to 31% to reduce the load generated by direct solar radiation input. It was also discovered by Mokhtari *et al.,* [19], sources of heat that can be developed on people's bodies include urban air convection, incident solar radiation, reflected solar radiation from pavements, and long-wave radiation from objects surrounding the person. According to other research, the number of passengers in the cabin does affect the quality of air velocity supplied Chang *et al.,* [20].

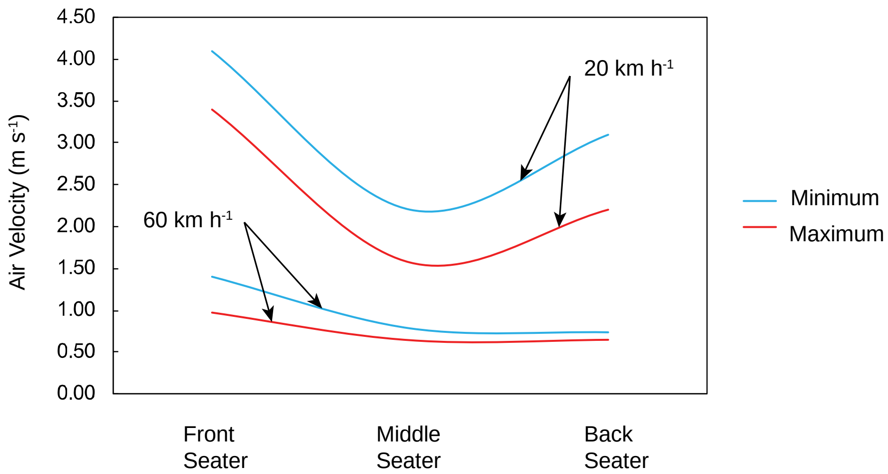


Fig. 5. Air velocity comparison has taken at the minimum and maximum regulator speeds with different bus speeds of 20 km h^{-1} and 60 km h^{-1}

Figure 6 illustrates the inside of the bus air conditioning ducting. The digital thermocouple was installed into the air conditioning outlet to reach the interior section of the ducting and measure the temperature at three different heights: top, middle, and bottom. The shuttle bus used in this study has six evaporator blowers mounted on the front side of the vehicle between rows 1 and 5 that help in the distribution of the cooled air inside the bus cabin. With an overall body length of 11985 mm, it is expected that the cooled air travel to the back of the bus will result in reduced air velocity and higher temperature. Referring to Figure 5, the hypothesis was proven when air velocity at both 20 km h^{-1} and 60 km h^{-1} recorded the same condition with the front seater receiving the highest air velocity compared to the middle and back seater. Air velocity helps on delivering the cooled air to the cabin compartment as soon as it has been released from the evaporator. However, Figure 4(a) shows that the middle seater is recording the lowest temperature even though air velocity is lower compared to the front seater. The evaporator blower operates in a centrifugal motion, transferring cooled air into the ducting using centrifugal force. This causes the cooled air to initially strike from the rooftop to the bottom side of the ducting before swirling through it and delivering air through the outlets. Under higher regulator speeds, most of the front air conditioning outlets may have missed the cooled air supply due to this striking factor. When the regulator is at minimum speed, the cooled air had a lesser striking effect resulting in a more stable and lower temperature in the front seater as in Figure 4(b).

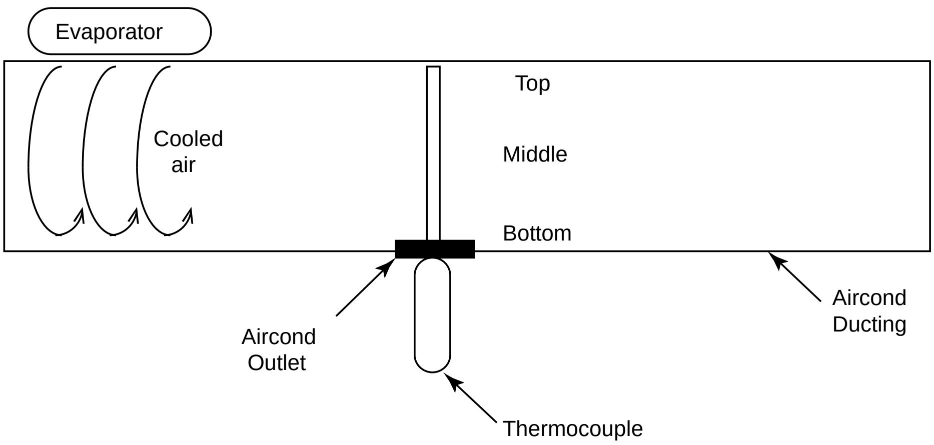


Fig. 6. Airflow phenomenon inside the air conditioning ducting

4. Conclusions

In this study, the behavior of air velocity and temperature of a shuttle bus has been examined by altering the bus speeds and regulator speeds. Results show by altering the bus speeds and regulator speeds will eventually affect the air velocity and temperature value at the air conditioning outlets. The changes seen at increasing bus speeds were that the temperature was able to drop at approximately 3 °C while the air velocity measured at the air conditioning outlet also decrease by 2 m s^{-1}. This will probably be affecting the efficiency of the cooling capacity inside the bus cabin. It was also found that the shuttle bus air conditioning design which locates the evaporator blower at the front side of the bus would create a difference in air velocity and temperature performance throughout the cabin seater. These can be seen when regulator speeds increased from minimum to maximum affecting the temperature to reduce at the range of 3-5 °C while seeing no significant change in air velocity at the middle seater and back seater air conditioning outlet. Overall, this study was implying the results of air velocity and temperature up until the air conditioning outlets. It was acknowledged that there are many other ways of measuring and evaluating the thermal comfort level. That is including the involvement of human factors to understand the details of behavior on the satisfaction level of thermal comfort. This study can be a proper milestone for advanced research in the future. Future research also can be focused on designing a good air conditioning system design by modifying the evaporator location, outlet and ducting design.

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