POLITECNICO DI TORINO

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Master's degree thesis

Solar Assisted Light Electric Vehicle

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Abstract

Electric vehicles are greatly encouraged because of the policies for the reduction of pollution and greenhouse gas emissions. The pleasant and satisfying environment is a mandatory in-vehicle cabin both in electric vehicles and internal combustion engine vehicles. To avoid the heat from the engine, and innovating air conditioning system design, the coolant in electric vehicles must be implemented. The issue is solved by studying it broadly. The use of an electric compressor instead of the mechanical compressor is the most natural solution for cooling; on the other hand, a positive temperature coefficient (PTC) heater is used to give a heating alternative to the engine coolant heater core. HVAC demands of the electric vehicle can be up to 40 % of the total energy consumption, therefore using the idea of solar panel on the rooftop of car for running the HVAC system of the car could be helpful. The purpose of this thesis is to elaborate the effects of several weather conditions on the cabin of electric vehicles, buses, and food trucks, with an idea to know about the energy required for the cooling and heating demands of the cabin. The estimation of electricity produced from solar panels on the rooftop of the bus, electric vehicle, and food truck and then using that energy for the HVAC demands of vehicle cabins. I simulated the PV solar panel for the car in different temperature and environment conditions such as cloudy, partially cloudy, and sunny day scenarios to know the power production for each situation. Then I simulated the HVAC system of the car in WLTP driving profile in different external temperature conditions to predicts the energy demand in each state. I considered an average drive for a light electric vehicle 50 Km per day. Results showed that solar energy is not enough in severe cold weather conditions, but it has a good impact on mild temperatures for the HVAC system of the car. I consider the demand of energy for HVAC of the vehicle based on the real-world weather data and driving profile.

Contents

1 INTRODUCTION

Heating, Ventilation and air conditioning (HVAC)

Electric vehicles are greatly encouraged because of the policies for the reduction of pollution and greenhouse gas emissions. The pleasant and satisfying environment is a mandatory in-vehicle cabin both in electric vehicles and internal combustion engine vehicles. The heat from the engine can be removed, a modern air conditioning system design, coolant in electric vehicles must be implemented. It is being studied broadly, to solve the issue. Some researchers have conferred the idea of thermoelectric air conditioning, where the thermoelectric modules can provide heating and cooling to the vehicle cabin. This has the benefits of long life, having no small noise size, no moving parts, and proper temperature control. However, this technology was not approved because of low efficiency [1,2]. Nowadays this technology is used in short-distance small electric vehicles keeping in mind poor figures for the quality of thermoelectric material and used in cooling some luxury cars and heating seats. [3]. The use of an electric compressor instead of the mechanical compressor is the most natural solution for cooling; on the other hand, a positive temperature coefficient (PTC) heater is used to give a heating alternative to the engine coolant heater core [4-6]. An electric vehicle with a 42-volt air conditioning system was suggested. The system has an integrated PTC heater, a blower, a compressor, an inverter, heat exchangers, and pipes [5]. The temperature of the cabin decreases fast initially and then varies more consistently. From the results, it has been shown the internal environment of the vehicle cabin could be retained comfortably and balanced by a 42 V electric air conditioning system in hot weather conditions. Plentiful heat energy could be supplied by PTC heater to warm up the vehicle cabin, but as the battery electricity provide this energy. It leads to a decrease in the driving range up to 24 % due to the low energy efficiency of the PTC heater in fully electric vehicles [7]. Another suggested option was fuel-fired heater without electricity usage for heating, but it is not appropriate for the environment. The heat pump AC system has been focused much on the research. It provides both heating and cooling by using the 4-way valve, which reverses the refrigerant flow direction. It is on the concept of the vapor compression cycle. It has been declared by Lee [8] that the power consumed for the same heating capacity by the heat pump system was nearly one-third of the electric PTC heat pump AC system. The heat pump system is considered a more feasible solution than other climate control systems suggested for Electric vehicles because the heat pump AC system has larger than one coefficient of performance (COP) [9].

Vapor Compression refrigeration- Dedicated Heater AC system

This concept is fascinating due to some modifications as compared to conventional ICEVs. The compressor is electrically not mechanically, and electric or fuel operated heater provides heating instead of hot coolant heater core [9]. Heaters are of two types, direct and indirect. Air is directly heated up to condition the cabin with the direct heating method, while in indirect heating, the cabin is conditioned indirectly by heating secondary working fluid (such as water, coolant or oil, etc.), which in turn transfer the heat to the cabin. The vehicle cabin can be more comfortable by combining different heating ideas.

Vapor compression refrigeration- Electric heating (VCR-EH) systems.

The electric heaters are economically feasible, as available commercially. The characteristics of small space, low weight, swift response, and most important environmental protection make it more beneficial and viable for electric vehicles. If the electric water heater is mounted outside, then high voltage cables are not needed to route to the vehicle cabin, therefore in case of the crash, a safety measure for the passenger is integrated into vehicle design.

AC system "i-MiEV" was introduced for EVs developed by Mitsubishi Motors Corporation [16]. This system is present in the figure given below. The method comprises of the refrigerant cycle with an electrically driven compressor for cooling, and for heating, there is a coolant cycle with a positive temperature coefficient (PTC) heater. There are four layers of PTC heater, control board part, PTC element part, upper coolant passage part, and lower coolant passage part. High voltage cable is avoided in-cabin as it is installed under the hood area. The test results of "i-MiEV" showed that it is better than conventional engine vehicles. But the cooling system decreases the driving range by up to 15 %, and the heating system reduces the driving range by 45 %.

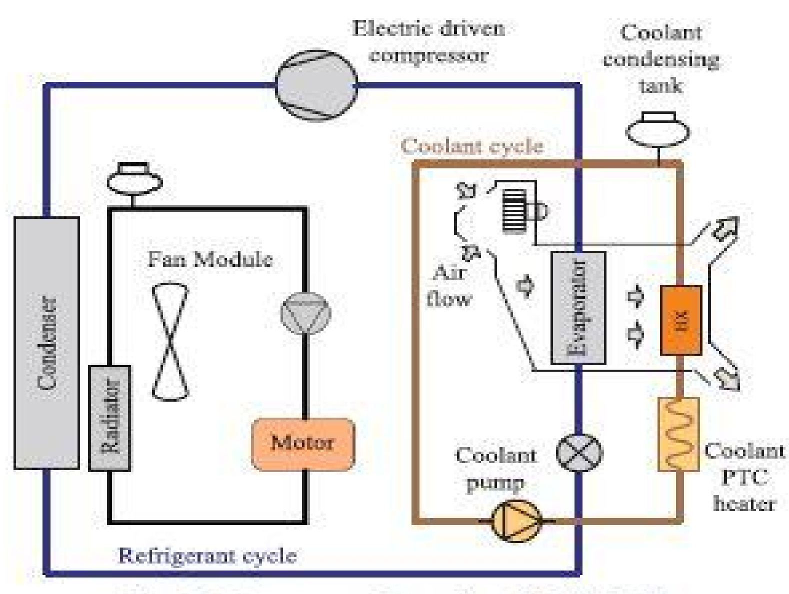


Figure 1AC system configuration of i-MiEV

In 2018, Bellocchi et al. [68] found that power consumption of the AC system was as high as 32% of the energy required for propulsion, which can decrease the driving range from 94 km to 72 km for Italian cities. For pre-conditioning and hygrometric comfort improvement, a VC-HP system equipped with an energy recovery ventilator (ERV) was proposed. The ERV is an air-to-air regenerative HX that exchanges both latent and sensible heat between the external airflow and the exhausting air from the cabin by means of a separating membrane. The figure of the system is shown in Fig. 13. The refrigerant flow is controlled by means of two 4wVs, which switch between cooling and heating mode. The system was proved to lessen the driving range by 45 %.

EV of the Dongfeng motor corporation used a heating system (indirect EH systems) designed by Sun et al. [20]. It has been proved from experiments that it takes 20 minutes for defrosting when the ambient temperature is -18 C, while it takes 10 minutes for demisting when the ambient temperature is -3 C. they concluded that the defrosting and demisting of the vehicle could be met by the heating system. Cabin heating and windshield defrosting of EV provided by the heating system, developed by Nemesh et al. [21]. This system consists of an electric coolant pump, high voltage PTC coolant heater and coolant control valve. The two operating modes of the operation are: Bypass mode and Link Mode, in Bypass mode heating system, is separated from the engine and coolant flow through the cabin, while in Link-Mode, the heating system is shared with engine and coolant flow through the cabin. From the experimental results, it is elaborated that initially, it warms up like conventional vehicles while in Bypass Mode, it warms up faster than a traditional hybrid car.

Solar Assisted AC system

For climate control, the option of a solar-assisted AC system is also fascinating for EV, as the solar cell can provide both heat-insulating layers and recharge the battery. The batteries are being fully charged by the system, which provides energy for the AC system and can also prevent the vehicle from the radiant heat of the sun through the roof. The maximum value of the required cooling capacity can be reduced by 40 % [130]. Solar assisted heat pump system was designed by Ma et al. [131]. The roof of the compact car is covered by a solar cell, which can generate about 225 W power. It was concluded by Zhao that the two-hour generating capacity by the solar panel could keep the system running for half an hour [133]. The solar ventilation system was included in the third generation of Prius [134]. The built-in solar panel provides energy to the solar ventilation system for operating the fan within the AC system. When the vehicle is parked in the direct sunlight, this system provides the ventilation of the vehicle interior. The solar panel produces nominal 22 V DC and 3.6 amp, consisted of 36 polycrystalline silicon cells.

Air cycle heat pump system integrated with a turbocharger, a blower, and a regenerated HX was proposed by Li et al. [35] for EV in 2017. It is indicated in the thermodynamic analysis that higher heating capacity and thus high COP can be achieved if the blower installed before the compressor. The results show that power consumption can be reduced by about 23 % under the same conditions of the air cycle with turbocharger compared to the PTC system for EVs. The cooling COP is much lower than vapor compression systems and is usually below 1.0.

Plugin Electric Vehicle

Air cycle heat pump system integrated with a turbocharger, a blower, and a regenerated HX was proposed by Li et al. [35] for EV in 2017. It is indicated in the thermodynamic analysis that higher heating capacity and thus higher COP can be achieved if the blower installed before the compressor. The results show that power consumption can be reduced by about 23 % under the same conditions of the air cycle with turbocharger compared to the PTC system for EVs. The cooling COP is much lower than vapor compression systems and is usually below 1.0.

Plug-in electric vehicle is the hottest topic nowadays, and it has attained extraordinary attention. Up to some extent, the rising interest intends fast circumstantial advancement in policy, technology, and industry planning intend to trigger the uptake of this emerging technology. The PEV endorsement is encouraged from all aspects, executing various financial and non-financial incentives. [plug in]

PEV can play a vital role in reducing air pollution and greenhouse gases emission both in transport and overall if deployed on a larger scale. Despite the fact, this new technology influences the potential community challenges, so rapid deployment should not be expected. The internal combustion engine (ICE) is well established for decades, and PEV shall compete with it. Furthermore, the owner of PEV must have adaptations of various habits, starting from the inferior like the plugging in of the vehicle at work, home at night or at office during the day, to the major as subscription to a car share program to have alternative for longer distance traveling or routing road going to coincide with charging stations.)

Direct-current fast charging (DCFC) is the recommended, a quick fix, to support long-distance traveling and ease the range anxiety in plug-in electric vehicles. But DCFC is considered more expensive as compared to the usual workplace or residential charging. Especially the cost for fast charging applications can be significantly affected by the electricity demand charges. The fast-charging cost can be reduced by deploying solar photovoltaics (PV) panels and energy storage batteries. For low utilization loads, energy storage can only be more productive and can help to lessen demand charges.

Mostly the charging of PEVs in the current situation is done at the owner's house. But a series of proper charging stations or vehicle supply accessories are mandatory for those who couldn't get better recharge vehicle at home, helping to manage range anxiety problems, and making possible long-distance traveling. Availability of electric vehicle supply equipment and charging stations make the electric vehicle comparable in mobility opportunities to the regular gasoline vehicle. Particularly the electric vehicle battery can be refilled quickly by direct current fast charging (DCFC), as it supplies 50kW or more Power, helping to add in 20 min range of 50 miles or more. Extreme fast charging is studied in order to reduce refilling time more. Excessive fast charging is characterized by charging up to 400 kW, which can contribute a range of 200 miles in about 10 minutes.

DCFC (Direct Current Fast Charging)

The expanded adoption of PEVs in the United States and the network of DCFC stations are increasing proportionally. In the United States, 2305 DCFC stations or 6688 plugs and 402 Tesla proprietary superchargers were operating in April 2018 [5]. Furthermore, there is the planning of more DCFC stations [6]. But as per the previous literature for low utilization cases, DCFC stations can arouse high electricity costs [11,12]. This total electricity cost is widely impacted by the retail electricity fixed and demand charges. Fixed charges are independent of the power consumed per month, while the demand charges are directly proportional to the maximum power consumption and independent of the total energy used in total.

Cost Reduction

Using market structures, like restructuring standard electricity price, or with technology, the high cost of electricity for DCFC can be reduced. For instance, for a five-year introductory period in Southern California Edison, new optional PEV rates are proposed in which demand charges will be waived to incentivize new market low utilization stations [15]. Different methods can be studied to mitigate the high cost of electricity, such as deploying the DCFC station in conjunction with solar panel photovoltaics (PV), implementation of a configuration of co-location in which the DCFC station is connected to the existing meter within a commercial building and energy storage, i.e., battery.

Photovoltaic

The charging cost of PEV and the impact of the PEV charging on the grid can be reduced using PV [30-33]. The deployment of energy storage (battery) in alliance with PV is considered by many studies to overcome solar intermittency. The PEV charging station, coupled with PV in a workplace parking garage, would be more beneficial to vehicle owners as compared to home charging, and the garage owner will earn profit within the life of solar panels [34]. It has been shown by Azuara Grande [36] that DCFC station with PV and storage is more cost-competitive economically in Spain, that can provide electricity between 8 and 11 a.m. and 3 to 7 p.m. at 0.4 euro/kWh and 0.25 euro/kWh between 11 a.m. and 3 p.m.

Electric Vehicle Solar Parking

The linking of the development of clean solar electricity and electric vehicle charging is intended by the concept of solar parking lots. The parked electric vehicles are provided shade and charged with electricity generated by solar panels.

The solar parking lots for electric vehicles may be private or public property and can be installed anywhere at the shopping center, workplace, supermarkets, hospitals, hotels, restaurants, train stations, airports, universities, highway, city entrances, and so on. There is too much parking space in the world which can be converted to solar parking lots without the need for new land. The parking space in the United States is approximately 11,200 km2.

Modeling PV in Energy Plus

The remote area PV system is being modeled in energy plus. The surplus PV generation is supplied to the simulated retail building after meeting the demands of PEV charge demand. The maximum power consumption is 100 kW when two PEVs are being charged simultaneously because the site has two 50 kW DC fast-charging stations. Determining the size of PV from this study is that the minimum peak capacity of the PV should be 100 kW. The modeled PV module has a peak capacity of 230 W, so 540 total modules are required to have a peak capacity of 124 kW. The excess 24 kW is because the PV output is usually lower in real conditions than the rated power at standard terms. The area is 3762.57 m2 of the modeled building roof. 37 % area of the roof of the building is covered by installing a total of 540 modules, in which 36 parallel strings of 15 modules in series with a row spacing of 0.6 m and a tilt angle of 15.14 are being installed [40]. The inverter with a maximum continuous output power of 110 kW is selected.

Proposed Methodology

The methodology developed in this section is to use a renewable energy source such as PV and DM of the end-use load to absorb PEV penetration at the retail site. To keep the PEV penetration transparent is the aim of the recommended methodology, i.e., to take in additional increment in building peak demand.

PV operation

The owners of PEV are being given priority over the building consumptions to charge their vehicle immediately without any delay. The simulated building demand is increased by the PEV charge profile, as shown in the figure. PV generation tries to overcome the increased demand because of PEV charging. PV generation is dependent upon the weather conditions though it is available all day. The output of the PV varies, at every, I minute intervals, with a change in solar irradiance on a simulated day. The extra PV energy is provided to the mock retail building during the absence of PEV charging.

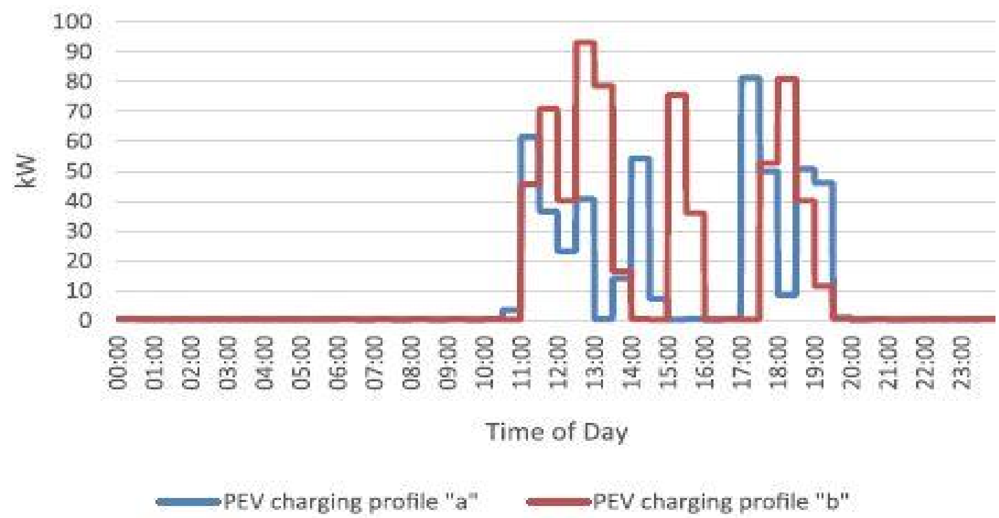


Fig. 2. PEV charging profiles considered in this study.

DM of end-use loads

The DM of two primary energy consumption loads, i.e., lighting and HVAC, is performed to reduce the building's electrical demand if PV is unable to withstand the load due to PEV charging. DM alone is responsible for PEV charging during low or no PV generation events, i.e., during evening and nighttime.

Zones' Priorities for DM

The control of lighting and HVAC loads of all zones in the retail building is based on the priority given to them. To absorb PEV penetration lighting and HVAC loads of lower priority zones are controlled first, followed by higher priority zones. The priorities allocated to the zones for the application of DM are shown in the table. The assignment of the priorities is based on the significance of activity performed and also on the density of the population. The zones other than entrances and sales areas are assigned lower priority as these zones have not sales potential. Corridors and mechanical rooms, due to low occupancy, are appointed a lower priority.

SOLAR DRIVEN REFRIGERATION (solar driven cooling)

The breathtaking rise in demand for high cooling and the occurrence of upcoming solar-driven technologies has increased the interest in solar cooling technologies. The idea of a cooling system driven by solar is not new (Butti and Perlin, 1980) [1]. This concept of the cooling system is further developed after about one century from the publication of the ideal textbook of Mouchot (1869) [2]. Among the others, the Solar Experimental station of the Italian CNR in the 60 (Silvi, 2003) [3] by the Italian pioneer.

Until the first oil crises in the 70s of the 20th century, the idea of a solar cooling system and most of the solar technologies were limited to the "curiosity-driven" domain. The United States and Japan carried out many activities in the 80s, and some remarkable results of introducing new technologies, approaches, and components, were achieved.

The demand for electricity is being affected by the growing demand for cooling services in most of the countries. It results in unfeasible seasonal peaks, the risks of blackouts, and the increase in the cost of electricity (Banaras et al., 2007a, 2007b; Desideriet al., 2009a, 2009b) [4].

The hourly demand for electricity in Delhi affected by cooling demand in summer is an example of such an impact. The number of greenhouse gases in the atmosphere from such trends have too much influence on it, both because of leakage of high GWP (Greenhouse warming Product) refrigerants and emissions related to fossil electricity consumption. A more profound action contradiction should come from a diffused application of solar cooling systems as the cooling services are more desirable where there is a string of solar radiation is available. (Kalogirou, 2004) [4].

Main characteristics Of Solar Cooling system

The solar cooling systems are represented by the mentioned key ingredients (1) solar collectors, (2) a thermally driven cooling process, (3) EVENTUAL heat rejection units to expel the waste heat of the cooling process, (4)a thermal storage system to buffer the solar energy as with the cooling demand.

Sunroof

The breathing air temperature can be reduced by 5.7 C by utilizing the natural phenomenon by providing inlets at the foot level by opening the sunroof up to 6 cm, which is a reduction approach equivalent to the operation of HVAC blower at medium speed (6.9 C) [6]. But this method is not resistant to extraneous factors such as pollutants, moisture, rain, and critters, etc.

Cracking the windows

It is being found by Robert and Roberts [7] and King et al. [8] that the cabin soak temperature can be reduced up to 16.4 C by cracking all the windows by 5 cm [9]. The comparison of temperature increase was made by GIBBS et al. [10] by exposing two cars to the sun from 14:30 to 16:00.

Solar-powered ventilator

The solar-powered ventilator has been examined early and studied intensely by Chiou, which is the most extensively used approach for the reduction of internal cabin temperature [11]. Solar-powered ventilator system that has been tested consists of six fans (1.7 W) at a rate of equal to 0.077 kg/s [12]. The temperature reduction was insignificant when the air was being blown into the vehicle through the HVAC heater/defroster ducts and any other natural body leakage space. Contrarily the decline in the air temperature was significant at 5.6 °C because of convection heat loss driven by the internal airflow when the air was being pulled in through any natural body leakage areas or through the HVAC heater/defroster. Thus, it was concluded by them that blowing the air into the cabin was less effective as compared to using a solar-powered ventilator to evacuate air of the cabin. For decreasing the cabin soak temperature to that of the ambient temperature, two improved fans and a motor-powered by the solar panel were used by Saidur et al., to pull out the acquired heat inside the car cabin [13]. The temperature was reduced by 12.4 °C as the airflow rate was improved by 0.063 kg/s [14]. According to Jasni and Nasir, the cabin air maximum temperature can be reduced by 3.3 °C by fitting solar-powered ventilator with every side window. But they concluded to diminish the interior cabin temperature by Solar-powered ventilator was impractical.

(single/Mix-mode)-Powered ventilator

Experimental analysis was carried out by Gowtham et al. of a solar-powered ventilator in combination with a thermoelectric generator which uses the heat recovery from the exhaust of the vehicle's engine without using a car battery, to decrease the cabin temperature through supplying proper ventilation considering the draining effect of car battery [15]. It was confirmed by them that within 20 min the temperature inside/ outside the car could be equalized by 5-6 units of these prototypes. Infrared-reflective (IRR) windshield is used as a pre-ventilation with a 15 min to pull out the acquired heat from the cabin before using AC to diminish the thermal load on the HVAC system [16]. It was confirmed that a total of 9.9 °C reduction in the thermal soaked cabin temperature from this combination. IRR windshield help to reduce 4.0 °C and 5.8 °C for just in time.

2. Solar chimney

The solar chimney is the approach used for temperature reduction because of its ability to drive airflow via the chimney channel from the thermal buoyancy force, temperature force caused by a change in air density [17].

2.1 System description

The SC system is shown in the following figure; it is a single pass flat-plate solar air collector made up of an enclosure used for mounting and protecting it from the environment, a single glass cover, a flat plate made of a black metallic as an absorber, an air gap for making channel to escape air to colder region and insulation below the flat plate and sides used for heat loss minimization.

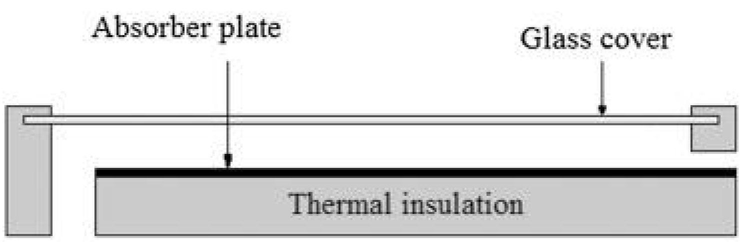


Figure 2 Solar chimney

Solar chimney for soak temperature reduction

Solar chimney concept is a natural ventilation approach to enter the airflow through space, so no mechanical work is needed; the different pressure zone help to ventilate the area by flowing air between the openings. The density difference between exterior and interior air due to temperature difference between space and its surrounding results in buoyancy force, which helps to induce more flow.

The buoyancy force ensures the flow by overcoming the gravitational force and frictional loss between the two openings and duct [18]. If there is a higher temperature than outside, then hot air has low density, so it will move up and skip from the top opening, and the cold air will enter from the smaller opening [19]. The term stack effect is used when there is the movement of airflow through space, and pressure is the most concern and issue. For overthrowing the negative thermal gravity under the plan of mass air flow, enough draft is generated by density variation along with the collector channel feed by solar collector [20], [21]. Then the natural ventilation is boosted up, and power generation is increased by the induced airflow and helps to evacuate the hot air from the soaked cabin.

Due to the temperature gradient between the foot level and cabin ceiling during the soak period, two opening at a different height in the cabin can be provided, and the solar chimney is integrated on the cabin roof. For evacuation, the cabin acquired heat airflow by natural convection can be induced to replace the hot air by cold ambient. The natural phenomenon through space can be developed by pressure difference, which can be influenced by temperature force known as buoyancy force or stack effect.

Buoyancy Force

The difference between the top and the base of a column of fluid due to height between opening, or the hydrostatic pressure difference between outside and inside space is due to the driving force for natural draft or stack effect. The pressure gradient along the vertical direction over the wall of space will be created, and the densities difference will be developed as the temperature changes between the two areas [6]. The drop-in pressure due to the stack effect that is used to evacuate the air through the duct can be calculated according to Bernoulli's principle [23], [24].

The pressure difference or driving pressure due to stack pressure or buoyancy force ΔP that helps to drive the air through chimney can be found from the following method.

$$\Delta P_s = P_i - P_0 = g \int_0^h (\rho_i - \rho_0)\ dh$$

In terms of temperature, this equation can be shown by the Bernoulli equation with the combined ideal gas equation of state.

$$\Delta P_s = gh(\,\rho_i - \rho_0) = gh\Delta\rho = \frac{\rho_0 gh\Delta T}{T_i} = \frac{\rho_i gh\Delta T}{T_0}$$

where

ΔP_s Stack pressure (Pa)
P_i Static pressure at the inlet (Pa)
P_o Static pressure at outlet (Pa)
ρ_o Density of the outside air (kg/m^3)
ρ_i Density of the air in the chimney (kg/m^3), as same as ρ_f. Commonly ρ_i is assumed to be constant within the chimney or to vary linearly with height [25].
g Acceleration due to gravity (9.81 m/s^2)
h Stack height of the chimney channel, vertical distance between the two openings (m)
ΔT is the difference of temperature between inside/outside chimney (°C)
T_i Inside chimney temperature (°C)
T_o Outside chimney temperature (°C)

2.3. Proposed system cycle

The SC ventilation integrated into the cabin roof is shown in figure during the soaking period. The planned system passively ventilates the car cabin during hot days. The proposed method is shown in the picture given below.

A rectangular hole is made and linked to the inlet of the collector channel through a flexible duct on the cabin roof. The temperature of the car cabin and SC significantly increases while parking it on a hot sunny day. Due to closeness to the absorber plate and solar panel, the temperature inside the chimney channel will be significantly higher than the cabin air temperature. Density difference is created among the three zones due to the temperature gradient between the different systems, which helps to evacuate the hot air out of the vehicle cabin due to natural draft through chimney channel and to its surroundings, as the air in the chimney is warmer, so having less density. The hot air in the cabin is replaced by ambient air, which is pulled in through the ventilation air conditioning (HVAC) ducts and natural body leakage areas to restore. The ambient air temperature will be dominant on the entrapped hot air due to the continuous cycle during hot days.

Solar Chimney development

The main objective of the SC is to remove the accumulated soaked heat through the convective air stream from the cabin of parked vehicles by inducing mass flow rate to keep the vehicle cabin thermally comfortable for the vehicle occupants upon entry. Though the construction and design of the SC were mainly depended on the energy balance equation of the different ingredients of the system, to ensure the proposed strategy effective its impact on the reduction of cabin temperature and literature recommended and the previously developed comprehensive theoretical model's optimization results to study the SC performance. Formulation results and consideration are also included such as the rate of heat buildup in the vehicle cabin estimation and the mass flow required to remove the heat build-up, SC geometry calculation, selection of right properties of the material (absorptivity and emissivity of the absorber plate, transmissivity), optimization of specific parameter (inclination angle, air channel gap), and taking into consideration the metrological parameters (solar radiations, orientation, etc.). The performance of SC and cabin temperature reduction is dependent on the above-mentioned environmental factors.

Required air mass flow rate

The main driving parameter in this methodology is the expected air mass flow rate (m) that is used to evacuate the accumulated heat from the vehicle cabin. The predicted air mass flow rate to maintain the car cabin air temperature can be calculated from the following equation.

$$m = Q_{gain}/C_{cv}\Delta T$$

Where,
Q_{gain} is the thermal energy gained per unit time (W),
C_{cv} is the air specific heat at constant volume (0.71 kJ/kg)
ΔT is the difference between the interior and exterior temperature of the vehicle cabin.

The principle of thermodynamics, energy conservation, and fluid dynamics helps to estimate the heat gain (Qgain) in the vehicle cabin [28]. Heat gain in the vehicle cabin is determined to 39.5 W by assuming the tropical climate conditions as in Rome. During the soaking- parking period to equilibrate the cabin air temperature, this amount of warmth is needed to be removed by SC. The results are confirmed to be acceptable by comparing them with the other researcher cabin models for a standard sedan family car. For instance, the energy accumulated in the car cabin was 30.54 to maintain its temperature to the level equal to the ambient temperature [27]. According to [26] the average was considered 50 W. the distinction between the results of those approaches was that the little difference in the environmental conditions and cabin geometry (solar radiation, air velocity, and ambient temperature), heat gained by the cabin varies based on the assumed boundaries and initial state, and the time selected for the calculation. However, the required mass flow rate of air found to be 0.011 kg/s handled by SC.

Geometrical calculation of Solar collector

The suitable geometries of the solar collector to cool the vehicle cabin by injecting the ideal mass flow rate can be calculated according to the theory of flat plate solar collectors. The area of the collector is thus found by carrying out a thermal efficiency equation of the collector. The instantaneous thermal efficiency under steady sate condition of convectional solar thermal collectors is stated in [29,30,31].

$$\eta_{th} = Q_u / A_c I_t$$

Then to handle this flow rate, the required area of the solar collector is calculated. The experimental measurement conducted for this study to measure the different design parameters (collector geometry and mass flow rate) aid in the adopted values of environmental parameters. Under this condition, the corresponding heat removed by the SC by inducing mass airflow rate is given by the equation.

$$Q_u = mC_f \Delta T$$

where,

Qu is the heat removed or evacuated by the collector, (W).

Ac is the collector absorbing area, (m2).

It is the total incident solar radiation per unit time per unit area on the tilted absorber's surface and set at 900 W/m2.

C_f is the air specific heat (kJ/kg.k) at the mean temperature and calculated at (T_f) of hot air in the chimney.

ΔT $T_{fo} - T_{fi} = T_f - T_C$

T_{fo} is the collector outlet airflow temperature (K).

T_{fi} is the collector inlet airflow temperature (K).

T_f is the mean airflow temperature in the chimney (K).

The area of the collector (A_c) found by them was 0.53 m^2. The area of the outlet channel (A_o) is found by (L.W) and (d.W), respectively.

A_c =L.WW =A_c/L

A_o =d.WW =A_o/dv

So,

Ac/Ao = L/d

Where,

L is the collector length, (m).

W is the collector width, (m).

D is the air gap between absorber and the solar panel glass.

The proposed SC is developed by considering the following parameters based on the above equation

- The collector absorbing area, *Ac*=0.53m2
- The outlet cross sectional area of the channel, *Ao*=0.053m2,
- Collector length, *L*=1 m.
- Collector width, W=0.53 m.
- The air gap, *d*=0.1 m.
- Inclination angle is set at 12°.
- Opening size is set as a unity

The required flow rate is secured by considering a factor of 1.5 practically.

Car with PV installed ventilation fan

A vehicle parked in an open space directly to the sun using PV powered motor-fan for ventilation technique was used by M. Kolhe et al. The temperature of the vehicle cabin can reach up to 60 ®C when it is parked in an open space while the sun is clearly shining. They examined the PV powered DC motor ventilation fan in order to reduce the car cabin temperature and to make efficient electric cars [35].

Experimental Setup

The Renault Zoe electric car was used for the experimentation of PV powered ventilation in Edinburgh Napier University. The cabin temperature was measured by placing thermocouples in it. The placement of thermocouple is shown in the figure.

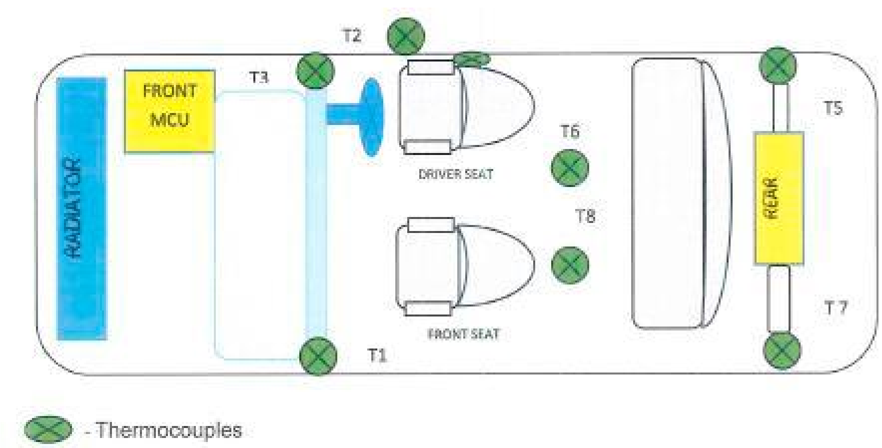


Figure 3 Thermocouples representation [35]

Data Measurement

The measurement of the car temperature was observed for six days. We consider only the first observation and the last observation [35].

Day 1 – 3: Two fans of 10 W and 12 W were used, fans were mounted the rear side of the car, and the front windows were released. Fans were operated directly from PV solar panels.

Day 1-3. Solar Radiation Measurement

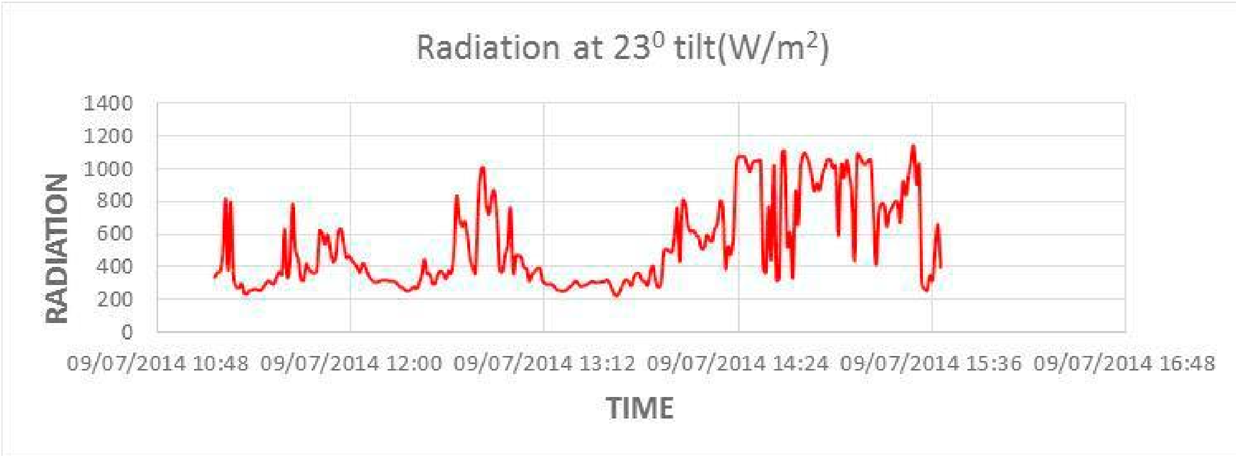


Figure 4 Solar Radiation [35]

Measurement of Temperature

The temperature measurement of rear and front of vehicle cabin is in the following graphs.

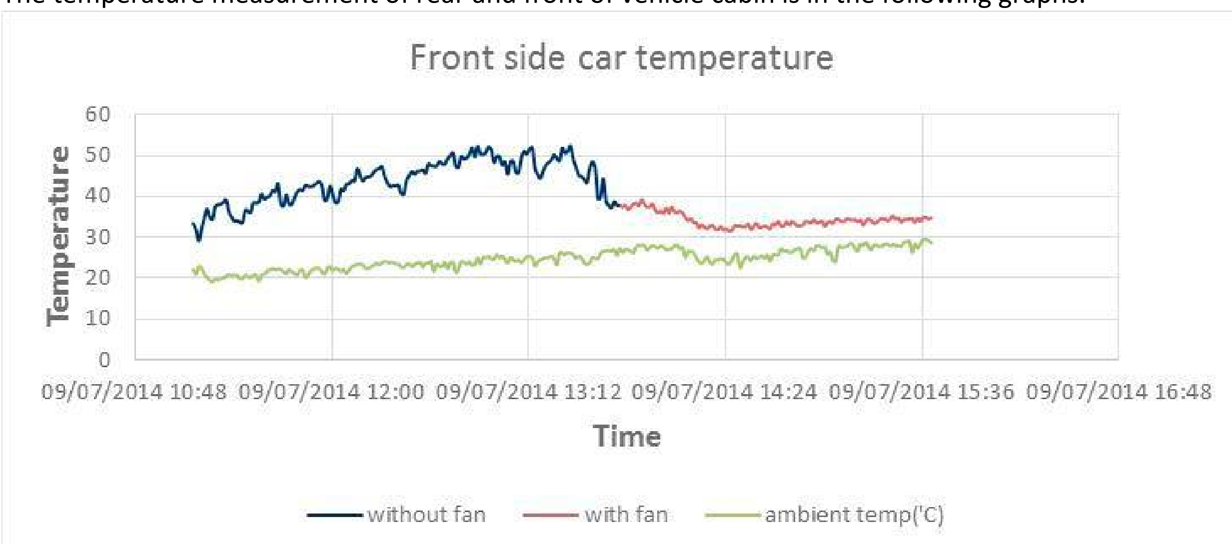


Figure 5 Temperature on Front side of car [35]

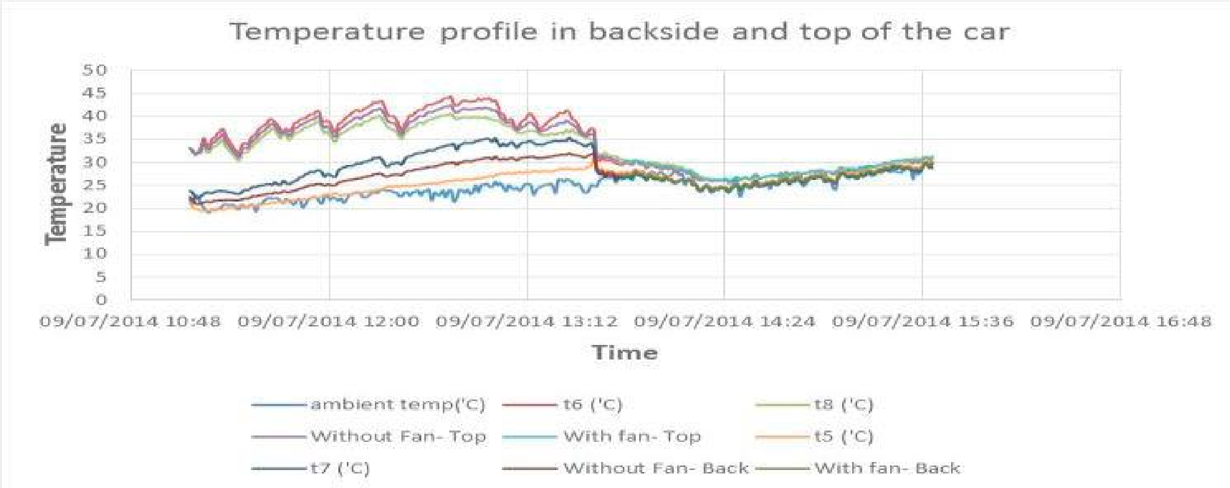


Figure 6 Temperature on backside and Top of car [35]

The above two graphs show the temperature details of the rear and front of the car with and without fans. The vehicle inside cabin temperature was recorded 52 °C at maximum value. The cabin temperature starts reducing and reach an average cost of 33 °C after turning on the PV powered fans. It was also observed that the maximum temperature at the backside of the car was 35 °C and the average temperature of the top side was 43 °C. the temperature drops to 25 °C after turning on PV powered fans.

Day 6:

The temperature variations in the car cabin were only measured in this time period. The aim of this test was to do the analysis of cabin temperature for 24 hours.

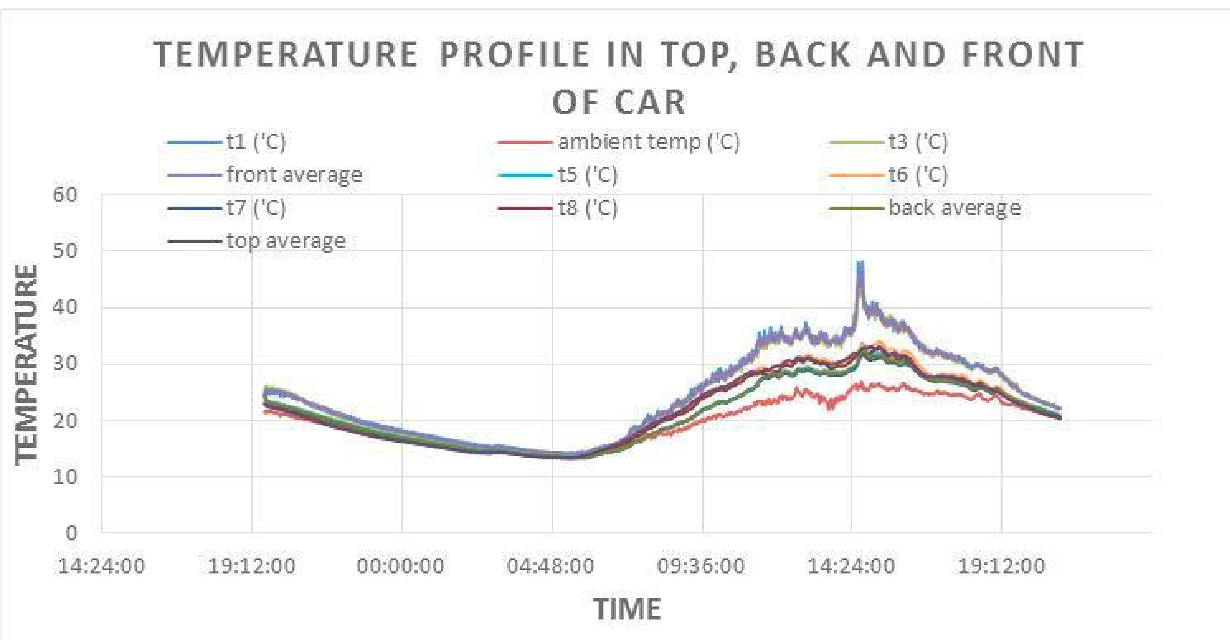


Figure 7 Temperature on Front, Back and Top of Car [35]

An increase in temperature up to 48 C was recorded due to thermal lamination. The heat descended to nearly an ambient value at 8 PM because of sun fall.

Conclusion

we can conclude from experimental results that the ventilation system powered from the PV modules integrated on the roof of a vehicle during the summers can decrease the cabin temperature. The temperature of the vehicle cabin can be reduced to nearly an ambient temperature value.

Hybrid Photovoltaic Thermal (PVT) technology

Solar PV thermal collector is a technology that is capable of both producing electricity and acts as a thermal absorber. Together with heat and electrical power can be produced at the same time. A little fraction of solar radiation is used to produce electrical energy, and the remaining is just a waste heat responsible for increasing the temperature of PV cells, which decreases the efficiency of the solar cell [36]. Thermal and photovoltaic systems are merged into a single unit; the size of the module can be reduced, increasing the benefits of the solar source [35]. The hybrid solar PVT technology help to utilize the waste heat and use it for beneficial purposes. Using the waste heat of PVT help to keep up the electrical efficiency at enough level [36].

The PVT integration can be of several types, which are air, water, or evaporation collectors. The fascinating properties of the PV/T system are.

• it is a multi-function used both for producing heat and electricity

• the combined efficiency is always higher than the two separate systems

• The heat output is used for both cooling and heating purposes depending upon the requirements. It is cheap and practical.

Solar Assisted Heat pump integrated with PVT

the hybrid solar collector is specially designed based on an electric heat pump system capable of covering the needs of cooling, ventilation, and heating system. The maximization of the seasonal coefficient of performance (COP) of a heat pump is in the list of advantages of a PVT collector. The electrical and thermal efficiency of the system is increased by the PVT collector.

Solar assisted Heat Pump

The solar-assisted heat pump system is a unique heat pump system integration with solar thermal technologies. The combination of the PVT and solar-assisted heat pump system is considered as the best approach for space heating and PV cooling.

The performance of the subsystem or system is improved by the coupling of the heat pump system to solar thermal hybrid collectors. The energy collected by the solar thermal collector at low temperatures may not work efficiently indirect heating, but his strength could be the source for the heat pump system in winter. The utilization of solar irradiance and maximization of COP of the heat pump is done by integrating hybrid collectors with heat pump systems.

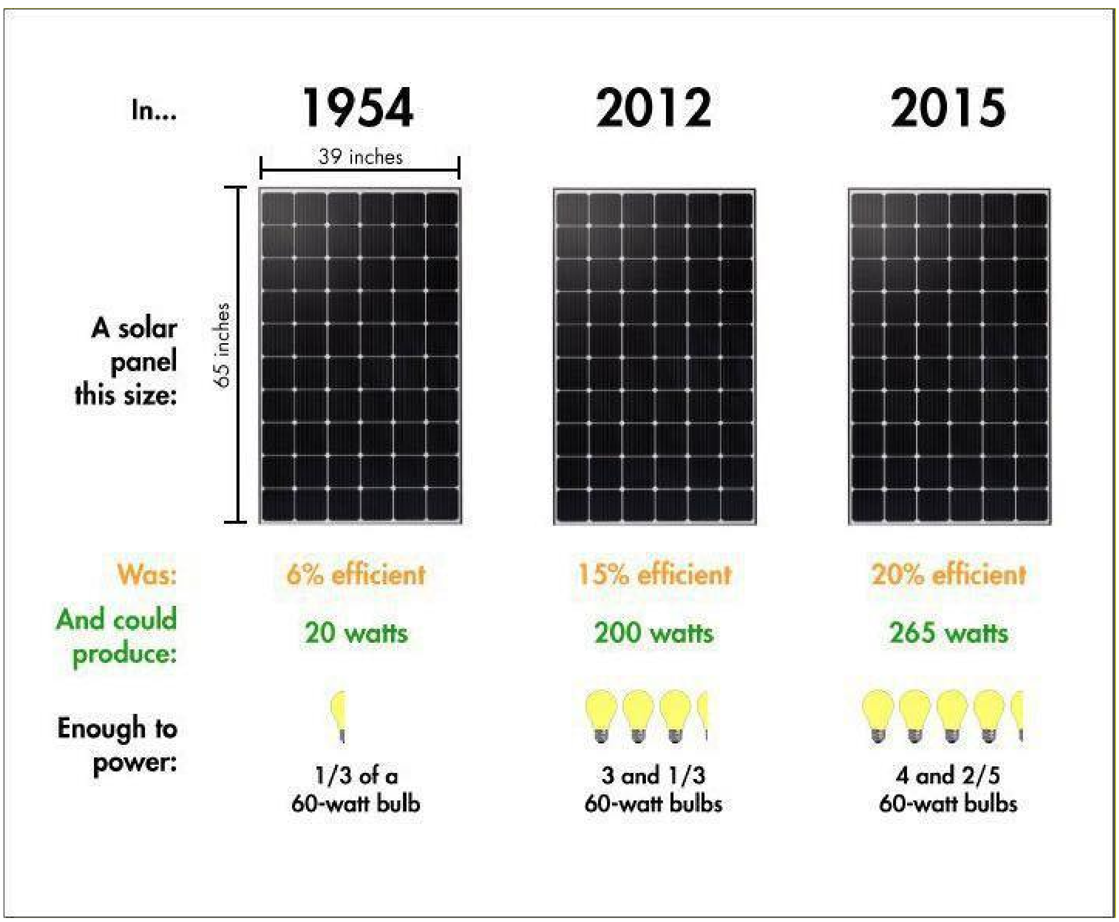
Rome Case study

Solar Power Production Estimation

Electrical energy is produced by harnessing the sun rays or photons or solar energy. This energy is produced by solar panels composed of PV cells established. The photons are converted to electrons as the sun rays fall on the panel; these electrons are direct current (DC) electricity that is transformed into alternating current (AC) power by flowing them through an inverter. The electrical power produced from solar energy is then used, and the solar energy produced is measured by an energy meter. The efficiency of the solar cells, the size of the panel, and the amount of light falling on the solar panel are the key factors of the amount of producing electric energy. The amount of light falling on the solar panel is dependent on the season and weather conditions. As the amount of sunlight is a variable quantity so we can't predict the production from the solar panel.

Efficiency of solar panels

The solar ability is directly related to the amount of solar sunlight or energy from the sun to be converted to electrical power. In the mid-20th century, the capability of the solar cells was only 6 % to take the energy from the sun. However, the efficiency increased progressively to 15% in 2012 and 20% nowadays, the power rating of a solar panel is defined by the combination of the effectiveness of the cell and the size of the panel.



Average Solar Panel Power rating

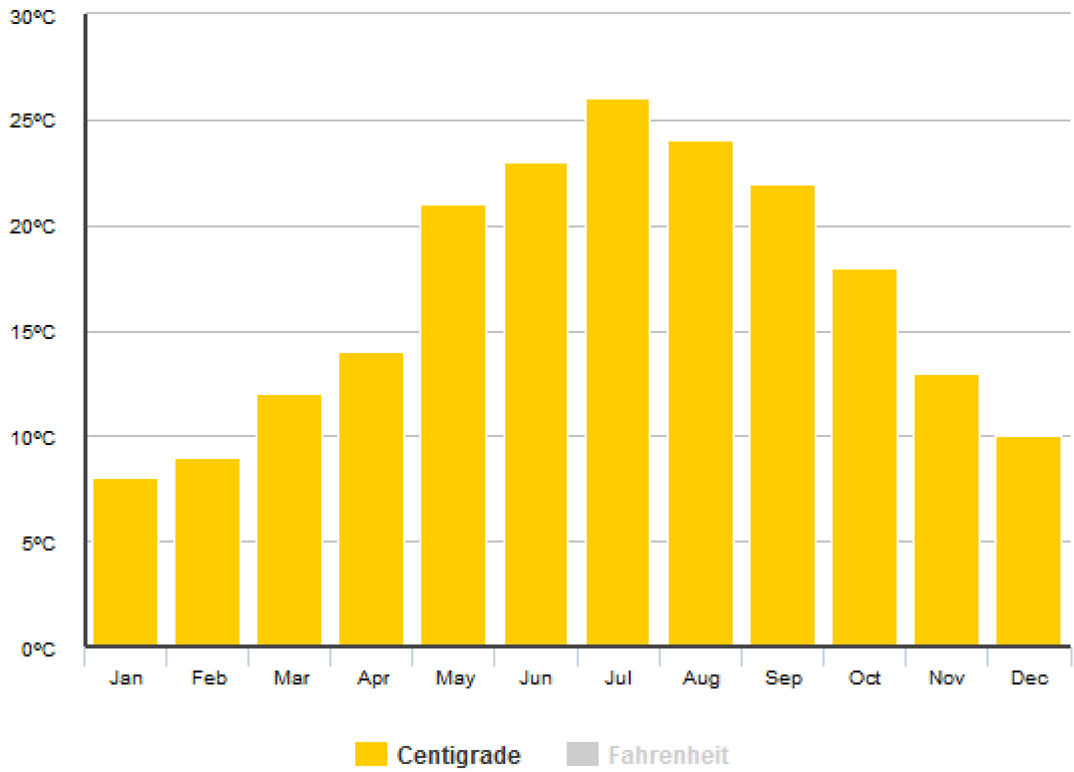
The average power rating produced nowadays by the solar panel is 265 W, variable up to 320 W depending upon the size and efficiency. The panels are being tested under ideal conditions called "peak sun" analogous to 1000 W of sunlight per square meter of surface, that is equivalent to the energy from the sun at noon during a hot summer day, on the equator, to determine the Standard test Condition (STC) rating. If the label on the back of the solar panel shows 250 W, it means the module will produce 250 Wh of electricity if it receives full sun for one hour. So, we consider the solar panel as one energy source to be installed on the rooftop of the electric vehicle having the characteristics shown in the table [15].

Dimension	1.65 m (L) × 0.99 m (W)
Area	1.63 m2
efficiency	20%
power rating	260 W
weight	20 kg

Average Temperature

Rome and its metropolitan area have chilly winters and warm to hot summers due to its Mediterranean climate. The climate of Rome is warm- temperature subtropical, according to Troll-Paffen climate classification. The average temperature of Rome is around 16̊ C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
°C	8	9	12	14	21	23	26	24	22	18	13	10
°F	46	48	54	57	70	73	79	75	72	64	55	50



Average sunshine times daily

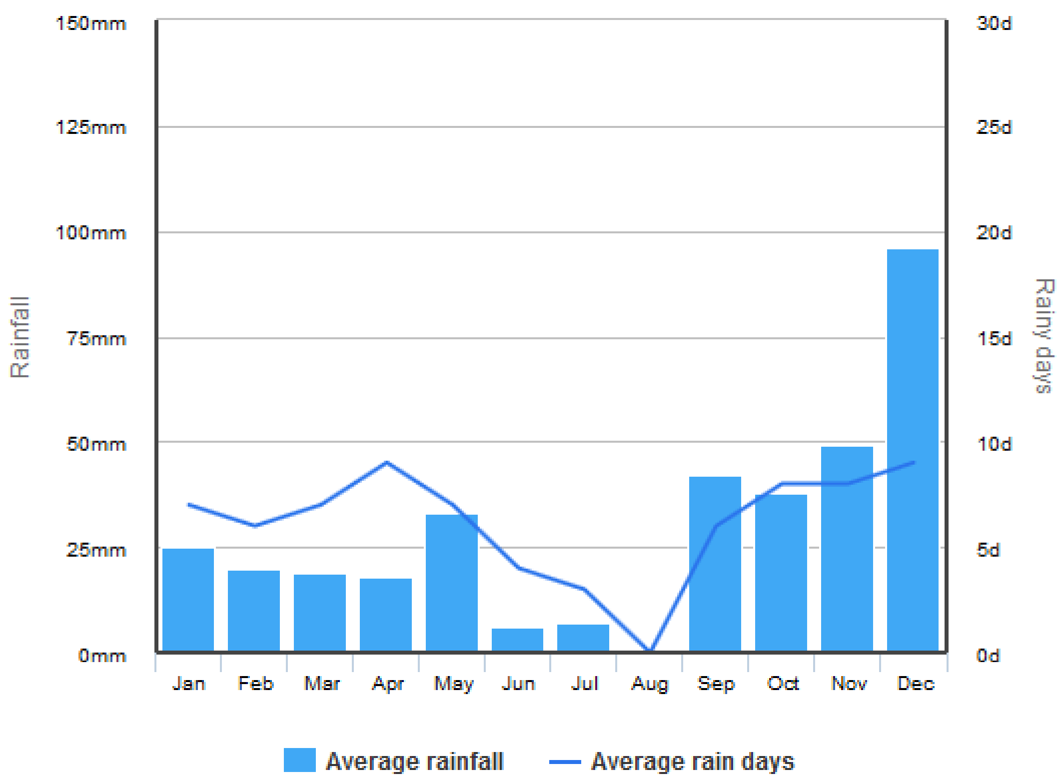
Rome has the advantage of having one of the highest numbers of hours of daylight in Europe. Compared to the northern part of the continent, the winter days are not short; the average daylight hours in the winter are 10 hours. The table shows the hours of light in different months in Rome.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours	4	5	7	7	9	9	11	10	8	6	4	3

Average Rainy days

The average rainfall per year in Rome is conferred to be 837 mm (33 inches) or 68.8 (2.8 inches) per month [16]. The rainfall per year is 83 days on average or 6.9 days a month with a quantity of rain, sleet or snow, etc. average rainy days during a year are shown in the table.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mm	25	20	19	18	33	6	7	0	42	38	49	96
Days	7	6	7	9	7	4	3	0	6	8	8	9



Rome has a high potential of using solar energy as per the high number of sunny days, on average 282 days in a year, and daylight hours. Solar energy can be employed in this sector due to high demand from the population, and it is a necessary fossil fuel and natural source consumer. The sunshine for power generation in countries like Japan (not a solar country) can be used for just 1100 hours per year, while in Rome it 2525 hours per year, which is 2.3 times more than Japan.

Annual sunshine hours = Average Daily Sunshine Hours × 365 = (4+5+7+7+9+9+11+10+8+6+4+3)/12 × 365 = 2525 hours.

Heat Pump for EV HVAC

Waste heat from within the vehicle to heat the vehicle cabin is done by today's car. Waste heat can be heat from the engine or heat from the ambient air. This technology is useful in conventional fuel vehicles as it produces heat in significant quantities.

But a challenge is being faced by EV and Hybrid EV due to the fact of producing less heat by their engines. Waste heat can be produced from the electric element, but this could surf a vast amount of electrical energy, which results in a reduced driving range. The driving range of EV can be decreased by up to 40 % by depending on the battery to produce heat.

The heating and the cooling problem of EV is being solved by using the new technology of the heat pump. Though this technology is not new in the automobile industry, it is coming now.

A heat pump transfers heat to and from a working fluid (a refrigerant) to the air, working as a heat exchanger. Heat pumps can both help to cool and heat the vehicle cabin and help in increasing the battery estimated range extensively. It was determined by Behr that the scale of the car should increase by 40 % -50% compared to a conventional system because their heat pump will provide heating in EV by integrating into the refrigerant circuit.

Working principle of reversable heat pump

The working principle of the reversible heat pump system, which is already presented by Lemort et al. [19], is shown in the figure. The heat pump in cooling mode works as a conventional automotive AC system, while it works as air to the glycol-water heat pump in the heating system in which heat is transferred to a vehicle cabin with a heater core located in the AC module. Conventional AC automotive components are used to assemble the heat pump. The compressor is a variable swept volume wobble plate compressor; the front heat exchanger (outdoor heat exchanger) is a conventional louvered fin and plate heat exchanger, generally used as condenser in automotive AC systems, and the heater core (indoor unit in heating mode) and the evaporator (indoor unit in cooling mode) are the heat exchangers located inside a conventional automotive AC module. For heating to complete the system, a traditional expansion valve and heat exchanger of an aluminum plate are selected.

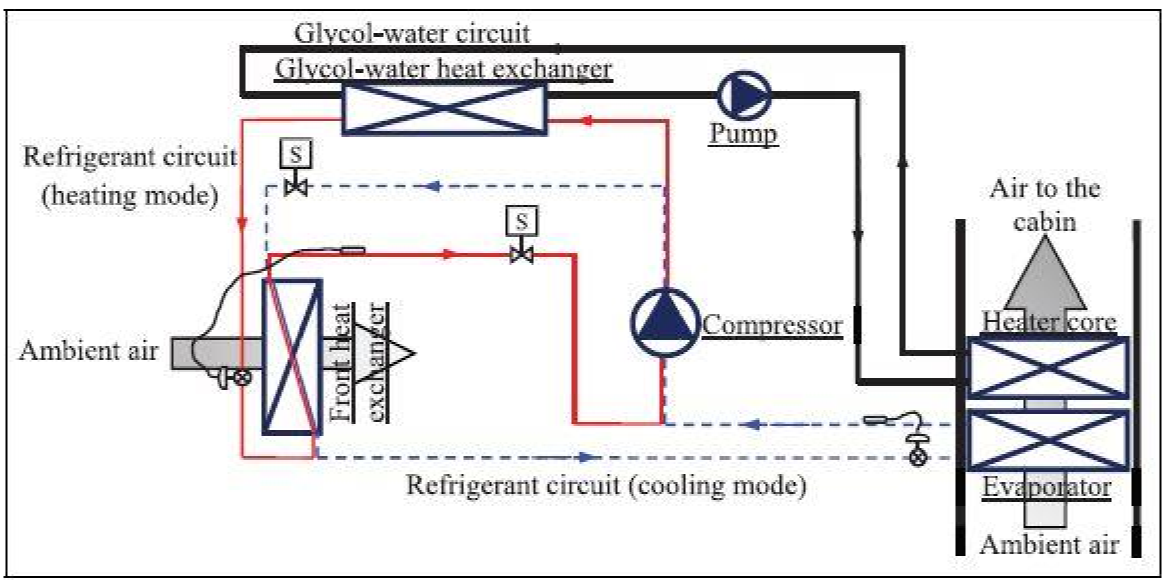


Figure 8 Heat pump

Mathematical Modelling

The thermal changes of the heat pump are described here in this part. Simulink program is designed from these equations. Validation of specific heat pumps helps in the suggestion of simulation. To specify all the changes in the heat pump circuit, especially describing the refrigerant, is more complicated. Therefore, simplifications are considered for simulation purposes.

A heat pump is entirely considered as a constant mass flow of refrigerant qref.

The energy value of sub-components is calculated by simulation. The impact on the other calculations when some value is changed, the precision of estimation must be considered.

It is mandatory to know temperature between individual sub-components in this simulation so to determine the enthalpy of the refrigerant

The energy of refrigerant entering in an evaporator.

$$Q_{ev} = q_{ref} s_{ev} T_{ev} \text{ (W)}$$

The heat flow received from the environment through the evaporator can be expressed:

$$Q_{evap} = q_{air} c_a (T_1 - T_2) \text{ (W)}$$

Thermal power delivered by the compressor into a refrigerant;

$$Q_{comp} = q_{ref}(s_c - s_{evap}).(T_c - T_{evap}) \ (W)$$

The refrigerant as an energy input into the expansion valve:

$$Q_{cond} = q_{ref} s_{co} T_{co} \ (W)$$

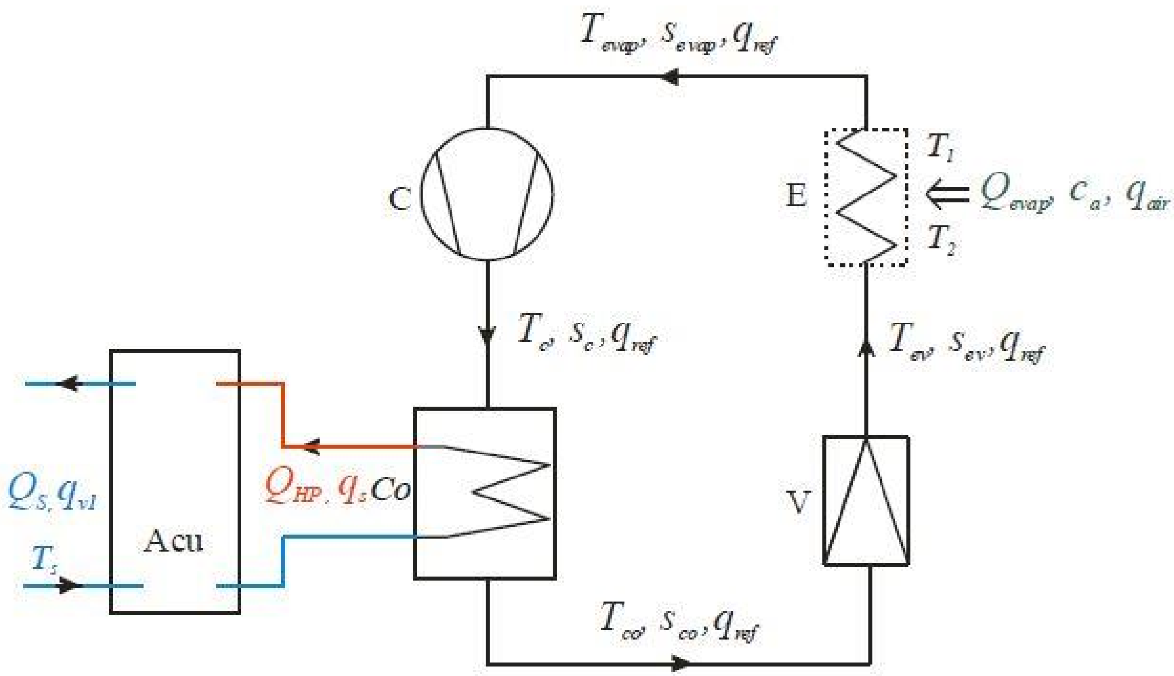
Subsequently, it can be presented, that the heat flux input to the storage tank is reduced of the

efficiency the heat exchanger, which is about 70-80 %:

The equation is used for the calculation as a simplification because the

s_{ev} and T_{ev} are not known. It presumes

$Q_{cond} = Q_{evap}$.



$$Q_{hp} = \left(\frac{Q_{exp} + Q_{evap} + Q_{comp} - Q_{cond}}{q_{ref} \cdot \frac{S_{co} - S_c}{2}} . c. q_s \right) . Q_z \ (W)$$

Mass flow calculation of hot water into the accumulation tank is determined:

$$q_s = \left(\frac{q_{ref} \cdot \frac{S_{co} - S_c}{2}}{c} \right) kg \ s^{-1}$$

The coefficient of performance is determined from the energy output of the heat pump and electrical energy and is related to the heating mode [3], [4].

$$COP = \frac{Q_{HP}}{W_c} = \frac{Q_{HP}}{\frac{Q_c}{\eta_c}}$$

Vehicle cabin Characteristics

The following table shows the cabin parameters, which affect the temperature of the cabin. Solar radiations in winter and summer 0.9 and 1.3 kW/m2 respectively, heat from the passengers, which is 120 W per person, and the size of windows is shown in the table.

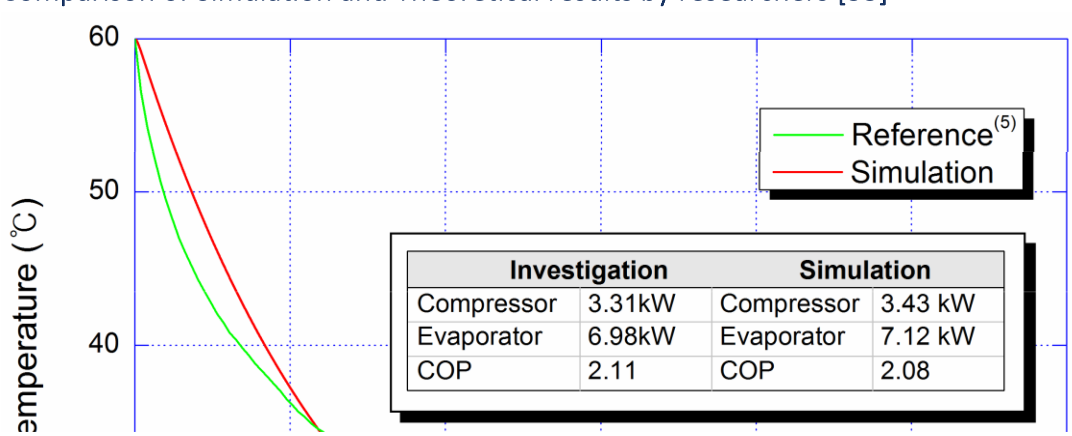
PARAMETERS	VALUES
CABIN SIZE	3 m3

FRONT WINDOW AREA	0.858 m2
SIDE WINDOW AREA	1.8064 m2
REAR WINDOW AREA	0.6232 m2
SOLAR LOAD	0.9, 1.3 kW/m2
HUMAN HEAT SOURCE	120 W

Test condition of cabin

	Parameters	**Values**
	Ambient Temperature	**30, 35, 40 °C**
Cooling Mode	**Target Temperature**	**20 °C**
Heating Mode	**Ambient Temperature**	**-10, 0, 10 °C**
	Target Temperature	**25 °C**
Number of Passengers		**1 - 4**
Control Method		**±0.5 °C**

Comparison of Simulation and Theoretical results by researchers [33]



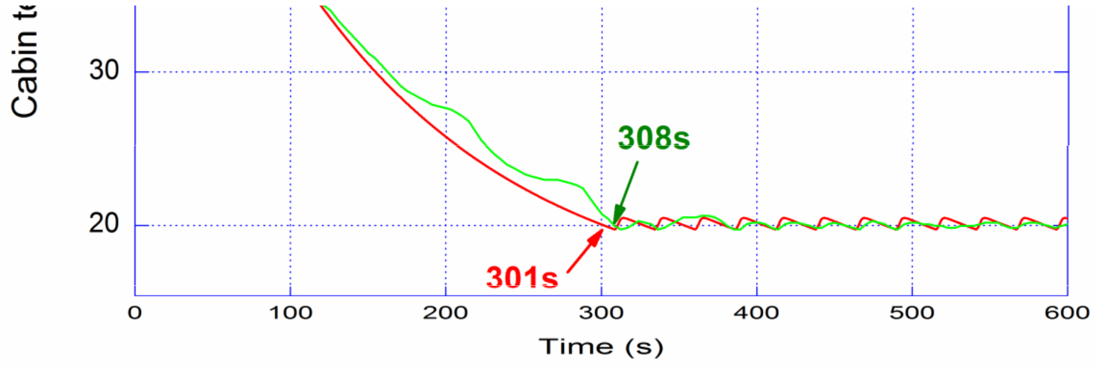
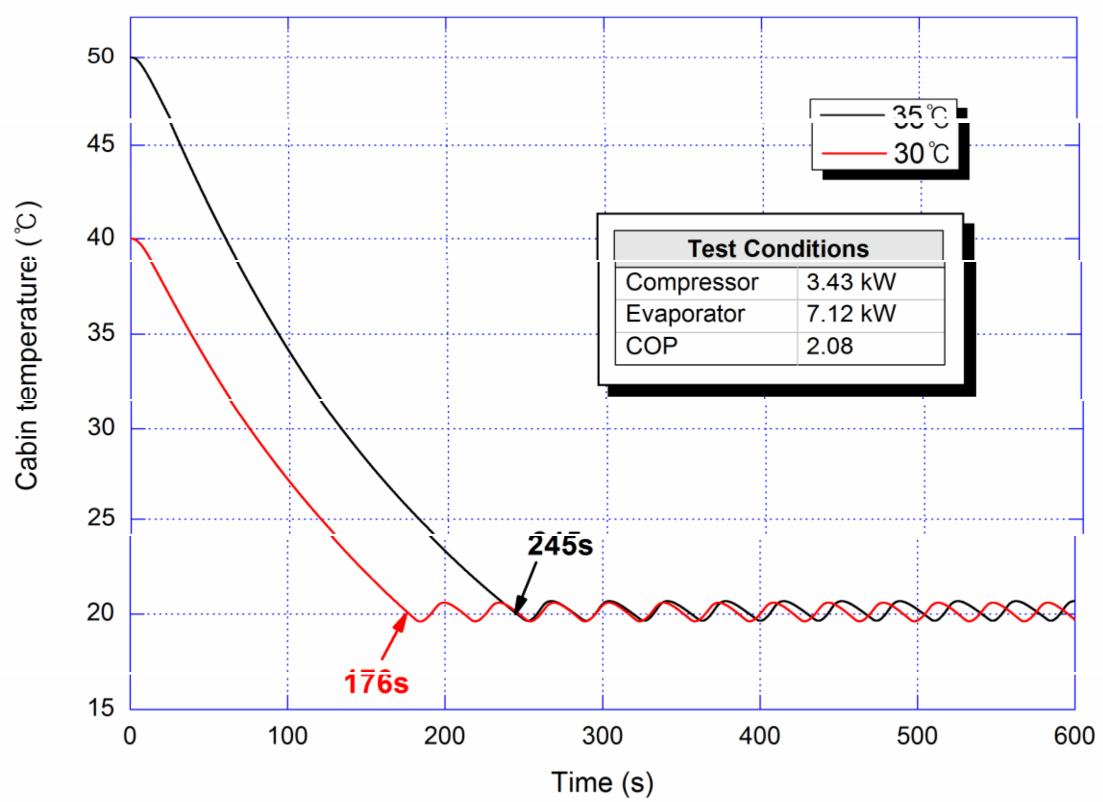


Fig. 5 Validation of cabin temperature variation with reference (33)

Validation of heating capacity with Lee et al. (32)

Ambient temperature (°C)		**-10**	**0** °C	**10** °C
	Heating Capacity (kW)	3.51	4.87	5.89
Investigation	**Compressor work**	2.18	3.63	4.74
	COP	1.61	1.34	1.24
Simulation	**Heating Capacity (kW)**	3.56	4.85	5.75
	Compressor Work	2.12	3.27	4.53
	COP	1.68	1.48	1.27

Cabin Temperature Variation at 30, 35°C [34]



The above figure shows the experimental results of simulation of the ambient temperature of 40 and 50 °C since there were no comparable experimental results for 35 and 30 °C. it takes 176 and 245 seconds from 40 and 50 °C respectively to reach the targeted temperature. Once the target temperature is achieved, the cabin temperature is maintained.

Heating characteristics of the AC/HP system

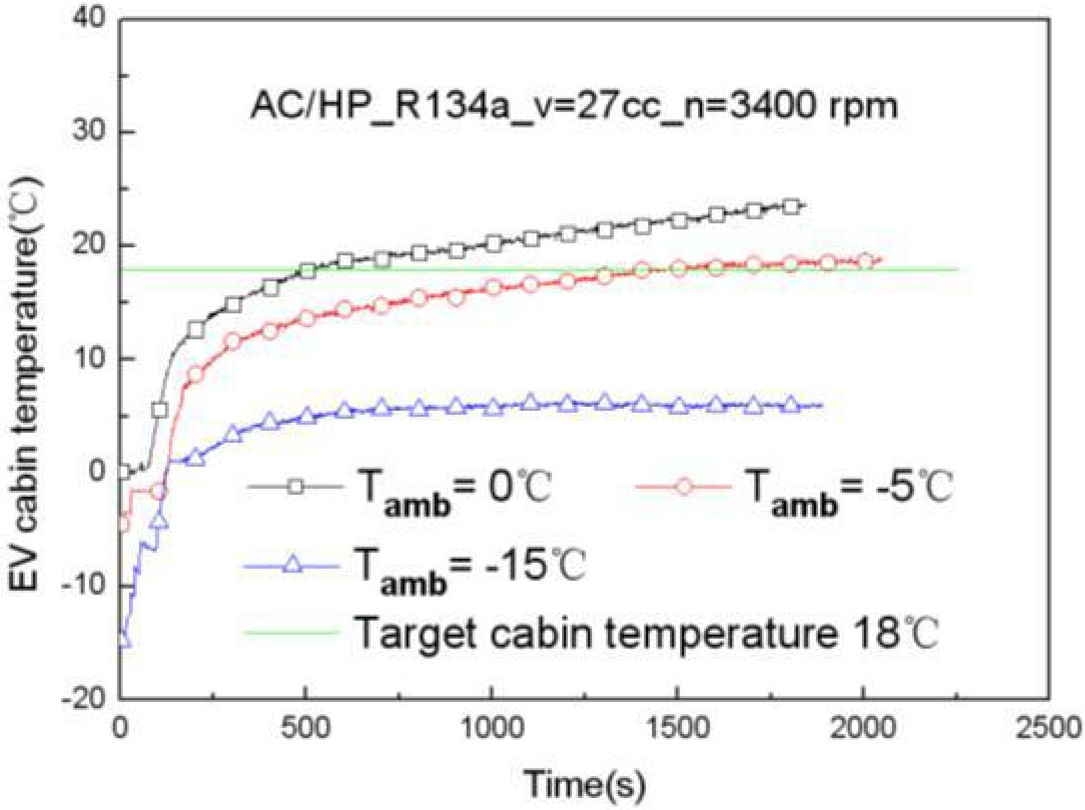


Figure 9 Variation of the cabin temperature

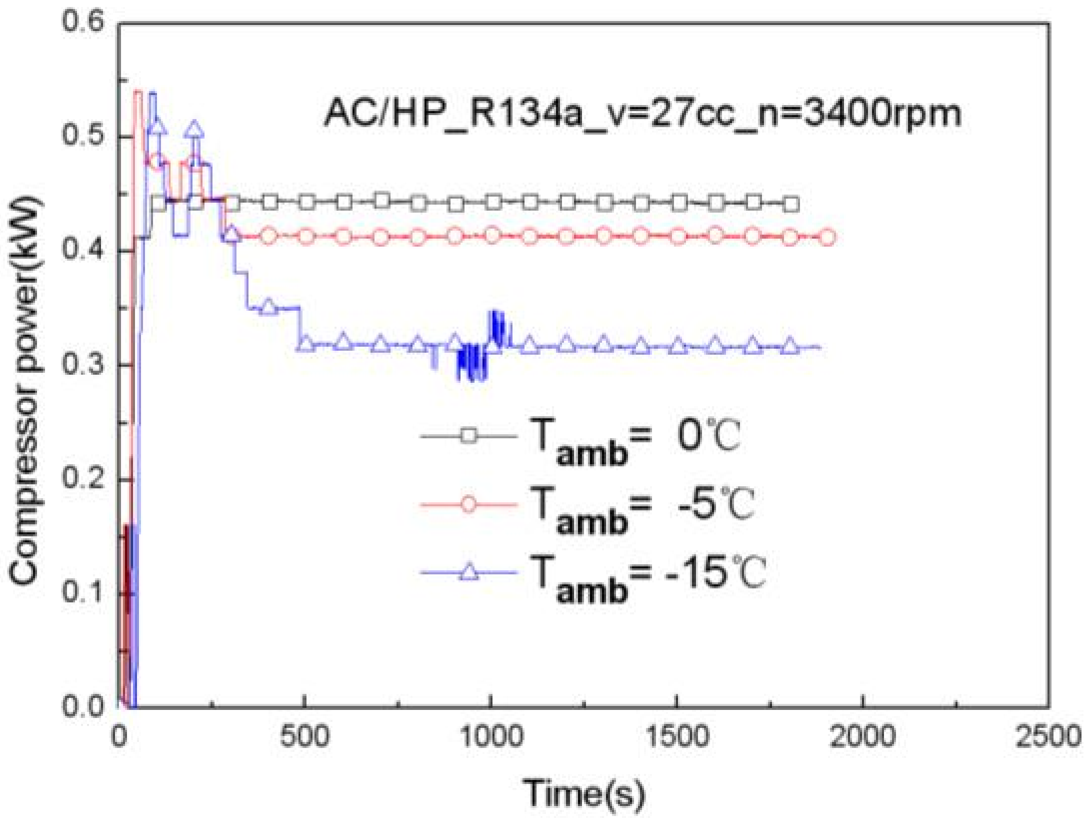


Figure 10 Variation of the compressor power consumption

Test results showed that, when the proposed AC/HP system was used to heat the EV cabin, the system performance was easily affected by the operating conditions such as the ambient temperature and compressor speed. Fig.3 shows the influences of the ambient temperature on the AC/HP system. In this case, R134a was served as the working fluid, the compressor 27cc was used, and the compressor speed was maintained at a moderate value of 3400rpm. It can be found from Fig.3(a) that the EV cabin temperature could be raised to 18°C under the ambient temperature 0 °C and -5°C. But the system heating capacity was barely acceptable at -5°C. As the ambient temperature dropped to -15°C, the cabin temperature could not be raised to 18°C, even the system working time was long enough. Fig.3(b) displays that the compressor power gradually became stable after the initial oscillation. With the decreasing ambient temperature, the initial power oscillation was prolonged, and the final power value was reduced distinctly. When the ambient temperature decreased from 0°C to -5°C, the stable amount of the compressor power was reduced by about 6.7%. This indicates that the influences of the ambient temperature on the power consumption exhibited the opposite tendencies for the AC/HP system and PTC heater.

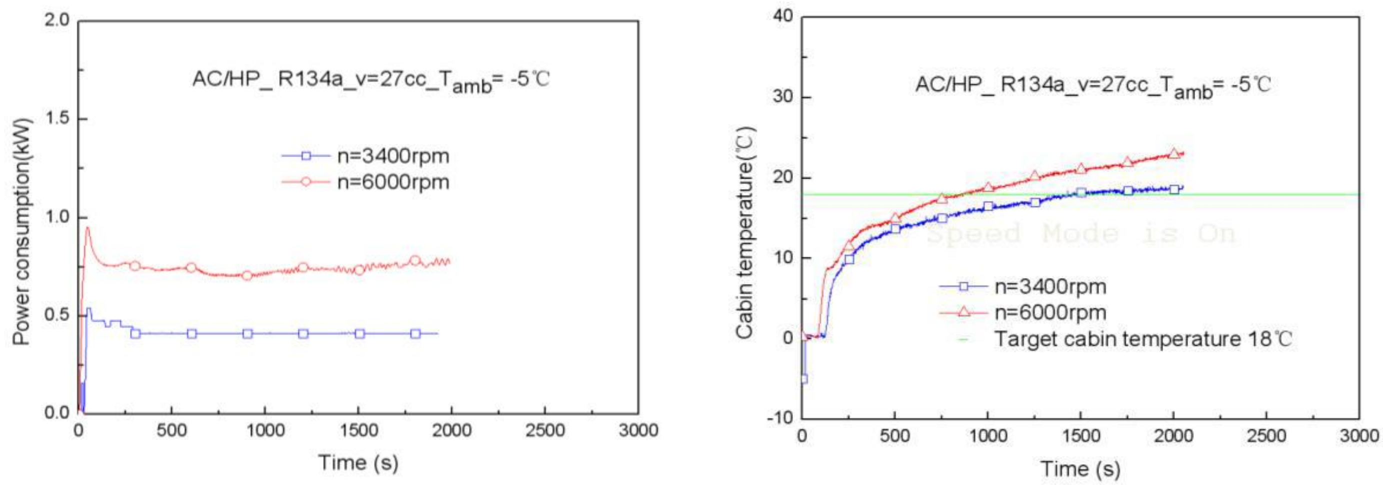


Fig (a) Variation of the cabin temperature under different compressor speeds;(b) Variation of the compressor power consumption [38]

Fig.a shows the impact of the compressor speed on the cabin temperature and compressor power consumption. The compressor 27cc and refrigerant R134a were still used, and the ambient temperature was kept at -5°C. Increasing compressor speed helped to shorten the healing process for the EV cabin. As the compressor speed rose from 3400rpm to 6000rpm, the required time for raising the cabin temperature to 18° C was reduced by about 600s. Meanwhile, the compressor power was increased by about 0.37kW (as shown in Fig4b); it indicates that regulating the compressor speed had a significant impact on the system power consumption [38].

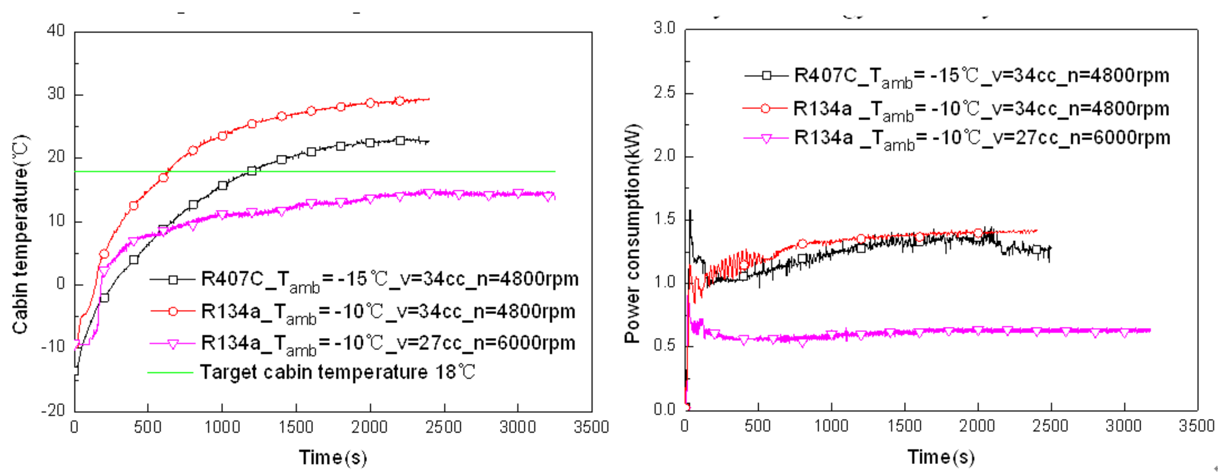


Fig: (a) Variation of the cabin temperature under different heating conditions; (b) Variation of the compressor power consumption [38]

Conclusion

From the above discussion, we can predicate that the amount of energy produced by the solar panel is enough for heating the vehicle cabin while the ambient temperature is below 0°C. As we can see in the graphs that it takes approximately 1300 seconds to reach the desired value of temperature, i.e., 18 °C with a 27 cc heat pump. As in this condition, the power it consumes is nearly 0.5 Kw, so by using the energy formula, it consumes 0.209 kWh, while a solar panel (250 watts) of 1.6 m2 area can produce 1.5 kWh per day if the sun shines for 6 hours.

Bus HVAC system

The HVAC system of typical buses has an air conditioning unit on the rooftop, and for heat distribution, it has foot-level convectors. The rooftop unit consists of several heat exchangers and a compression refrigeration machine for heating and cooling of air.

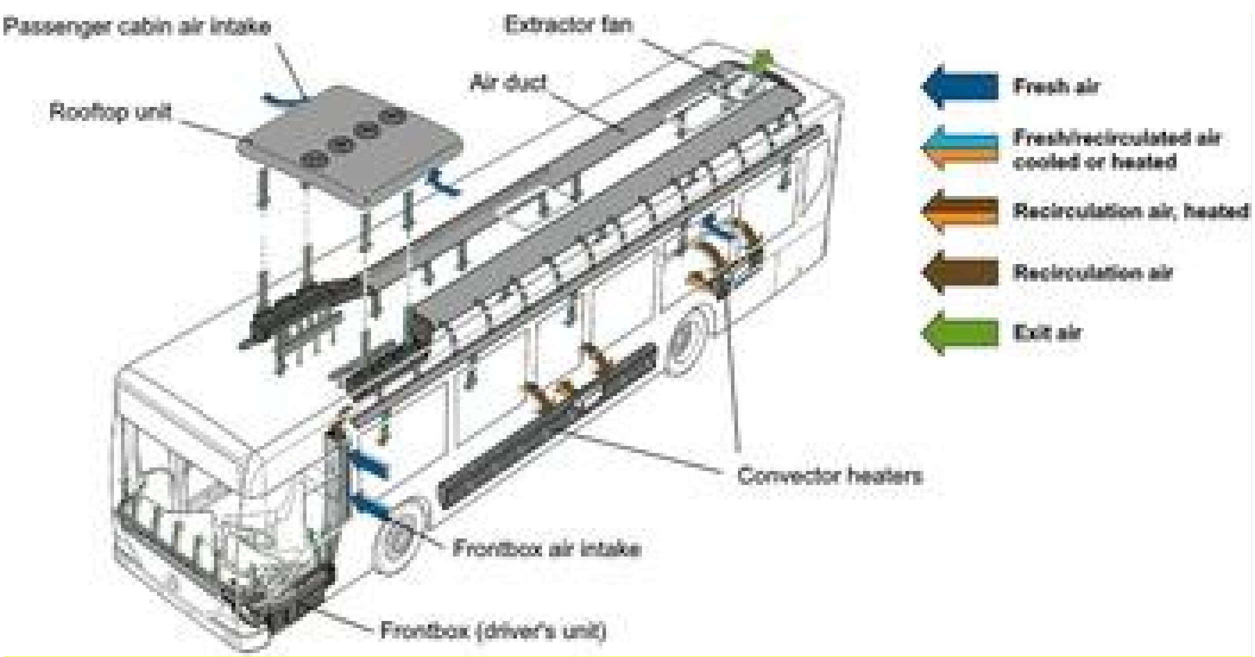


Figure 11 bus external view [36]

Bus Air Conditioning System

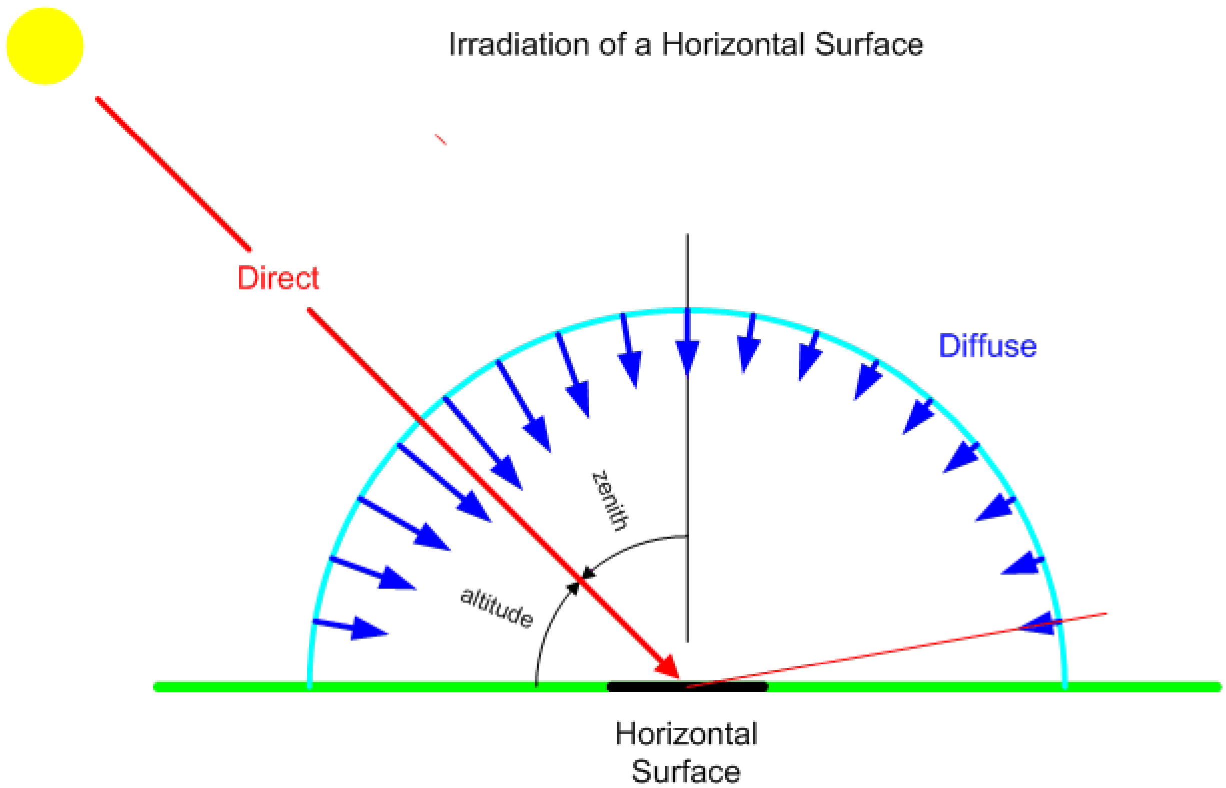
The number of solar panels required to fulfill the energy demand of the air conditioner on the bus for one month is calculated here. The calculations are done by a standard calculator and MATLAB.

Data Explanation

The data is collected from the metropolitan city of Chennai, India. The hourly global horizontal irradiance and daily minimum and maximum temperature data are presented.

Global Horizontal Irradiance

The global horizontal irradiance includes the total amount of short wave received by earth surface, the direct normal irradiance and diffuse horizontal irradiance. These are shown in the figure.

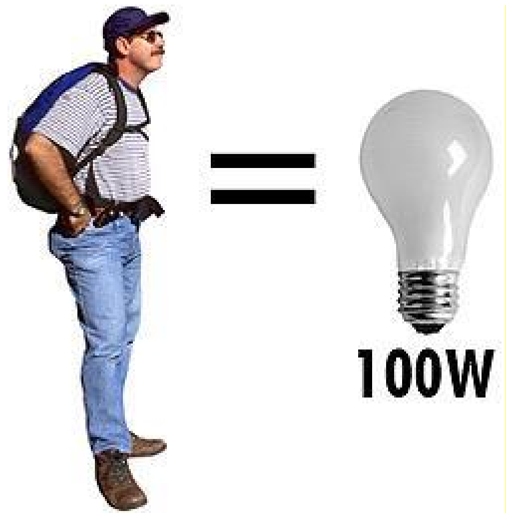


CALCULATION FOR DEMAND

The power demand for the compressor of the air conditioner is calculated here to maintain the temperature inside the bus. Solar radiations falling inside the bus through the glass, heat transfer through the glass window of the bus, and the thermal evaporation of the number of people inside the bus are the factors that affect the temperature of the bus. The total thermal KW demand can be found by adding the solar radiation data, hourly temperature, and heat transfer. The work done by the compressor is converted to electrical KW after seeing its thermal KW using the coefficient of performance (COP) of the selected air conditioner.

Heat from Human Bodies

The amount of energy Human body expend per day based on calculation is 8.37 x 106 joules. The average energy radiated by the human being is about 350000 Joule per hour if we consider that most of the energy left in the form of heat. This amount of energy is equivalent to the energy produced by a 100-watt light bulb if we convert the joule to watt. We can calculate the total amount of heat emitted by a human being on the bus by multiplying the capacity of the bus with the heat emitted by a single person.



Heat produced by single passenger = 0.1 kW

Number of passengers in Bus = 40

Total heat produced by the Passenger= number of passenger s* heat produced by single person

Total heat produced = 40*0.1kW = 4 kW

Heat through Glass Windows

The temperature outside the bus is the second major factor that affects the temperature inside it. A significant part of the heat transferred inside the bus from the environment is through the glass windows of the bus. To make it more accurate, we use the hourly temperature of the city, which can be found from the daily maximum and minimum temperature.

Heat through glass window = $A*U*(T_0-T_1)$
U - heat transfer co-efficient of glass
A – Area of glass window
T0 – outside temperature
T1 – inside required temperature
The coefficient for heat transfer through glass is about 3 $w/k\text{-}m^2$.

Radiation transfer through Window

Radiation from the sun passing through the window is also one of the important factors to affect the temperature inside the bus. The data for the emissions of the Chennai city and the radiation coefficient of the glass window can be used to find the heat due to radiation.

Heat through glass window(Q3) = A*U*global radiation

Where
U is coefficient of tinted glass

A is area of the glass window
The coefficient of tinted glass is about 0.1, the area of the glass is 13.28 m2. Heat transfer is calculated for every hour using hourly radiation data.

Total Power Demand

All the thermal loads are added to get the aggregate thermal demand. The thermal load demand is calculated for every hour. The coefficient of performance (COP) of the compressor of the air conditioner is needed to convert the thermal load to electrical demand by the compressor. The ratio of performance is between 2 – 4. R134a is used as a refrigerant, so the coefficient of performance is 2.15.

Electrical power = Thermal kW/COP
The above equation is used to convert the thermal kilo watt to electrical kilo watt.

Total Energy Demand

Air conditioner requires a different amount of energy every month because the climate varies every month. The following table shows the necessary amount of energy each month for the air conditioner.

Monthly Energy Demand Table

Month	Energy Demand(kwh)
January	494.70
February	478.35
March	507.29
April	504.72
May	519.55
June	486.99
July	505.81
August	493.88
September	486.32
October	491.29
November	462.94
December	491.85

The total number of solar panels required for the air conditioner is calculated from the monthly energy calculation. We can find out the amount of energy needed for the air conditioning of the bus for a whole year.

Energy required per year = 5923 kWh

Energy Supply Calculation

The power and energy produced by a single solar panel are calculated by using the hourly temperature, horizontal global radiation, and the selected monocrystalline module datasheet. The number of total solar panels required for supplying energy to the air conditioner can be found by using the energy produced by a single solar panel.

Hourly Temperature Calculation

The hourly temperature values can be found in this step by making calculations. With the help of Ashrae value, we can see the daily maximum and minimum amount of temperature. The following table contains Ashrae value for every hour.

Hour	Ashrae value
1	0.12
2	0.08
3	0.05
4	0.02
5	0.09
6	0.02
7	0.09
8	0.22
9	0.45
10	0.62
11	0.77
12	0.87
13	0.95
14	1
15	1
16	0.94
17	0.86
18	0.76
19	0.61
20	0.5
21	0.41
22	0.32
23	0.25
24	0.18

Hourly temperature = z* ((maximum-minimum temperature) + daily Minimum temperature
Whereas Z is Ashrae value.
They are using a while loop, and if conditions in the MATLAB, the Ashrae values are first assigned their respective hours.

Cell efficiency Calculation

The cell efficiency is different from module efficiency as cell efficiency is the efficiency of every cell in the module. The significant factors to find the cell efficiency are the calculated cell temperature, efficiency of the module given in the datasheet, and the standard operating cell temperature.

The cell efficiency can be found using the formula given below.

Cell efficiency = η*$[1+ \alpha p\ (T_c - T_{cstc})]$

Month	Energy produced by single panel(kWh)
January	43.611
February	49.177
March	51.086
April	57.197
May	58.522
June	48.79
July	51.192
August	44.373
September	47.73
October	42.887
November	34.524
December	42.203

Calculation of Power

The calculation of power for one module needs the area of the module, cell area, global horizontal irradiance, and cell efficiency to be known.

Cell area = 1.75 m^2

Module area = 1.88 m^2

Power = Module area * (cell area /Module area) * ($G_{Horizontal}$/1000) * $\eta cell$

Energy Calculation

The energy produced per hour by each panel is added to calculate the energy produced by a single panel in each month. The energy produced in each month is given in the following table.

Energy produced by single cell in each month

The table shows the lowest energy is produced in November with 34.524 kWh and the highest energy is produced in May with 58.522 kWh.

Description of the Selected solar panel

S. No	Description	Parameter
1	Dimensions	1956 × 990 × 50 mm
2	Efficiency	20 %
3	Power ($P\_(\max)$)	320 w
4	Voltage ($V\_(\max)$)	37.4 v
5	Current (I_max)	8.56 A
6	Short circuit Current (I_{SC})	9.01 A

Solar Panel Characteristics [36]

Number of Panels

The total number of solar panels required to power up the air conditioner/ heat pump is calculated from the energy demand of the air conditioner. The calculation is done by MATLAB of each month for accuracy.

Solar panel required for every Month

Month	**Energy Required(kWh)**	**Energy produced/Panel**	**Total PV panel Required**
January	494.70	43.611	11.344
February	478.35	49.177	9.7272
March	507.29	51.086	9.9297
April	504.72	57.197	8.8244
May	519.55	58.522	8.876
June	486.99	48.79	9.9811
July	505.81	51.192	9.8733
August	493.88	44.373	11.129
September	486.32	47.73	10.188
October	493.69	42.887	11.465
November	462.94	34.524	13.409
December	491.85	42.203	11.655

Solar Panel requirement [36]

Mostly 9 – 12 PV solar panels are required each month, so we choose 12 solar panels for best results to avoid unexpected losses in solar panels.

The total number of panels chosen is 12, in these two sets of six-panel are connected in series, and six panels are connected in parallel in order to improve the maximum power output.

Month	Energy produced/Panel	Total PV panel	Total energy Produced(kWh)
January	43.611	12	523.33
February	49.177	12	590.12
March	51.086	12	613.04
April	57.197	12	686.36
May	58.522	12	702.26
June	48.79	12	585.5
July	51.192	12	614.31
August	44.373	12	532.48
September	47.73	12	572.8
October	42.887	12	514.64
November	34.524	12	414.29
December	42.203	12	506.42

Total number of Solar Panels requirement [36]

Food Truck

The vehicle that can move and offer food service is called food trucks. Food trucks are generally designed as service of already packed food or limited to full kitchen facilities. Prepackaged snacks like candy bars, bottled drinks, and chips are found in processed packaged food trucks where food is not cooked and prepared. A variety of foods are offered, cooked, and made in kitchen service trucks like from hot dogs to cold sandwiches and hamburgers to full meals.

Food trucks are powered by a power cord that is connected to the utility. Food trucks stationed at the remote site or in motion are power supplied by a fossil fuel generator. Solar energy can also be one of the essential power sources for food trucks. The food truck's kitchen can be entirely or partially powered by mounting solar panels or photovoltaics PV on the roof of the car. Although solar energy can fulfill most of the energy demand of typical food trucks, the ability of solar panels to power up the food truck also depends on the size of the kitchen and the type of food offered [37].

Operation Requirement

A food truck has adequate space, depending on the variety of food that is offered. The standard tools found in the modern food trucks are listed below in the table. In the table, various appliances are shown with their operation time and their operating load. Some devices should be operating for 24 hours like a refrigerator as food needs to be kept refrigerated continuously [37].

Electric appliances	Operation Time (Hours)	Voltage	Power (watt)
Freezer	24	120	660
Beverage cooler	24	120	420
Salad sandwich refrigerator	24	120	725
Display refrigerator	24	120	420
Ice chest	24	120	1500
Fire suppression system	24/1	120	20/1000
Ice maker - ice cream	8	120	620
Lights internal	8	120	200
Vents fan	8	120	146
Convection oven	6	120/240	700
Rice Cooker	6	120/240	1500
Exhaust hood- fans	6	120	200
Tv display computer	6	120	300
Stereo/CD	5	120	200
Window curtain	5	120	500
Light external	5	120	500
Cash register	5	120	150
Coffee pot	5	120	1165
Heat lamps	5	120	250
Hot display case	5	120	250
Bun toaster	5	120	1000
Steam table	5	120	1500
Griddle	5	120	3000
Hot water heater	5	120	1500/2500
Rooftop AC	4	120/240	1920
Camera /security	12	120	250
Blender	2	120	300
Microwave	1	120	1500
Panini press	1	120	1500
Water pump	1	120	50

Meeting the Load

Calculations are made the same way, whether considering the power load for a food truck or for a brick and mortar restaurant powered by a solar power system or by a generator. Most of the power demand needs to be determined of all the electrical equipment that will be used at the same time. Appliances load values are commonly found on the tag nameplate or appliance stamp.

Apart from other appliances, the energy demand of air conditioner makes challenging to power up a food truck. Placement of exhaust fans at the right place and having the right exhaust fan to remove heat from propane cooking is the design problem. Running fans and air conditioning units at the same time is a wastage of energy as fans pull out the cold air [37].

Solar power Supply

Three different types of food trucks are considered to figure out the size and load of the solar system to set on the vehicle roof. We consider the power demand for Hot dogs, Ice cream, and Gourmet food trucks and the amount of power supply needed to meet the vehicle energy demand with the solar system, as shown in the following table [37].

Load type	**Gourmet (watts)**	**Ice cream (watts)**	**Hot Dogs (watts)**
Lights	800	800	800
Sign	400	400	400
Fan	1200	1200	1200
Freezer	0	660	0
Refrigerator	3360	0	3360
Oven	5760	0	0
Fire suspension	1440	0	1440
Total energy load/day	12960	3060	7200

Depending upon the wattages, efficiency, and voltage photovoltaic modules/ solar panels come in different sizes. The efficiency of power modules for utility usages are physically more significant and have higher efficiencies than the charging modules for batteries. The mounting of the solar panels/ modules need attention as flat generally gives less production but having the advantage of not to align in the sun direction, while tilted and extended module may need to be aligned with the sun also having the benefit of more production. Extending and tilting can increase production by up to 30 percent [37].

The useful area for the photovoltaic panels can be calculated after subtracting the space occupied by exhaust fans, air conditioning, skylights, and other equipment.

Truck length	10	12	14	16	18	20	22	24
Trailer 8 width area	80	96	112	128	144	160	176	192
Trailer 9 width area	90	108	126	144	162	180	198	216
Total photovoltaic DC watts	1440	1728	2016	2304	2592	2880	3168	3456

Solar radiation varies at different parts of the earth. Full sun hours are different for different areas like hourly data for NYC = 3.2 – 5.6 hours and LA = 4.6 – 6.6 hours. Solar PV modules produce DC current is then converted to Ac by inverter.

Eighteen feet truck is used in the table for the gourmet example. For 2430-watt DC array, total Nine modules of an Amerisolar AS-6P30 were selected. In Florida, with average radiation of 6.6 peak sun hours, 16038 watts could be produced from this array. If 20 percent of efficiency loss of the PV system is considered, then 13200 watts generated is more than required 12960 watts. Therefore, it is concluded that PV fulfills the power and energy demand per assumption for this example. The 18-foot truck, in this example, using propane for cooking, could function appropriately on solar energy for 6 hours a day. Inverter Flexpower 3648 is used that interfaces with utility and generator power. In this design, the power cable is used to connect to a 30-amp utility receptacle when the truck is parked [37].

EXPERIMENTAL SIMULATION IN MATLAB & SIMULINK

Mathematical Model of Solar in MATLAB

The mathematical model of a more realistic practical model is presented to model it in a Simulink. The output current of the solar module is presented as in the equation using Kirchhoff's first law.

$$I = I_{ph} - I_d$$

The I-V characteristic of solar panel solar cell called as Shockley's diode current equation from the theory of semiconductors is described as follow.

$$I_d = I_s\left[exp\left(\frac{q(V + IR_s)}{N_s KAT_0}\right) - 1\right]$$

Putting value of Id in equation 1, we get the output current I as follow

$$I = I_{ph} - I_s\left[exp\left(\frac{q(V + IR_s)}{N_s KAT_0}\right) - 1\right]$$

Output current is computed in case of PV cells coupled in a series_ parallel manner

$$I = N_p * I_{ph} - N_p * I_s\left[exp\left(\frac{q(V + IR_s)}{N_s KAT_0}\right) - 1\right]$$

Photovoltaic current I_{ph} can be illustrated as follow.

$$I_{ph} = [I_{sc} + K_i(T_0 - T_r)] * \frac{G}{G_{ref}}$$

Reverse saturation current and saturation current can be calculated as follow.

$$I_{rs} = {I_{sc}}\Big/\left[exp\left(\frac{qV_{oc}}{N_s KAT_0}\right) - 1\right]$$

$$I_s = I_{rs}[T_0/T_r]^3 exp\left[\left(\frac{qEg}{AK}\right)\left(\frac{1}{T_r} - \frac{1}{T_0}\right)\right]$$

Experimental Simulation of Solar power Production in different Scenarios

Selection of Solar panel for simulations

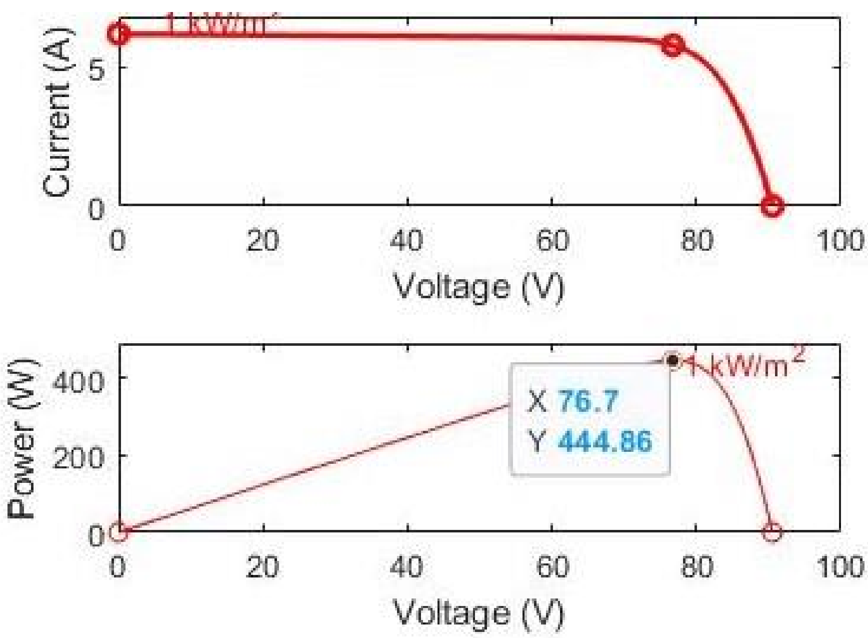
The solar panel selected for the simulation purposes was SunPower SPR-X20-445-COM. The electrical and mechanical properties of the solar panel module are given as follows.

Table: Solar Panel Module SunPower SPR-X20-445-COM features

S. No	Description	Parameter

1	Dimensions	2067 × 10460 × 50 mm
2	Efficiency	20 %
3	Power ($P_{(\max)}$)	415 w
4	Voltage ($V_{(\max)}$)	72.9 v
5	Current (I_{max})	8.56 A
6	Short circuit Current (I_{SC})	6.09 A

Shining Sunny day with sun irradiance @1000 w/m^2



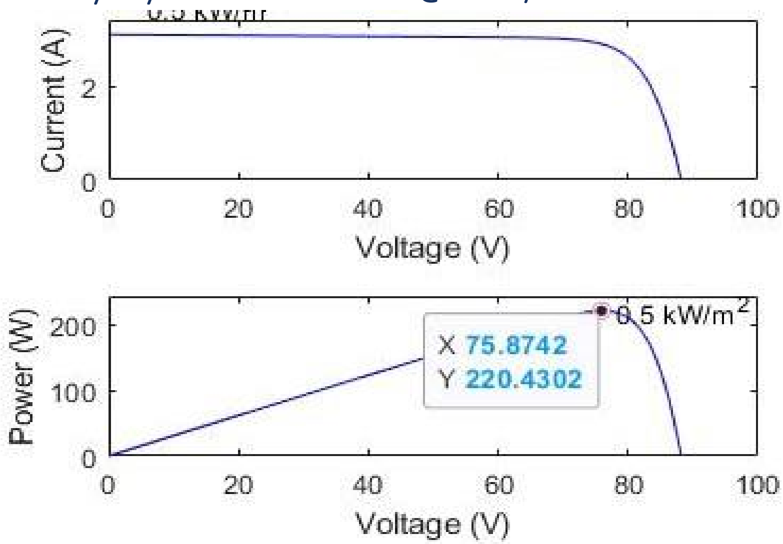
From the results, we can see that maximum power is 444 watts. If the sun shines for 6 hours a day the Energy, we can get Mathematically,

Energy = Power * Time

Energy = 444 watts * 6 hours

Energy = 2.6 kWh

A Sunny day with sun irradiance @500 w/m^2



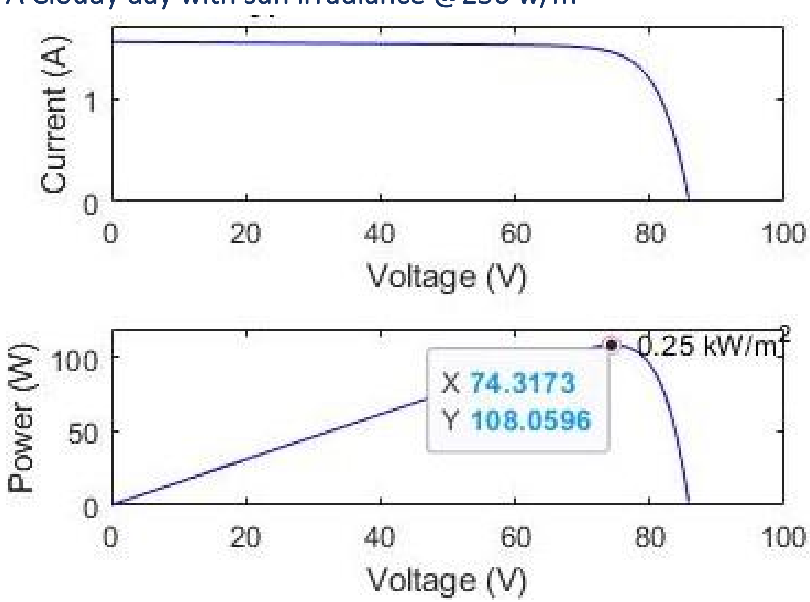
From the results, it is clearly shown that 220 watts are the maximum power we get on the output. If the sun shines for 6 hours a day, the Energy we can get Mathematically,

Energy = Power * Time

Energy = 220 watts * 6 hours

Energy = 1.32 kW

A Cloudy day with sun irradiance @250 w/m^2



The result shows the maximum power we get is 108 watts. If the sun shines for 6 hours a day, the Energy we can get Mathematically, Energy = Power * Time

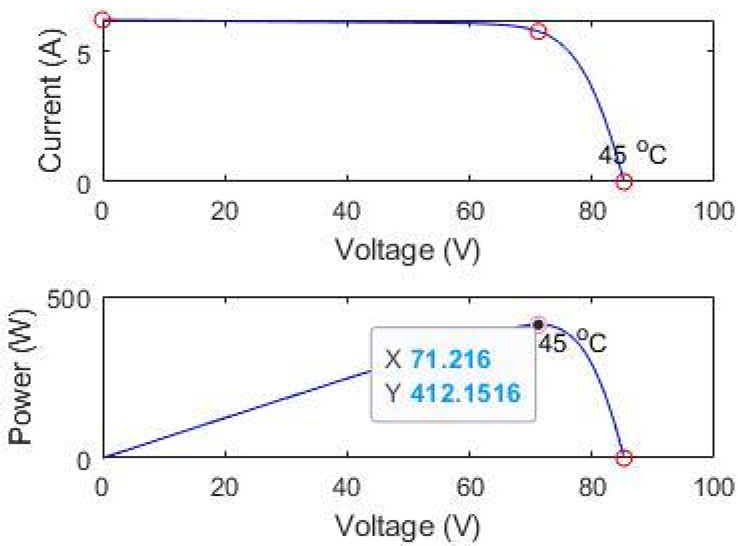
Energy = 108 watts * 6 hours

Energy = 0.648 kWh/day

Energy Production with different Temperature Conditions

We consider different temperature conditions for the same irradiance sun in order to evaluate the functionality of our chosen solar panel.

Power and Voltage Graph at 45 °C



External Temperature has a significant effect on the power production of solar cells. High temperature has a reversal effect on the production of solar panel as we can see the graph, the total power produced is 412.15 watt when the external temperature is 45°C. The total energy production for a single day with external temperature 45°C is calculated as follows if the sunshine for at least 6 hours.

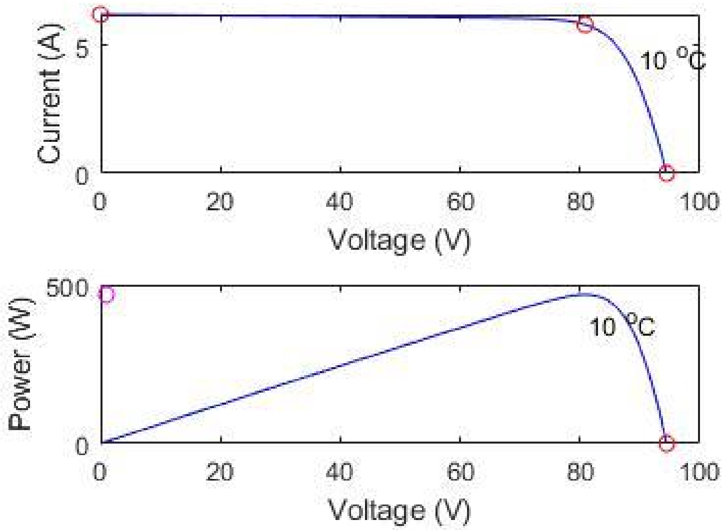
Energy = Power * Time

Energy = 412 * 6

Energy = 2.472 kWh/day

Power and Voltage Graph at 10 °C

Lower external temperature is useful for solar power generation. The power produced for the case we considered 45 °C temperature was lower as compared to the power produced in this case where we considered the external temperature as 10°C, as shown in the following figure.



The total energy production is given as follow.

Energy = Power * Time

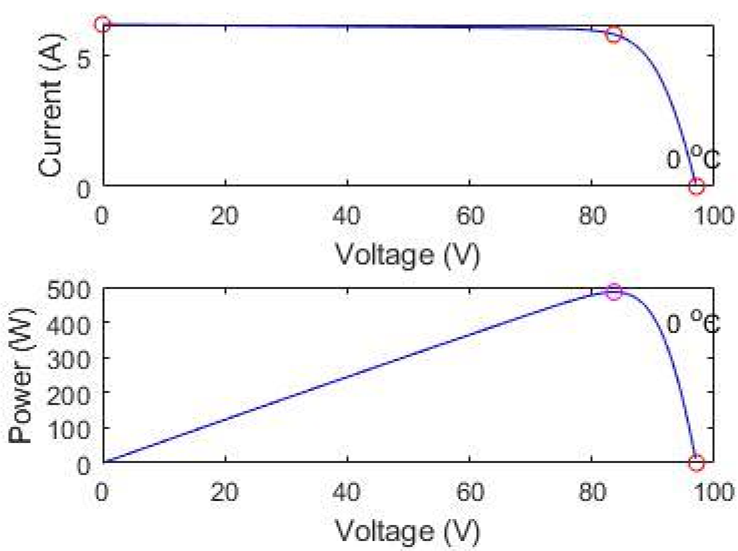
If we consider the sunshine for 6 hours a day, the total energy production will be as follow.

Energy = 469 watts * 6 hours

Energy = 2.714 kWh/day

Power and Voltage Graph at 0°C

As the temperature decrease the power production increases with same solar irradiance i.e. in our case, we considered 1000 w/m2.



Power = 485

Energy = 485 * 6 hours

Energy = 2.910 kWh/day.

Simulation of Car cabin mode in MATLAB

The estimation energy consumption by heating and cooling system in an electric vehicle require to make the thermodynamic model of the vehicle cabin, considering all the heat transfers and thermal interactions inside the car compartment itself and between car compartment and external environment.

The fundamental thermodynamic processes are considered for this model. Conduction, convection, and irradiance were found in this model. The first thermal interactions with the car compartment are being described in the following equations.

Convection

$$Q = hA\Delta T$$

Conduction

$$Q = \frac{\lambda A\Delta T}{L}$$

Convections and Conduction Combined

$$Q = UA\Delta T$$

Irradiation

$$Q = \mathcal{E}\sigma A(T_2^4 - T_1^4)$$

Enthalpy

$$H = mc_p T$$

Heat Absorbed

$$Q = mc_p \Delta T$$

First Law of Thermodynamics

$$\frac{dE}{dt} = Q + P + \sum_t m_t(h_i + \frac{w_i^2}{2} + gz_i)$$

Law of conversion of mass in closed system

$$\frac{dm}{dt} = \sum \frac{dm_{out}}{dt} + \sum \frac{dm_{out}}{dt} = 0$$

Where:

- T: temperature
- h: convection coefficient
- L: characteristic length
- U: global heat transfer
- $\mathcal{E}$: emissivity coefficient
- σ: Stefan-Boltzmann constant
- m: mass
- c_p: specific heat at constant pressure
- Q: heat
- H: enthalpy
- E: total energy
- $\dot{Q}$: heat flux
- P: mechanical power
- $\dot{m}$ mass flow rate
- w: velocity
- g: gravity acceleration
- z: height.

Heating system considered for simulation

The heating system is mandatory not only for increasing the vehicle cabin temperature but also useful for defrosting the windshield if the car has been for a long time at low temperatures. The considered system for heating in our simulation is PTC.

Positive Temperature Coefficient (PTC)

The component considered for heating the vehicle compartment is PTC, practically PTC is integrated into the heat exchanger and contributes to the heating of air passing through them, as shown in the figure.

PTC element is a simple resistor that transforms electrical energy into thermal energy. This heat is then shifted to the air through the radiator. Its main feature is that its resistance increases with its temperature. The electric current of PTC decreases after it reaches its working temperature. The heating power of PTC element considered for this work is 5kw.

Cooling System Considered for Simulation

Practically Air-Conditioning system is used everywhere for cooling purposes. The importance of A/C is not just limited to remove the cabin heat to maintain cabin temperature, but it helps in defogging the windshield for better visibility and for removing the moisture from the air.

The efficiency of the A/C is defined from the value of (COP). COP is the ratio between the useful cooling power provided and the required electric power. Usually, the COP value for A/C is higher than 1, meaning that it consumes less electrical power for the same heating level. The considered value for this simulation is COP = 3.

Thermodynamic Model of Cabin

The thermodynamic model of car is modelled based on the most important thermal energy transfers, those with higher heat fluxes were considered.

● Transfer of heat through doors both convection and conduction, internal and external.

$$\frac{dT_{doors}}{dt} m_{doors} c_{p,doors} = \dot{Q}_{doors,external} - \dot{Q}_{doors,internal}$$

$$\dot{Q}_{doors,internal} = U_{doors,internal} A_{doors} (T_{doors} - T_{cabin})$$

● Solar Radiations on roof, doors and dashboard

$$\dot{Q}_{roof,external} = I_{solar\ radiation} * \gamma_{doors} * A_{doors} - \mathcal{E}_{doors} \sigma T_{cabin}^4 - \alpha_{external} A_{roof} (T_{roof} - T_{external})$$

$$\dot{Q}_{dashboard} = I_{solar\ radiation} \gamma_{dasboard} \tau_{glass} A_{dashboard}$$

$$\dot{Q}_{doors,external} = 0.5 * I_{solar\ radiation} \gamma_{doors} A_{doors} - \mathcal{E}_{doors} \sigma T_{cabin}^4 - \alpha_{external} A_{doors} (T_{doors} - T_{external})$$

● Conduction and convection Through roof:

$$\frac{dT_{roof}}{dt} m_{roof} c_{p,roof} = \dot{Q}_{doors,external} - \dot{Q}_{doors,internal}$$

$$\dot{Q}_{roof,internal} = U_{roof,internal} A_{roof} (T_{roof} - T_{cabin})$$

● Transfer of heat by convection on interior and dashboard

$$\frac{dT_{dashboard}}{dt} m_{dashboard} c_{p,dashboard} = \dot{Q}_{sun} - \dot{Q}_{dashboard}$$

$$\dot{Q}_{dashboard} = U_{dashboard} A_{dashboard} (T_{dashboard} - T_{cabin})$$

$$\frac{dT_{interiors}}{dt} m_{interiors} c_{p,interiors} = \dot{Q}_{interior}$$

$$\dot{Q}_{interiors} = U_{interiors} A_{interiors} (T_{interiors} - T_{cabin})$$

● Passenger and Driver thermal and heat transfer because of metabolism

$$\dot{Q}_{driver} = \varphi_{human} A_{body} * 1.4$$

$$\dot{Q}_{passenger} = n_{passangers} \varphi_{human} A_{body}$$

● With tunable air recirculating factor, Enthalpy fluxes of air exiting and entering the vehicle compartment,,

$$\dot{H}_{in} = \dot{m}_{recirculating} \left(T_{cabin} c_{p,air} X_{cabin} \left(c_{p,cabin} T_{cabin} + \Delta h_{v,0}\right)\right) + \dot{m}_{fresh\ air} h_{fresh\ air} + \dot{Q}_{HVAC}$$

$$\dot{H}_{out} = \dot{m}_{air} T_{cabin} \left(c_{p,air} + X_{cabin} c_{p,steam}\right) + \dot{m}_{air} X_{cabin} \Delta h_{v,0}$$

The variations in the cabin air temperature can be found through thermodynamics law, putting together all the heat transfer equations, by equating the following two equations.

$$\frac{dU_{int}}{dt} = \dot{Q}_{dashboard} + \dot{Q}_{glasses} + \dot{Q}_{dashboard} + \dot{Q}_{interiors} + \dot{Q}_{doors} + \dot{Q}_{roof} + \dot{Q}_{driver} + \dot{Q}_{passenger} + \dot{H}_{in} + \dot{H}_{out}$$

$$\frac{dU_{int}}{dt} = \frac{dT_{cabin}}{dt}\left(m_{air}c_{p,air} + m_{water}c_{p,water}\right) + \frac{dm_{water}}{dt}\left(T_{cabin}c_{p,water} + \Delta h_{v,0}\right)$$

$$U_{overall} = \left(\sum \frac{1}{hi_{convection}} + \sum \frac{t_j}{ƛj_{conduction}}\right)^{-1}$$

Where

- U_{int} is system internal energy
- h is convection coefficient
- ƛ is convection coefficient
- t is the thickness of considered component

Final Simulation

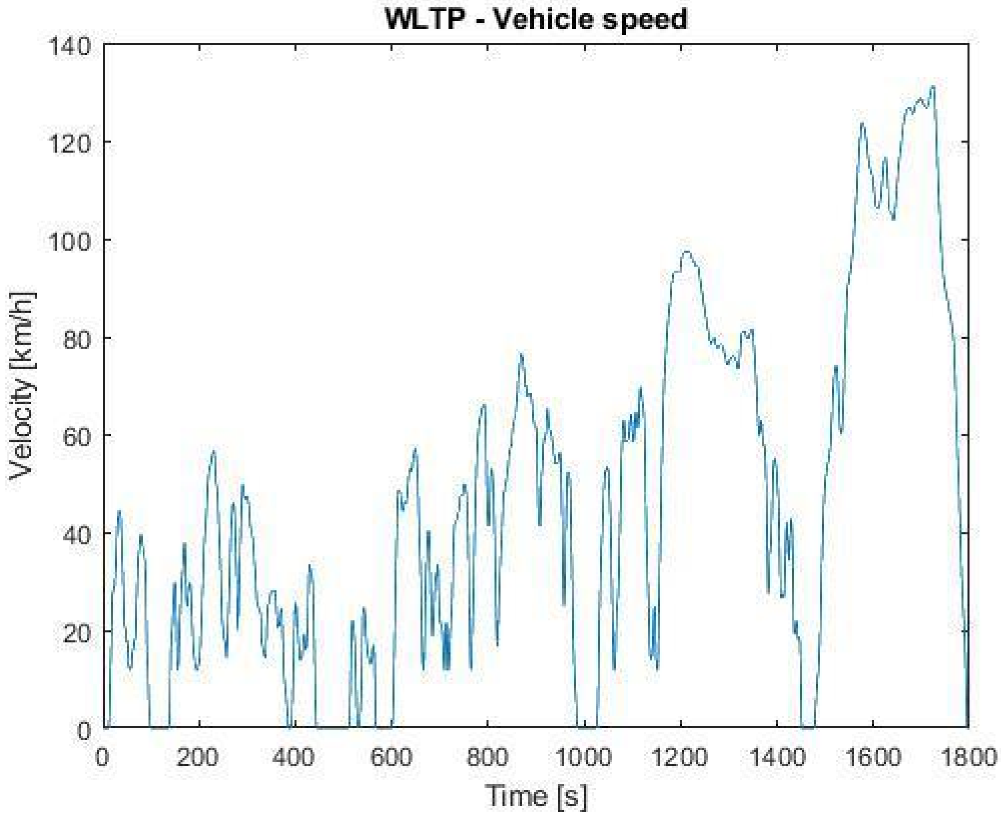
After putting them all together, we do the simulations during the WLTP driving cycle for different temperature values. The result of simulations for the WLTP driving cycles were, temperature trend over time for cabin and various cabin components, cooling, and heating power trend, secondary users' power demand over time, and finally, total energy demand for each considered external temperature.

Driving Cycle

The most common type of driving cycle i.e. WLTP was considered here for the simulations.

WLTP (class 3) Worldwide harmonized light vehicles test procedure:

It defines CO2 emission and level of pollutants, fuel energy consumption, and electric range for a light vehicle based on globally harmonized standards. It entered consideration for new car models in September 2017 and then in September 2018 for all vehicles. The main features of driving cycle WLTP are, total length covered in WLTP is 23.3 km having a maximum speed of 131.3 km/h and an average speed of 46.5 km/h. The WLTC for regular passenger cars is divided into four types of speeds, Extra-high, high, Medium, and Low rate. Different velocity trends over time are reported in the figure.

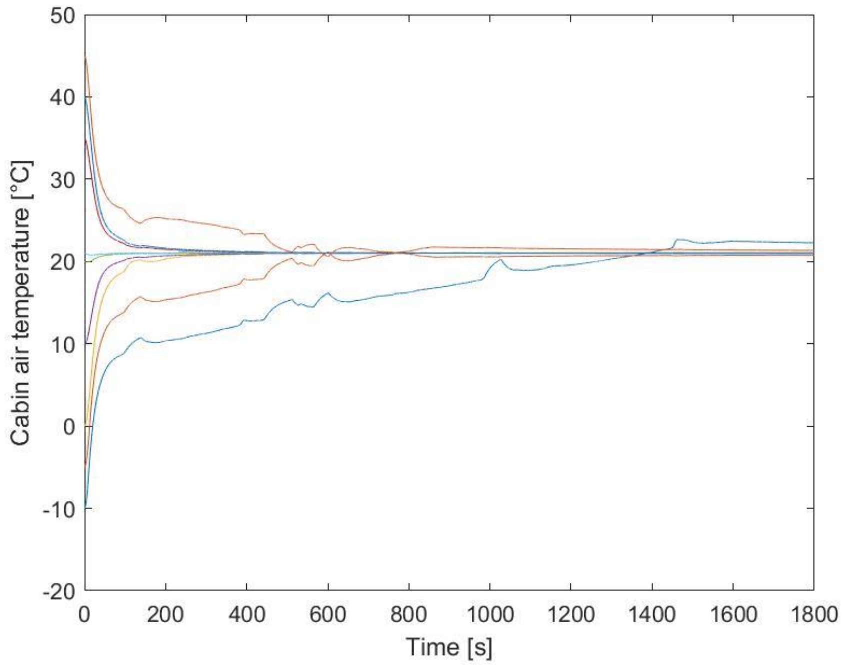


Results:

The results obtained here are for the WLTP cycle, mainly in the form of plots. The results obtained for various external temperature conditions are represented follow.

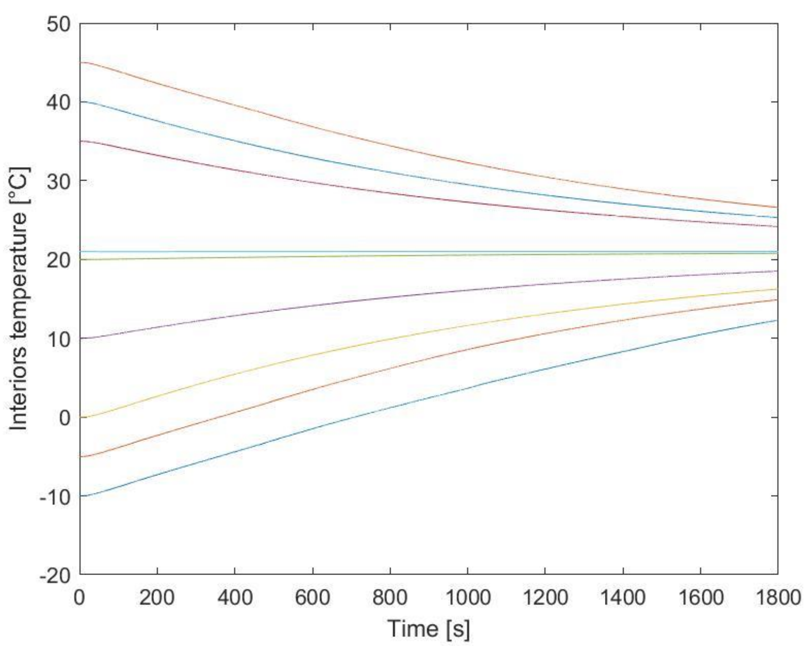
Cabin Air Temperature

The desired temperature for both heating and cooling is set to 21°C.

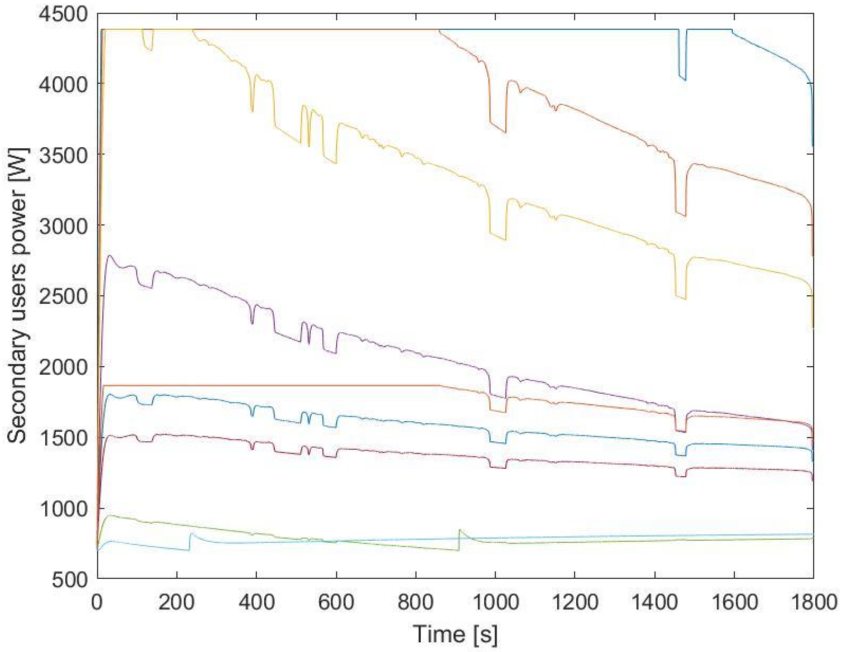


Simulation of cabin temperature for external temperature values equal to [-10 -5 0 10] requires a heating phase of the simulation model, while values [35 40 45] external temperature conditions simulated in this model require the cooling state of the HVAC system. The graph is showing the condition air temperature of the vehicle inside the cabin for the described external temperature values.

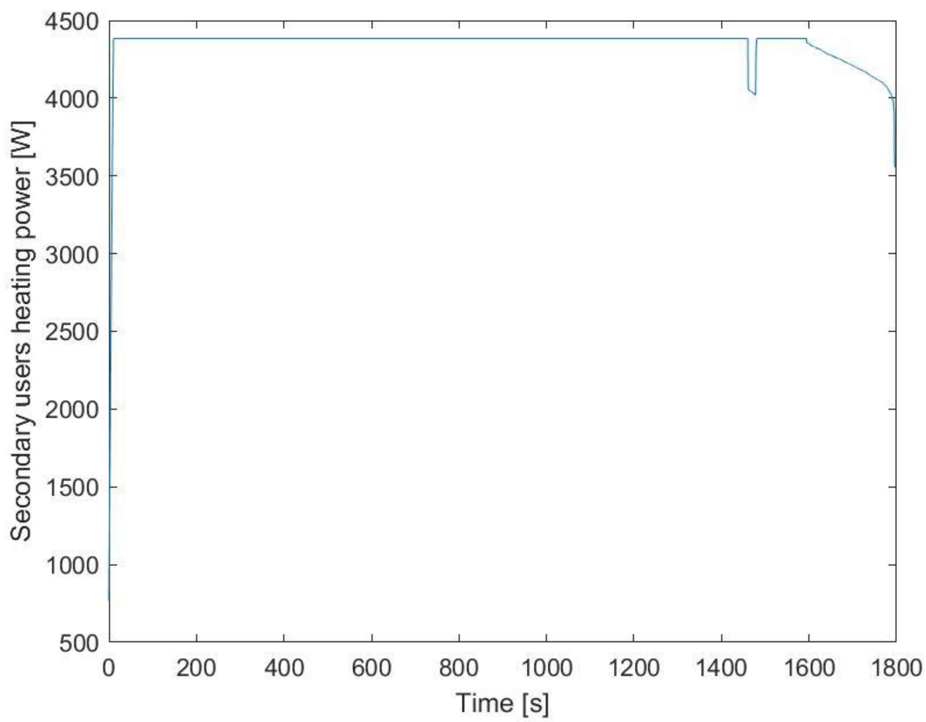
Cabin Interiors Temperature



Secondary Power Request

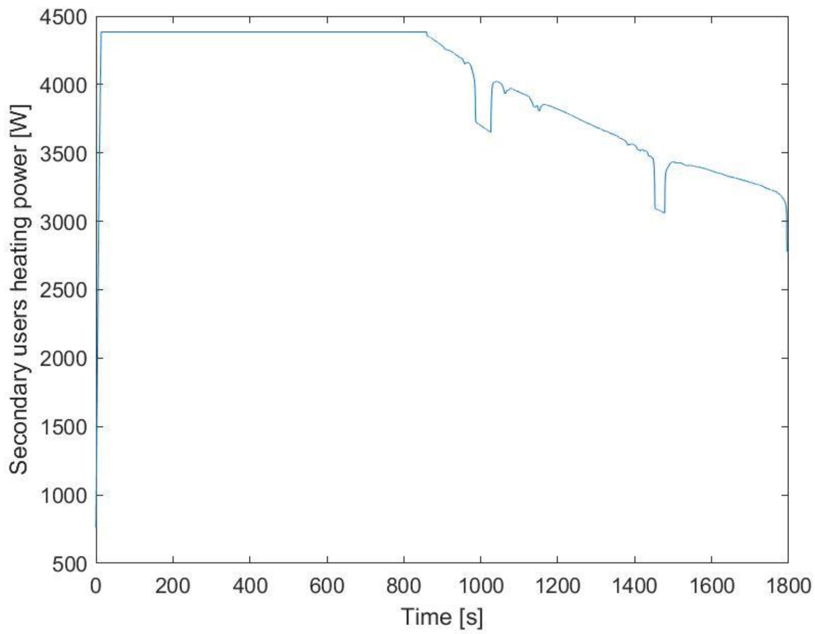


Secondary user heating Power Request @ -10°C External Temperature



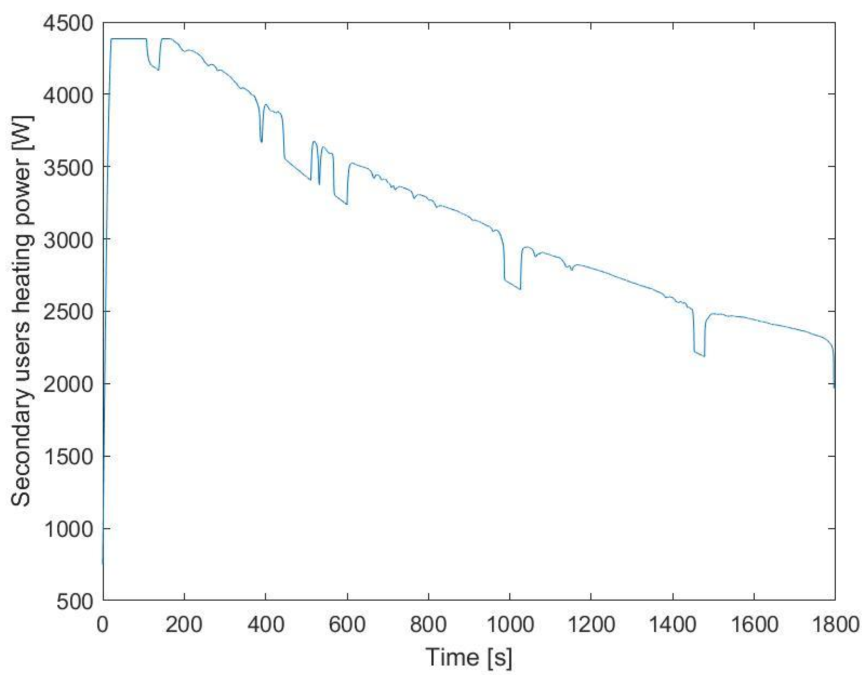
Extreme external weather conditions have a great impact on power consumption; As the graph shows, the PTC heating system uses its total available power to bring the cabin temperature to the desired set value.

Secondary user heating Power Request @ -5°C External Temperature



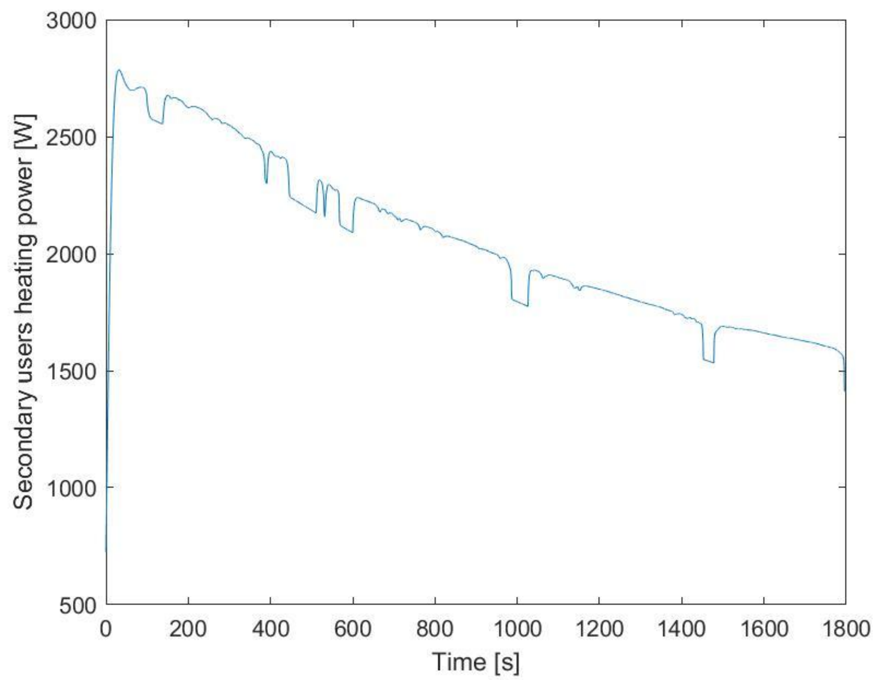
The power requirement for external temperature conditions at -5°C decreases after 700 seconds of a simulation showing that the cabin temperature nearly reaches its desired value.

Secondary user heating Power Request @ 0°C External Temperature

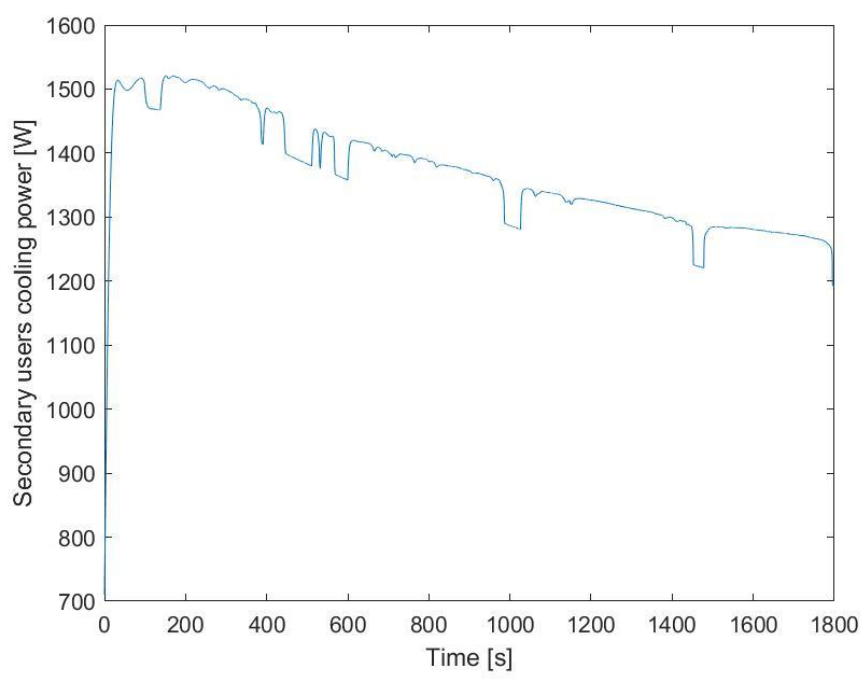


Power demand decreases as the value of external temperature, and the desired value temperature difference decreases. The amount of energy demand is much less as compared to external temperature conditions of -10°C and -5°C.

Secondary user heating Power Request @ 10°C External Temperature

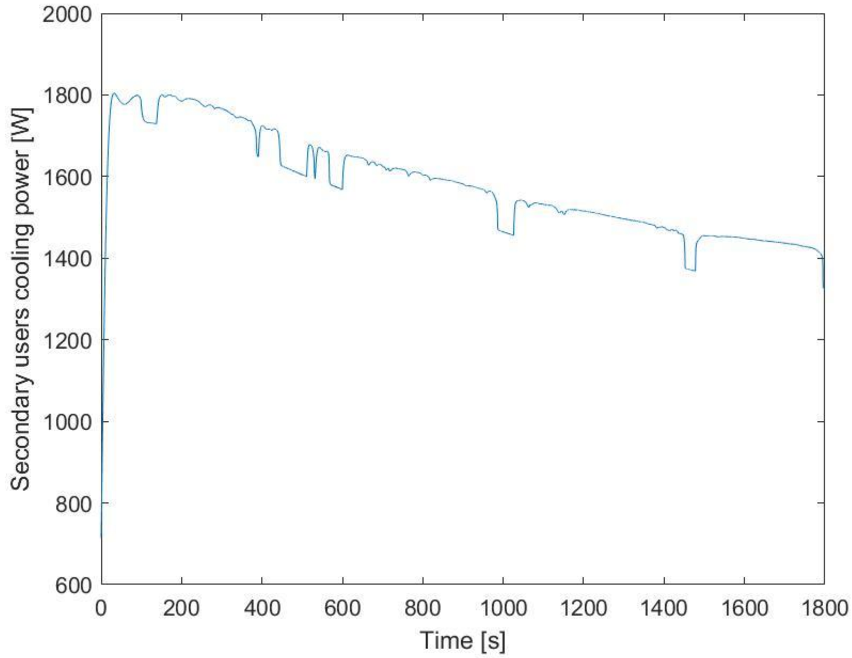


Secondary user cooling Power Request @ 35°C External Temperature

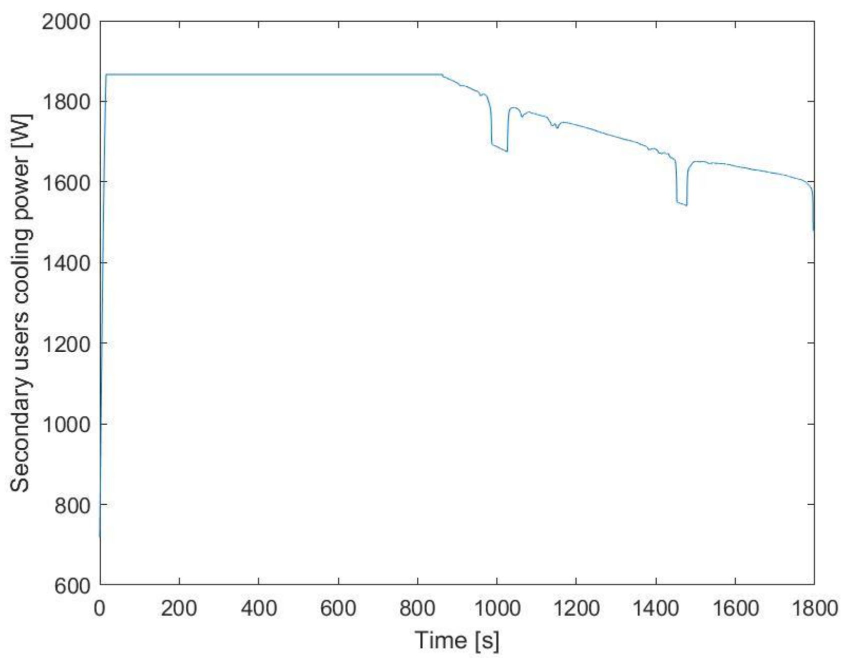


Cooling power demand in an electric vehicle is less as compared to heating demand in severely cold weather. The power demand increases in the cooling condition scenario, as the external temperature increases.

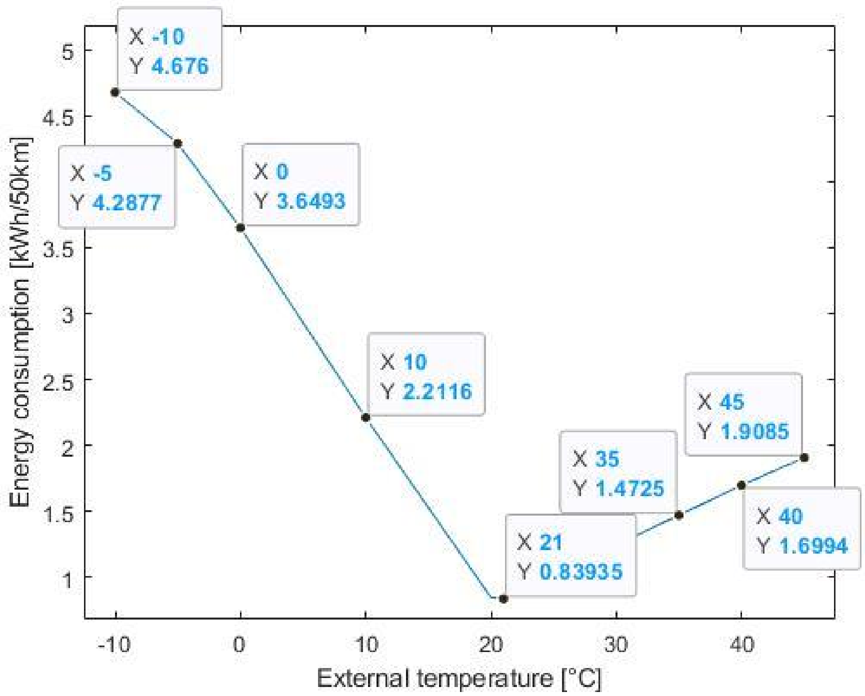
Secondary user cooling Power Request @ 40°C External Temperature



Secondary user cooling Power Request @ 45°C External Temperature



Energy Demand on Sunny Day with 1000 w/m2 irradiance at Various External Temperature for 50 km Drive



Energy Demand at -10°C

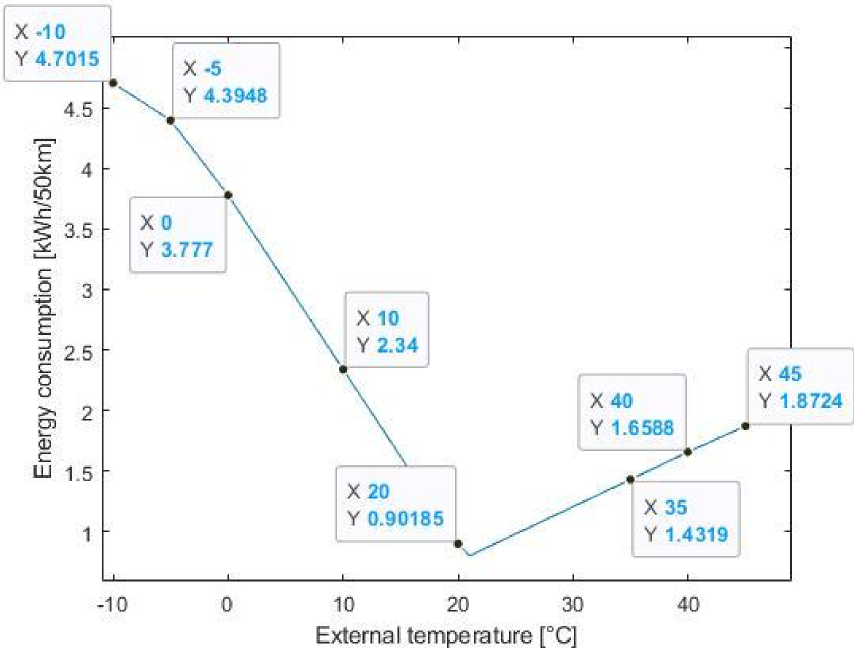
We can see in the graph the amount of energy required for -10°C is 4.67 kwh/50km, i.e. when the external temperature is -10°C and the car drive for 50 km in a single day, we require 4.67 kWh energy.

Table: Showing Total Energy Demand by Car HVAC and Energy Produced by Solar Panel

External Temperature	Energy produced/Panel	Energy Demand(kwh/50km)	Produced - Demand
-10°C	2.74	4.67	-1.93 kwh/day
-5°C	2.76	4.28	-1.52 kwh/day
0°C	2.910	3.64	-0.73 kwh/day
10°C	2.64	2.21	0.43 kwh/day
21	2.6	0.839	1.77 kwh/day
35°C	2.56	1.472	1.08 kwh/day
40°C	2.50	1.699	0.81 kwh/day
45°C	2.47	1.908	0.56 kwh/day

The table shows that energy demand can be fulfilled in hot weather from solar panels to maintain a comfortable temperature inside the electric vehicle cabin, while in winter, the demand value is more than the produced amount of energy from the solar panel. When the external temperature is equal to 10°C, the demand value is less compared to the electric energy produced. The extra energy from the solar panel can be used for other purposes in an electric vehicle, while in case of deficiency, the remaining energy is gained from the battery of the electric car.

Energy Demand at various External Temperature for 50 km Drive on Cloudy day



Graphical representation of the amount of energy required for the HVAC system of the car for 50 km drive on cloudy day scenario with respect to different external temperature conditions illustrate that heating vehicle consumes more energy compare to the sunny day scenario, while for cooling the electric vehicle cabin the amount of energy expended on a cloudy day is less than on a sunny day.

Total Energy Produced Vs Total Energy Consumed on cloudy day

The energy demand at various external temperature conditions and the energy produced by our selected solar PV model is shown in the table. The last column of the chart shows the amount of energy required from another source if the sign is negative, while if the sign is positive, it shows the amount of spared energy.

Table: Showing Total Energy Demand by Car HVAC and Energy Produced by Solar Panel

External Temperature	**Energy produced/Panel**	**Energy Demand(kwh/50km)**	**Production - Demand**
-10°C	0.71	4.7	-4 kwh
-5°C	0.67	4.3	-3.63
0°C	0.66	3.77	-3.11
10°C	0.65	2.34	-1.69 kwh
21	0.648	0.901	-0.25 kwh
35°C	0.643	1.431	-0.761
40°C	0.640	1.658	-1.018 kwh
45°C	0.634	1.8724	-1.23 kwh

The results show that the solar PV panel production on a cloudy day does not produce enough electrical energy to power up the heating and cooling system of the vehicle, so the amount of required energy will be provided by a battery in an electric car.

Conclusion

Heating, ventilation, and air conditioning of electric vehicle cabin has a big influence on the overall energy consumption of vehicle during different environmental conditions. Results of simulations showed very high energy demand to reach an acceptable comfort level for the passengers, both during very low and very outdoor temperatures. For light electric vehicles, the results showed that only battery as a source of energy, HVAC can have a direct impact on range. The solution for the range anxiety in our case is the photovoltaic (PV) module on the roof of the car. The energy produced from the solar panel module is used for the HVAC of the car cabin. The amount of energy produced in different weather conditions is simulated.

Furthermore, the energy consumption of a light electric vehicle HVAC system is simulated in different outdoor temperature conditions over the WLTP driving cycle representing real-world driving scenarios that led to getting important results much closer to reality. The amount of energy consumed by HVAC during the 50 Km drive cycle in different weather conditions has different values. The amount of energy required during very low temperatures is very high as compared to the energy consumption in very high outdoor temperatures. The amount of energy produced from the solar panel module in our simulation results was not enough to overcome the energy demand during severely cold weather and cloudy weather. While on the shining sunny day, we have the surplus energy during hot weather.

Therefore, as a conclusion of this work, it is necessary to say that in the future electric vehicle, the low energy consumption HVAC system and high energy-producing solar panel modules may have effective results to overcome the overall energy demand of car HVAC system.

Finally, since this work was carried out only on the simulative approach, it is important to validate the result found through experimental data in order to make a more reliable comparison between the real world and simulations results.

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