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# THERMAL CONDITIONS IN THE PASSENGER COMPARTMENT OF MICROCARS

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***Abstract***

*Electric microcars are means of urban mobility with a capacity for two people, and they are also used as delivery vehicles in restricted urban areas.A passenger compartment of the microcar can be exposed to significant thermal loads in both hot and cold environment. The cabin climate control can consume significant amounts of energyreducing the microcar's range. This paper deals with the identification and discussion of the microclimatic parameters and the causes of thermal discomfort in microcars. The results showed that despite the vehicle's small size, the thermal loads and thus the energy consumption for achieving and maintaining the thermal comfort are relatively high, especially when compared with the propulsion power rate and the battery capacity. The limited possibilities for implementing advanced technical solutions to mitigate adverse thermal conditions are identified as the main problem due to geometric, mass, and cost constraints.*

***Keywords****: microcar, micromobility, thermal comfort, cabin, air-conditioning*

## 1 INTRODUCTION

Thermal comfort is essential in all types of individual or public transport and should be achieved in all environmental conditions. Since microcars are often used by people with disabilities, the comfort in this type of transport is even more important.Microcars (or so-called mopedcars) have been present for the long time as an option of micromobility in urban areas. In addition to energy efficiency and space saving benefits, this transportation device should provide sufficient comfort to the user. Microcars are widely used in northern parts of Europe, and some Mediterranean countries also offer them on the market.It is estimated that European market volume in 2025 will reach 30,000 units of microcars of all categories [1]. There is no reliable data about microcars in operation (on roads). For comparison purposes, total electric vehicle (EV) market volume in European Union (EU) per year is about 2,000,000 new vehicles [2]. It is not stated whether the electric microcars are included in the figure.

Microcars are classified as quadricycles and divided in two sub-categories depending on power and mass (L6 and L7, [3]). The microcars analyzed in this paper belongs to L6 category of vehicles [3]: light electric quadricycles. These vehicles have the lowest rated motor power limit: up to 4 kW [3]. For that reason, energy available for the comfort systems is very limited, compared to other vehicles with a closed passenger compartment.The literature mainly covers thermal management and energy efficiency of standard-sized EVs [4, 6, 7, 8, 9, 10] as well as vehicles with conventional propulsion methods (internal combustion (IC) engines or hybrid powertrain) [11, 12, 13]. The approach to improving both the thermal conditions inside the cabin and the range of microcars is generally the same as for other types of vehicles. However, regular size passenger BEV's have more available installation space and higher mass limit than microcars, allowing more complex thermal systems (powertrain thermal systems, heat storage, advanced materials, several circulation pumps etc. [6]). Moreover, the price of microcars should be proportionally lower compared to a modern electric family or luxury car. In addition to achieving thermal comfort inside the cabin, the heating, ventilation and air-conditioning (HVAC) system is responsible for demisting and defrostingthe glazing, placing more demands on the energy storage.The microclimate conditions and hence human thermal sensation as well depend on air temperature, air velocity, relative humidity and mean radiant temperature. However, individual differences regarding physiological and psychological response, clothing insulation, activity and preferences in terms of air temperature and air movement also have a strong impact on thermal sensation. The expectation factor is also important for subjective perception of thermal conditions inside the vehicle. When someone is going to use the microcar, he or she is usually prepared to be faced with unfavorable thermal conditions, in the similar way like in a conventional passenger car. Clothing and acclimatization arealso important factors which are in accordance to the outdoor conditions [13]. The objective of the paper is to identify and analyse the most important design features of the microcars in terms of thermal conditions inside the cabin. Both thermal comfort and technical solutions for obtaining it are considered. Quantification of the thermal processes was done using analogy with cabins of other types of vehicles.

## 2 TECHNICAL CHARACTERISTICS OF MICROCARS

The main technical features of microcars were obtained by collecting available information from several European manufacturers of microcars. Figures 1 and 2 show examples of typical microcars.

The microcars of L6 category of electric vehicles have the following characteristics:

- four wheels,
- the unladen mass is up to 350 kg (without the batteries),
- maximum design speed is not more than 45 km/h,
- maximum continuous rated power does not exceed 4 kW.

***Fig. 1*** *Examples of electric microcars: Biro, Electroride Futuri 4, Eloped [14, 15, 16]*

Lithium-ion battery capacity in microcars is around 80-120 Ah [14, 16], i.e. 5-7 kWh [14, 17,18,19,20].
The common features of the L6 microcars important for thermal comfort in the cabin and for the HVAC system:

- capacity: one or two persons,
- passenger compartment volume: around 2 - 2.5 $m^3$,
- the cabin vertical projection area: around 2 $m^2$,
- the cabin surfaces are closer to the occupants than in conventional vehicles,
- the cabin is made of polyester, with aluminum and steel structure,
- inner sound and thermal insulation is made of composite materials,
- natural and forced ventilation (electric fans of variable speed, adjustable vents on the dashboard).

Optional equipment includes:

- heating (electric resistance heater - ERH): seats, air [14, 15, 16,17, 18, 20], blanket [19],
- transparent (panoramic) roof [14, 15, 16],
- heated rear window and/or windscreen [14, 18],
- air-conditioning (AC) [18], (Figure 3).


***Fig. 2*** *Examples of electric microcars: Axiam Minauto, Mobilize, Canta [17, 18,20]*


***Fig. 3*** *Control panel of a microcar equipped with the HVAC: commands of blower, windshield heater, seat heating and AC (Mobilize Duo) [18]*

## 3 THERMAL CONDITIONS INSIDE THE CABIN

There are three extreme cases of environment relevant for microclimate in the cabin: warm in summer, cold in winter and high humidity in both warm and cold weather. In conditions of high relative humidity, there is a risk of windows fogging up and a significant reduction in comfort.

In cold environments, it may be easier to achieve an acceptable microclimate due to

- the passengers' clothing that is adapted to the external conditions,
- the contribution of solar radiation, and
- the relatively simple principle of the heating system (electric heating).

The thermal conditions under steady-state operationexpected by the occupants are the same as in other vehicles.

According to the analogy with other types of vehicle cabins, the largest heat gains for a closed microcar cabin in a warm condition are caused by [21, 22]:

- solar radiation transmission through the cabin glazing, as a dominant factor –this results in direct effects on the occupants and in the increase of the interior surface temperatures;
- heating of the cabin walls by solar radiation;
- sensible and latent heat released by the occupant(s).

Total solar irradiation on the outer surfaces can beup to the order of 1 kW/m$^2$, and it presents the largest heat flux that enters the cabin. Initial conditions after the hot soak are very uncomfortable due to very high air and surface temperatures, like in any other closed vehicle. The heat transmitted through the glass caused by solar radiation is related to the normal projection of the microcar cabin in the direction of radiation. The maximum solar transmissivity of glass is in the region of incident angles that are less than 30°, being the most inconvenient case both in terms of solar radiation transmittance to the cabin interior as well as the direct effect on the passengers. Estimated maximum total heat flux will be around 700 W/m$^2$ for clear glass, and around 500 W/m$^2$ for tinted glass [22].

The frequent changes in the orientation of microcars and tall buildings in urban areas make this effect less critical than, for example, in the case of agricultural tractors or construction machinery. The absorbed part of the solar irradiation heats the cabin's roofand its temperature rises (40°C and more [23, 24]). The heat from the heated roof is released into the air by convection and by longwave radiation. This part of the heat is around ten times smaller than through glazing [22].

The Roof is smaller in size than in a passenger vehicle and thus offers less protection of solar radiation. Small cabin size results in small distance of occupants to the inner surfaces which can be on very high or very low temperature, promoting intense heat radiation.

Additional factors that make it difficult to achieve thermal comfort in warm conditions are driving with a closed cabin to prevent noise, pollution, and water ingress. Furthermore, the low speed of the microcar does not encourage natural ventilation of the cabin and the heat loss by convection.

Small interior volume (about half the volume of passenger car cabin or farm tractor cabin) demands high rate of air exchange. Fresh air needs to be conditioned, in both cold and warm conditions, putting more relative load to heating or cooling system because the air recirculation can not be practical.

## 4 THERMAL LOAD OF THE MICROCAR'S CABIN

The small size of the microcar and its cabin, compared to conventional cars, does not mean that the HVAC system is proportionally smaller and uses less energy. An analytical method of modeling thermodynamic processes in an air-conditioned cabin as a lumped system was used for calculation of microcar's cabin cooling load in warm conditions including the solar radiation [21, 25]. The calculation was performed using the following parameters and boundary conditions:

- size of the simplifiedgeneric cabin 1.5×1.1×1.5 m (L×W×H),
- interior air temperature 28°C, relative humidity (RH) 50%,
- outside air temperature 32°C, RH 50%,
- outer air flow rate 110 m$^3$/h,
- air temperature after the evaporator 6 °C,
- total heat transfer coefficient of the cabin of a stationary vehicle U = 10 W/m$^2$K [25],
- heat flux caused by the moderate solar radiation transferred through the windshield and the roof: 330 W/m$^2$ [25],
- driver and passenger.

This simplified calculation gives around 2 kW of the cooling load, which can be very variable depending on the boundary conditions. For transient operation, the cooling power should be higher. However, the lower thermal mass due to the low mass of the entire vehicle compared to larger vehicles, allows for lower energy consumption during transient conditions (cooling or heating the cabin).The value indicates that the energy for the air-conditioning could be almost the same as in conventional car, in contrast to the nominal power of the powertrain motor (4 kW in microcars vs. 100 kW and more in typical BEVs).

A typical BEV uses electric AC (EAC) scroll compressors with a coefficient of performance (COP) of around 2 [26]. However, the microcars do not have high voltage system as BEVs, thus the available power would be limited. For example, the power of EAC motor in BEV "BMW i3 I01" is 4.5 kW at the voltage of 200 to 400 V, while the nominal power of the propulsion motor is 125 kW.

In the cold ambient conditions without solar radiation, the heat is lost through the cabin envelope and by cold outer air intake (a minimum amount is required to maintain the air quality). Due to the clothing adapted to the outside conditions, interior temperature in the range of 13-16°C would be sufficient for short city driving.

Compared to vehicles powered by an internal combustion engine, electric microcars have no heat load from the powertrain, and therefore no waste heat energy to heat the cabin during the winter.In addition, the battery capacity decreases with the temperature. The installed power of the heating in BEV is approximately of the same order as the AC cooling power. For example, the electric heater in BEV "BMW i3 I01" has 5,5 kW. If installed, electrical resistance heaters are used in microcars either for direct heating (heated seats) or for indirect heating (air heating, window heating).

A microcar's cabin heat load in cold conditions was calculated using the following parameters and boundary conditions, for the same cabin characteristics:

- interior air temperature 13°C, RH 60%,
- outside air temperature 0°C, RH 50%,
- outer air flow rate 110 $m^3$/h,
- air temperature after the heater 50 °C,
- no solar radiation,
- driver and passenger.

The calculated heat load would bearound 1.8 kW. Figure 4presents the ratio of individual heat transfermodes, both in warm and cold environments.

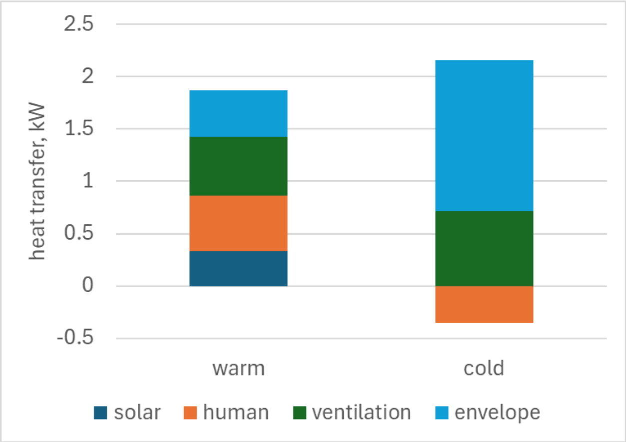


***Fig. 4*** *Modes of heat transfer in warm and cold environment*

In awarm environment with moderate solar radiation, the heat and the moisture released by the microcar's occupants can be the largest thermal load. In acold environment, a largetemperature difference between the outer and interior air is necessary to prevent discomfort and this presents the largest heat loss for the heating system. The heat released by the driver and the passenger is an additional heat source,given as a negative value in the heat losses.

Nominal energy consumption of microcars is in the range of 5 to 8 kWh per 100 km, valid for World Motorcycle Testing Cycle (WMTC) [14-20]. Considering the battery capacity and the nominal EAC/ERH power in a microcar, it is assumed that the use of an HVAC would have a much greater impact on driving range than in conventional BEV, again depending on the driving mode, environmental conditions and thermal comfort requirements.

Methods that would improve energy efficiency of the HVAC system and hence the microcar's range are generally the same as in any other vehicle [4, 5, 7, 11, 13]:

- cabin preconditioning during the charging,
- effective glazing system,
- advanced automatic control of EAC/ERH energy management,
- efficient distribution of theconditioned air.

However, zonal AC or cabin air recirculation are not practicalsolutions for microcars due to small size of the passenger compartment. Furthermore, implementation of any advanced solution leads to an increase in price above acceptable level for this segment of vehicle.

## 5 CONCLUSION

Microcars seem like a practical solution for mobility in urban areas. However, achieving a good thermal environment in a microcar while maintaining overall energy efficiency is challenging for several reasons. Electric microcars are powered by low-power motors, and the battery is sized accordingly. The power requirement for cabin thermal management is proportionally much higher than in a conventional BEV.

Considering the current technology of some microcars, there is room for improvement in both cabin thermal load and the conditioned airutilization. However, advanced solutions for improving both the thermal conditions inside the cabin and energy efficiency are currently expensive for this class of vehicles, and some of the solutions would increase the weight of the vehicle.

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