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Research and Modeling of Interior Temperature Regimes of City Electric Minibuses, which Use a Heating System with Thermal Batteries

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Abstract
Electric buses running on city routes have different thermal conditions than long-distance intercity buses. The main difference is the frequent stops every 0.5–1 minutes and the embarkation and disembarkation of passengers, which causes heat loss. On the other hand, such routes offer the possibility to recharge heating batteries with contactless or non-contact wireless charging systems during stops. In order not to reduce the driving distance of the bus by consuming energy from electric batteries for heating, one option is to use heating batteries. As the total duration of routes from one final destination to another varies from half an hour to an hour depending on the city, but the duration of parking at the end destination is 10–15 minutes, heating batteries must provide cabin heating for one full journey using fast charging while standing at the final stops. This is the main condition for choosing the energy capacity of heating batteries. In the research there was developed and in the article there is described a simulation model in MATLAB/Simulink, which allows modelling different heating power and temperature regimes by varying the bus cabin microclimate influencing factors, such as outside temperature, door opening duration, the heat emitted by passengers, etc. Recommendations are given for levelling the temperature in the cabin, which, according to the measurement data, is markedly uneven.

Keywords
electric minibus, heating, temperature, modelling

1 Introduction

A challenge for electric buses is to organize heating and cooling power to not decrease the driving range but still provide sufficient thermal comfort for the driver and passengers. The energy consumption for heating a bus can reach up to 35% of the main battery's energy (Barnitt et al., 2010; Evtimov et al., 2017). It means, that for passenger electric vehicles (EV), the energy consumption due to heating and cooling system can reduce the overall driving range by 40%–60% under typical standard driving conditions (Barnitt et al., 2010; Chiriac et al., 2021).

For heating the passengers compartment of electric buses the following systems are usually used:

- electric heaters (PTC);
- heat pumps for heating and cooling;
- fuel-operated heaters, using diesel or similar fuel (e.g., Webasto, Ebespächere, etc.).

With convection electric heaters for bus interior heating in winter the energy consumption is on average 0.75 kWh/km (Chiriac et al., 2021). For example, the heat losses can reach about 17.4 kW for a 12 m long bus, depending on the materials of the vehicle and considering only the thermal conduction through the structure of the bus and the heat loss through the open doors. For a typical large city bus with a length of 12 m an average value of energy demand for heating can be 12–14 kW (Chiriac et al., 2021). Of course, it depends on the length of bus and a lot of otherfactors such as materials, configuration, areas etc. HVAC system increases energy consumption by up to 56–60% at −17 °C to maintain the desired microclimate (Impari, 2019). The studies of another authors show that it is possible to increase the mileage of electric vehicles, that use drive batteries for heating, by preheating of passengers compartment using

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plug-in electric heater by 4% at an ambient temperature of approximately −7 °C (Barnitt et al., 2010), but this is not a solution. Applying infrared electric heaters it is possible to reduce energy consumption up to 50% compared to conventional heaters (Bauml et al., 2014), but it is suitable for small vehicles, and also consumes energy from electric batteries, reducing mileage. Using of fuels, produces emissions and therefore this eliminates the benefits of electric vehicles as a green transport. Heat pump consumes the electric power from the vehicle's electric batteries, reducing driving range on a single charge.

In general, all the existing bus compartment heating methods listed above either consume electricity from electric batteries, reducing the distance traveled with one charge, or pollute the surrounding environment with emissions, that do not correspond to the main purpose of the implementation of electric transport.

The using of heating batteries with phase change materials (PCM) for electric bus heating, by charging them simultaneously with electric batteries, is one of the possible solutions for heating passenger compartment of the electric buses without using energy from electric batteries. In addition, latent heat thermal energy storage (LHTES) systems have higher energy-storage density and lower complexity than that of other HTES systems. It should be noted that the use of PCM heating batteries in passenger transport is not yet widespread, although it can certainly be developed in the future. PCM heating batteries for vehicles are already being produced. The studies in this article also include the using of PCM heating batteries for heating a city bus. The developed model can be used to determine the parameters of the components of the innovative minibus heating system, using PCM heating batteries. The microclimate parameters of the passenger cabin and the dynamics of their change are affected by all the factors listed above. Therefore, it was necessary to create a simulation model that would evaluate all of them in the modeling process and also allows to evaluate the main parameters of the cabin heating elements.

Providing thermal comfort for electric bus passengers is an important task, but it has certain specificities depending on the application of the bus. Using the bus in urban conditions during the season, when heating is required, the following aspects should be taken into account:

- the passengers are dressed in autumn or winter clothing, which is not worn throughout the journey;
- the bus has frequent stops in intervals 30–60 seconds, when the doors are opened for 5 to 30 seconds, and boarding and disembarking take place, also creating intensive air exchange;
- the passengers emit a certain amount of metabolic heat that compensates the heat losses;
- the duration of the journey between the final destinations, where the batteries are to be charged using fast charging option, may be different in different routes and in urban conditions can vary within 0.5 to 1 hour.

The main objective of the research was to develop a mathematical simulation model for modelling the temperature regimes and power balance in the passenger compartment of city electric bus at different operating conditions by using PCM heating batteries as the source for heating, as well as justifying the power of the heat sources to ensure a temperature regime that meets comfort criteria. The model should provide the possibility to model the cabin heating dynamics as well.

In parallel with the simulation model development, an experimental electric minibus heating system with PCM heating batteries was developed, which was built into the minibus. Using this system, experimental studies were carried out for both stationary and moving buses in order to obtain the necessary numerical data for the creation of the model, as well as to validate the model results.

2 Theoretical description of processes

The main processes for heat flow to the ambient area for an electric bus can be assumed, as following:

- outdoor surface heat transfer;
- indoor surface heat transfer;
- wall conduction.

This characterizes the main and relatively predictable heat losses from the bus as the ambient heat losses through the bus structure. The other essential heat losses occur through the open doors at the stops. Losses through the bus structure are the most significant, and four components – the windows, the walls, the floor, and the roof representing about 78% of the total bus heat losses. The main heat losses occur through the windows (about 26%), while the other three heat loss components have almost the same amount (about 8.1–8.3% each). In terms of other heat losses, a large part of the losses in city buses occur through open doors, up to 22% (Chiriac et al., 2021).

The heat balance of the bus cabin consists of both losses and heat gains. Considering both losses and gains, the heat balance can be expressed as follows (Chiriac et al., 2021):

$$Q_{total} = Q_p + Q_{sun} + Q_{mot} + Q_{bat} + Q_{vent} + Q_z + Q_d + Q_{hsyst}, \quad (1)$$

where:

- Q_p: metabolic heat from passengers;
- Q_{sun}: heat from the sun radiation;
- Q_{mot}: heat from the drive electric motor;
- Q_{bat}: heat from the electric batteries;
- Q_{ven}: heat losses by air exchange caused by the ventilation system;
- Q_z: ambient heat losses;
- Q_d: heat losses through the open doors at the stops;
- Q_{hsyst}: heat from the heating system.

Metabolic heat of one sitting passenger and standing passenger are defined as 60 W/m^2 and 70 W/m^2, respectively. On the other hand, the ISO 8996:2021(en) (2021) standard provides the following value for sitting passenger 55 W/m^2. A medium value of 60 W/m^2 is accepted, which, for one person, results in 60 × 1.8 m^2 = 108 W in average (Tanyeri and Başlamışlı, 2020). Another study mentions that for a standing or sitting person it can be approximately 100 W (Abdulsalam et al., 2015), which is very close to the above mentioned. The heat that enters the bus cabin from the passengers depends on how they are dressed. The thermal insulation of clothing is characterized by the parameter clo, for example, for winter clothing it is 2–3 clo, for ordinary indoor clothing 1.2–1.5 clo (Simion et al., 2016). Passengers usually take off their outerwear on intercity buses, but stay in winter clothes on city buses. Therefore thermal comfort temperature in the city bus cabin is lower. Under such conditions, the number of passengers does not significantly affect the heat demand. For example, as shown by other studies, at 0 °C with a minimal load and full occupancy the average energy demand for bus heating increases only by 5% (Basma et al., 2020).

The inside air flow rate for the buses depends on the operating of the air conditioning system. It is in the range between 0.05 m^3/s and 0.3 m^3/s. During winter conditions, the ventilation system can work at the lowest productivity to reduce heat loss. Thermal efficiency of heating can be improved by the recirculation of the cabin air whereas fresh air is used for maintaining adequate air quality (Lajunen et al., 2020). But, for a city bus with frequent stops in an interval of 30–60 seconds, the air exchange is mainly determined by the open door. Heat loss through the open doors depends on the route of the bus, the number of stops, and the number of passengers getting on and off the vehicle. Heat losses through an open door can be approximately determined using formula $Q_d = V \times \rho_{air} \times c \times \Delta T$. Assuming that the intensity of air exchange through an open door is V = 0.4 m^3/s (Chiriac et al., 2021), the heat losses can reach approximately 15 kW for a single 1.44 m^2 door. This means that during one stop for 20 seconds, the amount of heat loss through the open door can reach approx. 0.083 kWh (depending on air temperature difference). The average time between two stops for a city bus is about 30 s (Göhlich, 2018), that is similar in many cities in different countries, as well as in Latvia. The duration of bus standing at the stop depends on the number of passengers getting on and off and it is on average 4 seconds per passenger (Xue et al., 2022). Air exchange mainly takes place through the open doors, as well as the ventilation system of the bus often works in recirculation mode, therefore heat loss through ventilation can be underestimated during calculations (Niemyi, 2020).

Drive electric motor is located in the front of the experimental bus placed outside under hood, therefore the incoming heat in the passenger compartment is small and it will not be considered in this analysis as well as the heat from electric batteries. Therefore, it will not be included in the heat balance in the further part of the study.

The losses to ambient environment Q_z depend on air speed, respectively combination of bus speed and wind speed and direction. For the vehicles, the convection coefficients of the outer surfaces depend on the vehicle speed. For the inner space, the coefficient depends on the inside air speed v, relative to the inner surfaces (Tanyeri and Başlamışlı, 2020), as follows: $\alpha = 9 + 3.5v^{0.66}$ W/m^{2}K.

It is necessary to ensure a temperature suitable for the comfort conditions even with a small number of passengers, therefore, when determining the heat supplied for the heating of the cabin, the heaters have to be able to provide the amount of heat also under these conditions. The city bus conditions are different in comparison to long route intercity busses. The passengers stay in the bus for a short period of time and are dressed in winter clothing that is not taken off. Therefore, the amount of heat that they emit is significantly lower and to ensure a comfortable microclimate, such a high temperature as in an intercity bus is not required. On the contrary, the temperature should be significantly lower, otherwise the passengers will start sweating and the change in temperature when they get off the bus can have an adverse effect on their health. Lower temperatures also reduce the amount of heat needed to heat the bus cabin. Mentioned considerations for city bus heating system must also be taken into account. In Latvia, the temperature in the bus cabin is usually stipulated in the contracts concluded with passenger transport companies, and usually during winter it should be between 15–17 °C on average.

Therefore, when developing a simulation model, it is necessary to determine the influence of above described various urban passenger minibus operation conditions on the required heat capacity of heating batteries for passenger cabin heating such as the number of stops during route, door opening duration, amount of passenger and outdoor air temperature.

3 Experimental investigation object and methods

In order to study the temperature distribution in the bus and the influence of external factors on it, experimental minibus trips were made, performing appropriate measurements.

Main characteristics of electric minibus OPP M2 (the structure and interior were created from a converted body of a Mercedes Sprinter cargo van, transforming it into a passenger minibus):

- dimensions: 7361 × 1993 × 2815 mm;
- interior headroom: 1820 mm;
- passenger seats: 18;
- electric motor continuous/peak power: 70/160 kW;
- range: 70 km;
- electric battery capacity: 44 kWh.

For experimental studies, a cabin heating system was created and installed in the minibus using PCM heating batteries. Fast charging system from a three-phase network and an additional wireless intermediate charging system for these heating batteries were developed. The developed bus heating system by using fast charging heating batteries is schematically shown in Fig. 1 and it is highlighted by a red line. The heating system consists from 2 parts: the electrical control system and hydraulics for heat carrier. Hydraulic connections are marked in black and electric parts in blue.

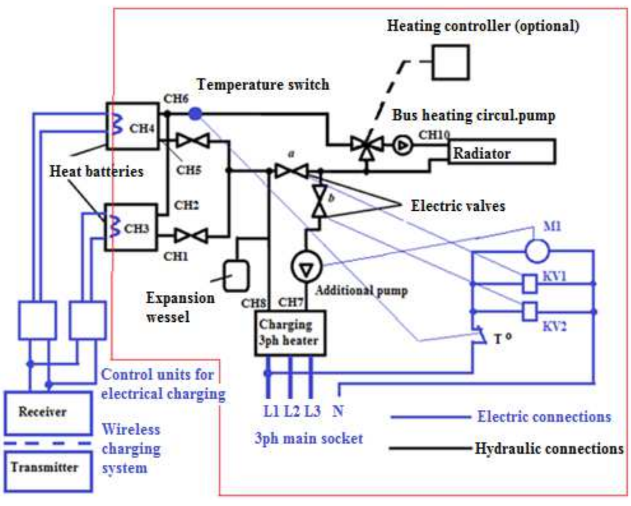

Fig. 1 Schematic diagram of the developed bus heating system with temperature sensors (CH)

The heat carrier is heated using a high-power three-phase once-through electric heater (up to 24 kW for charging of 2 or 3 pcs of heating batteries with energy capacity 3.5 kWh each) This system makes it possible to fully charge each heat battery much faster, i.e. in about 15…20 minutes depending on the previous charge level, which corresponds to fast charging time of the electric batteries. The charging and discharging parameters in real conditions are researched by testing heating system integrated in the electric bus. The charging duration was confirmed by experimental studies.

Additional wireless charging system provides power up to 10 kW and is intended for short-term additional charging while standing at stops. This system was studied separately and was not used in the experiments during this research.

Rides were made on a real city route, stopping at stops and opening doors for passengers to board and disembark. The duration of the full trip is approximately 50 minutes with 19 stops. Temperature measurements were made using K-type low-inertia thermocouples, by accumulating data in the GL840 logger produced by DATAQ with an accuracy in the measurement range of ±0.05% and a temperature resolution of 0.1 °C. Trips were made both with a preheated cabin and from a cold state, when the average stabilized temperature of the cabin was equal to the ambient temperature.

Fig. 2 shows the temperature curves for one of the journeys, which reflect the temperature distribution in the bus cabin at specific points.

As can be seen from Fig. 2, opening the door causes a rapid drop in the air temperature at the bottom of the door which is lower than the cabin floor, which becomes close

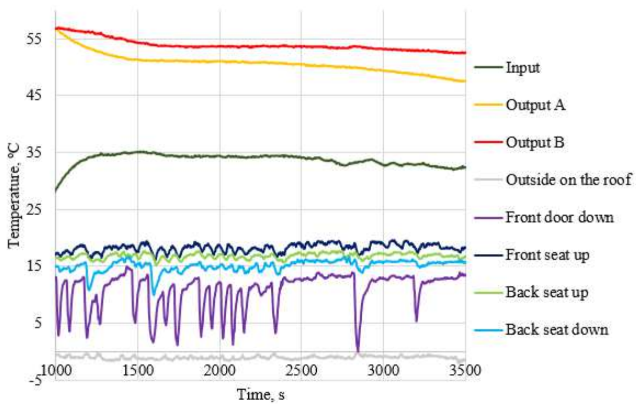

Fig. 2 Temperature distribution in the minibus cabin during the journey, when opening the doors at the stops

to the outside air temperature. But the air temperature near the passenger seats, even near the doors, changes by a relatively small value.

Heat from two PCM heating batteries A and B with a heat capacity of 3.5 kWh each was used for heating the bus cabin. PCM batteries have the advantage of having a higher energy density than sensible storage and features the ability to provide thermal energy at a constant temperature during the phase changing process (Li, 2016) compared to other types of heating batteries. The energy of electric batteries is not consumed for heating. The energy density of PCM thermal batteries is high, reaching 201 to 285 Wh/kg, compared to electric batteries, e.g. Li-Ion, for which it is from 150 to 200 Wh/kg (Dreißigacker, 2021). During one trip, i.e. for about 50 minutes, a comfortable average air temperature for a city shuttle bus was maintained in the bus cabin at about 16.5 °C. In this study, the bus cabin was preheated to the mentioned temperature before departure.

The difference in temperatures of the heat carrier at the outlet of the batteries shown in Fig. 2 (output A, output B) is explainable by the fact that, due to the position, the batteries have different lengths of supply pipes, thus there are different length of the path of the heat carrier and hydraulic resistance, hence also the flow. The heat carrier was supplied to a standard minibus heating radiator located along one side wall of the minibus, which does not have a door.

As can be seen from the input curves, the heat energy consumption from the heating batteries changed relatively little when the doors were open, and this is basically explained by thermal inertia, as well as the cool outdoor air not being able to cool the radiator surface to a low temperature so quickly during the stop.

The average time at stops on the city route with open doors was determined experimentally and is approximately within 10–20 s.

4 Results and discussion

In order to be able to determine the heat losses during the trip, when opening the doors at the stops and the power consumed to compensate them, the heat flow equations of the bus cabin was developed:

$$\frac{dQ}{dt} = \sum_{i=1}^{n} Q_i, \tag{2}$$

$$Q = c \times m \times T_s = c \times \rho \times V \times T_s, \tag{3}$$

$$Q_{in} = c \times q_m \times T_{out} = c \times V_d \times \rho \times T_{out}, \tag{4}$$

$$Q_{out} = -c \times q_m \times T_s = -c \times V_d \times \rho \times T_s, \tag{5}$$

$$\frac{dQ}{dt} = Q_1 + Q_{in} + Q_{out} + Q_z + Q_p \times n, \tag{6}$$

$$Q_z = \frac{1}{R}\left(T_{out} - T_s\right), \tag{7}$$

$$\begin{aligned} \frac{d\left(c \times \rho \times V \times T_s\right)}{dt} &= Q_1 + c \times V_d \times \rho \times T_{out} \\ &-c \times V_d \times \rho \times T_s + \frac{1}{R}\left(T_{out} - T_s\right) + Q_p \times n, \end{aligned} \tag{8}$$

$$\frac{d\left(T_s\right)}{dt} = \frac{1}{c \times \rho \times V}\begin{pmatrix} Q_1 + c \times V_d \times \rho \times T_{out} \\ -c \times V_d \times \rho \times T_s \\ +\frac{1}{R}\left(T_{out} - T_s\right) + Q_p \times n \end{pmatrix}, \tag{9}$$

$$\begin{aligned} T_s(t) &= T(0) \\ &+\int_0^t \frac{1}{c \times \rho \times V}\begin{bmatrix} Q_1 + c \times V_d \times \rho \times \left(T_{out} - T_s\right) \\ +\frac{1}{R}\left(T_{out} - T_s\right) + Q_p \times n \end{bmatrix} dt, \end{aligned} \tag{10}$$

where:
- Q: cabin air heat content (J);
- Q_i: incoming and outgoing heat flows (W);
- c: specific heat capacity (for air c = 1006 J/(kg·°C));
- m: mass of air (kg);
- T_s: average air temperature in the cabin (°C);
- T_{out}: outside air temperature (°C);
- ρ: air density (ρ = 1.29 kg/m^3);
- V: volume of air in the cabin (V = 20 m^3);
- Q_1: heat flow from heating batteries (Q_1 = 5000 W);
- Q_{in}: heat flow entering the cabin by air (J/s or W);
- Q_{out}: heat coming out of the cabin by air (J/s or W);
- Q_p: heat flow from one passenger (Q_p = 108 W);
- n: number of passengers;
- q_m: air mass flow rate (kg/s);
- V_d: air flow through one door (V_d = 0.2 m^3/s);
- $T(0)$: initial air temperature in the cabin (°C);
- Q_z: heat loss through the walls, windows, the floor and the roof of the bus (J/s or W);
- R: the thermal resistance of the outer structures of the bus, 0.004 °C/W.

In order to be able to generalize the effect of door opening on cabin temperature, a simulation model was created in MATLAB environment, which can be seen in Fig. 3.

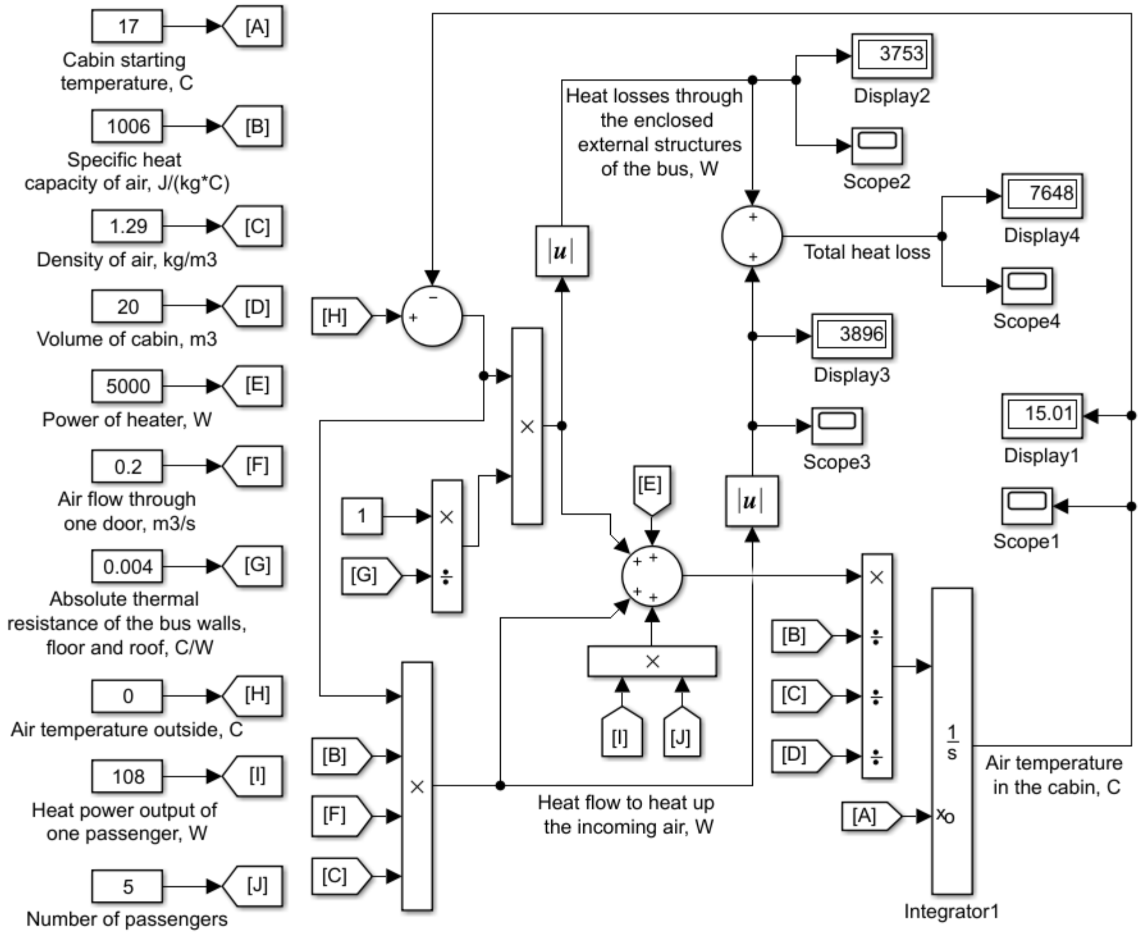

Fig. 3 Simulation model in MATLAB/Simulink

The model assumed that the cabin temperature was equalized. The total thermal resistance R = 0.004 °C/W for the heat flow through the external structures of the bus in the stationary state was determined experimentally. The model also evaluates the heat emitted by passengers according to experimental studies. The model does not evaluate how heat loss changes depending on driving speed and wind direction.

Using the developed simulation model, it is possible to simulate the average temperature changes of the cabin (Fig. 4) and heat energy loss changes through external structures enclosing the bus, as well as a result of air exchange through the doors of the cabin, until the thermodynamic balance occurs after ~300 s.

For the validation of the developed simulation model, the simulated results were compared with the experimental ones. The simulated curves of cooling (Fig. 4) were compared with the experimentally obtained cooling curves during opened bus doors. Fig. 5 shows one of the experimentally obtained temperature curves of the passenger compartment with the doors opened at the stop.

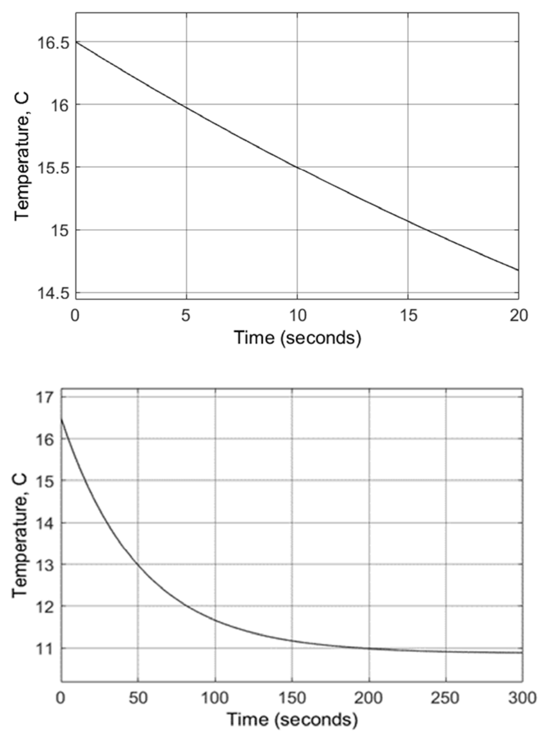

Fig. 4 Simulation of the average cabin temperature drop with opened doors (during a period of 20 and 300 s)

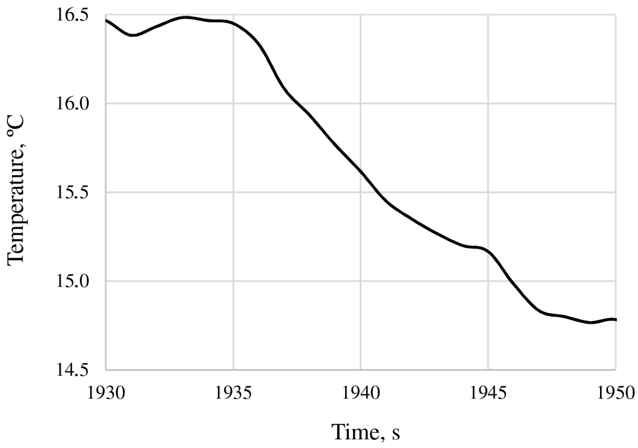

Fig. 5 Experimentally measured average cabin temperature drop with opened doors (during period 20 s)

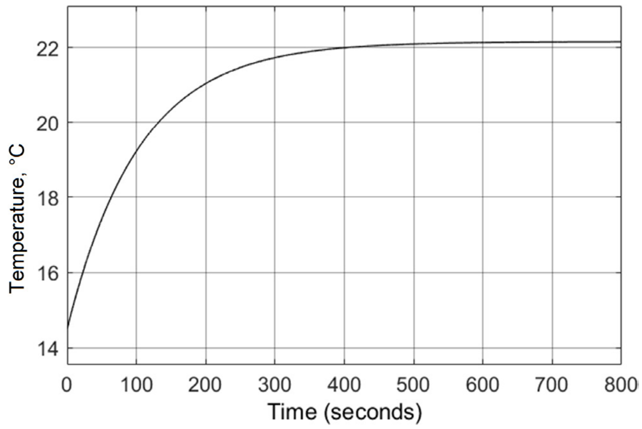

Fig. 7 Simulation of the average cabin temperature changes with closed doors (P = 5 kW, T_{out} = 0 °C, T(0) = 14.7 °C, n = 5)

Measurements were made while driving on a real route, the time was recorded starting from the moment of departure.

The real duration of stay at the stop was about 20 s, after which the doors were closed and the cooling of the cabin ended. Therefore, at this point in the experimental graph (Fig. 5), the drop in the temperature curve ends. The simulated and experimental curves are very similar, which indicates the conformity of the model to the real conditions and allows their application with high reliability.

The simulation model also can be used to simulate the heating of the cabin when the doors are closed, entering specific parameters: initial cabin air and outside air temperatures and heating power values. From the moment when the door is closed, the temperature starts to rise. As can be seen from the experimental curve (Fig. 6) and the simulated curve (Fig. 7) (starting point from the beginning of simulated curve), while the door is closed at an interval of about 50 s while driving between stops, the temperature in the cabin increases from the initial approximately 14.8 °C to approximately 16.8 °C.

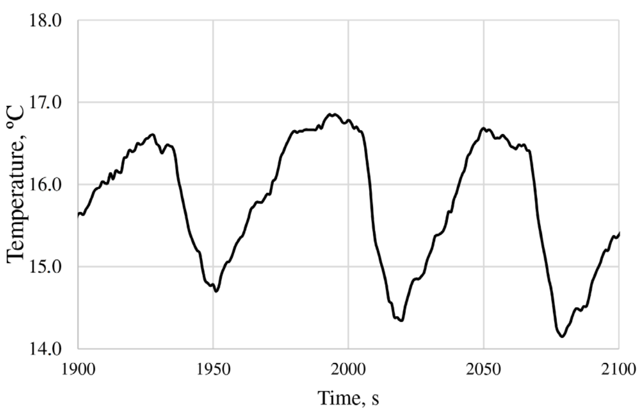

Fig. 6 Experimentally measured average cabin temperature drop with opened door (during period 200 s)

One of the tasks of developing the model was to find out what amount of heat energy from heating batteries is needed to compensate heat losses through open doors at bus stops. Here we can use the created model to simulate the operation of the cabin heating. From the curves (both the simulated and experimental curves) it can be seen that, for example, the average temperature in the cabin drops by an average of 2 °C, when the door is opened, if the outside air temperature is 0 °C. In order to compensate for this drop in temperature, additional heat must be supplied from the batteries, which must heat the incoming outdoor air. The average cabin temperature of 16.5 °C can be reached after about 35 s with such supplied heat power of 5 kW. Since the average journey time between stops is about 60–80 s, this capacity is completely sufficient to ensure a normal microclimate in the cabin.

On the other hand, the heat loss through the bus surfaces changes when the average air temperature in the cabin decreases until it recovers to the previous value, while the incoming outside air warms up. The heat balance of this process can be described by Eqs. (11) to (14):

$$Q_{HA} = Q_{air} + Q_z , \quad (11)$$

$$Q_{air} = \left| c \times V_d \times \rho \times \left(T_{out} - T_s \right) \right| , \quad (12)$$

$$Q_z = \left| \frac{1}{R} \left(T_{out} - T_s \right) \right| , \quad (13)$$

$$Q_{HA} = \left| c \times V_d \times \rho \times \left(T_{out} - T_s \right) \right| + \left| \frac{1}{R} \left(T_{out} - T_s \right) \right| , \quad (14)$$

where:

- Q_{HA}: required heat flow from the heating batteries, during door opening (W);
- Q_{air}: heat flow to heat the incoming air (W).

The total heat loss during door opening decreases depending on the temperature difference between the interior and the outside temperature, until it reaches thermodynamic balance, when the incoming heat energy is equal to the outgoing heat energy (Fig. 8).

The total heat losses are significantly higher during the first seconds of opening the door, but then they stabilize until they reach ~5550 W. Using the created simulation model, it is possible to determine what the heat losses of the bus will be with different number of passengers and with different door opening durations. The experimental measurements in Fig. 9 show, that the temperature in the middle part of the cabin is significantly different from the temperature near the door, as well as its vertical distribution. The average temperature of the cabin was ~16.5 °C and was maintained throughout the route. While the door was opened, the temperature dropped, but when the door was closed, the temperature increased until it reached the previous temperature before the door was opened.

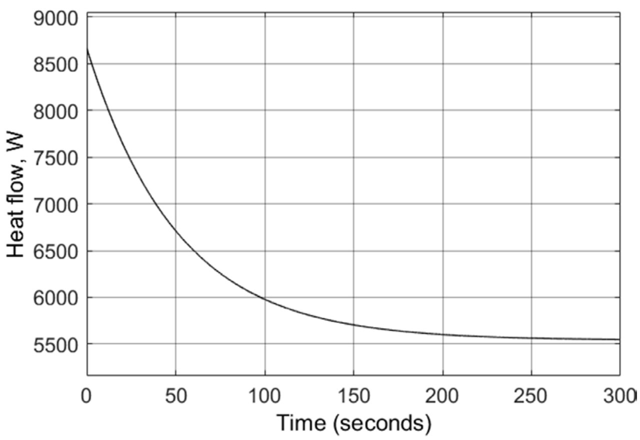

Fig. 8 Simulation of total heat loss during door opening

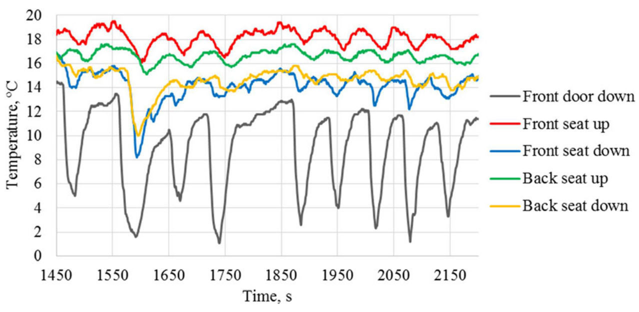

Fig. 9 Experimentally measured temperature distribution in the bus cabin

The heating time of the cabin during the journey is significantly affected by the duration of the door opening and the number of stops. If the door is kept open for a longer time, it also takes longer to warm up the cabin again. The previous cabin temperature was not always reached before opening the door again at next stop.

When using the conventional radiator of the bus heating system, it is not possible to obtain an even temperature distribution in all points of the cabin. Near the door, in the lower part, when the door is opened, there is a significantly greater temperature drop than, for example, in the middle part of the cabin.

In the lower part near the seats, the temperature fluctuation was significantly higher than near the ceiling. On average, the air temperature in the cabin dropped by about 2 °C during one door opening. The average duration of door opening at one stop varied between 10–20 s.

5 Conclusions and evaluations

The experimental research and results of modeling lead to the following conclusions:

- In city buses, it is not necessary to maintain the same high temperature as in intercity buses, because the passengers stay in the such buses for a shorter time and they are dressed in winter clothes. The average temperature no more than 16…17 °C allows to reduce heat consumption for cabin heating in comparison to intercity buses.
- The temperature distribution in the passenger compartment is uneven: the difference between near the ceiling and near the floor can be up to 6–7 °C. In order to ensure a more even heat distribution, it is necessary to change the arrangement of the radiators in the cabin, compared to the standard arrangement on one side, and to create a separately adjustable heat carrier supply for each radiator.
- However, it is not useful to try to maintain the average cabin temperature near the cabin floor next to the doors when they are opened. This would significantly increase the heat consumption from heating batteries.
- To ensure an even temperature, the solution could be small individual heating elements near each seat.
- The developed model allows simulating the required heat flow and the energy capacity of heating batteries for cabin heating depending on thermal resistance of bus surfaces as well as on several external factors, such as the number of passengers, door opening duration, outdoor and indoor air temperatures.

- When closing doors after passengers boarding at stops the optimal average cabin temperature of 16.5 °C supplying heating power 5 kW can be reached in about 35 s when outside temperature is about 0 °C. Since the average journey time between stops is about 60–80 s, this power is completely sufficient to ensure a normal microclimate in the minibus with 18 seats. By entering corresponding parameters, the model can calculate parameters for buses with different sizes and number of seats.
- According to the modelling results, in order to ensure the necessary comfortable temperature level (average 16.5 °C) in the passengers compartment of the city route electric minibus with 18 seats at outdoor air temperatures of around 0 °C two heating batteries charged at the final stops with a total heat capacity of 7kWh are sufficient. It has also been validated experimentally. In colder weather, additional charging of heating batteries could be provided by wireless charging at stops.

As a result of the research, the novelty and importance of the developed model is characterized by the fact that it allows to simulate temperature regimes, their dynamics depending on multifaceted influencing factors, as well as the application of PCM heating batteries as the heat sources, which are currently rarely found in passenger transport, but whose use should be promoted in the future.

The application of the study can be limited by the fact that, before modeling, the heat transfer coefficient of the specific bus must either be determined experimentally or calculated. This may vary depending on different bus designs. But this factor is closely related to the dimensions of the bus, i.e. surface areas and volume. Therefore, there is a certain proportionality here when applying modeling to a different bus. Of course, it is also determined by the materials used in the construction of the bus.

The results of the research were used in the improvement of the developed electric minibus heating system which was built into the electric minibus. One of the problems that should be solved in future research is the means of ensuring uniform temperature distribution in the passenger cabin and the possibilities of reducing heat loss.

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