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Activity 3.7. Work visit at „Gheorghe Asachi” Technical University of Iasi, Romania

Scientific and Research Activities on TUIASI over the Project

“Improving the cross-border public transportation using electric buses supplied with renewable energy”

Project EMS-ENI code 2SOFT/3.1/54

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ACTIVITY 3.3.

THERMAL MODEL OF THE INDOOR ENVIRONMENT

Research and analysis regarding the thermal aspects of the interior of the electric bus:

1. Realization of a model of the inside geometry of the electric bus – UTM responsibility.

2. Develop a thermal model for the indoor bus environment using a dedicated CFD software package based on finite element method – TUIASI responsibility.

3. Realization of simulations based on the thermal model.

4. A comparative analysis between the temperature measurements inside the bus provided.

Contents

CHAPTER 1.
THERMAL MODEL INSIDE THE BUS ENVIRONMENT

Heat transfer theory, heat balance method and U-Value definition can be named as the foundations used in calculations and modelling. Based on the heat transfer theory there are three mechanisms for transferring heat: conduction, convection and radiation.

The total heat released to the cabin is given by:

-Ambient load, as the thermal load caused by the temperature gradient between inside air and ambient temperature,
-Radiation loads,
-Metabolic load, generated by human body,
-Ventilation load, as the flow of fresh air,
-Engine/Motor load, due to the motors of the bus,
-AC load, for keeping the internal temperature in the comfort zone by heating or cooling.

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Heat Transfer Model

1.1. Heat conduction

Conduction follows Fourier´s law for one-dimensional heat conduction.

$$q = -kA\frac{dT}{dx}$$

Where:
q is the heat-transfer rate, W;
A is cross-sectional area, m^2;
k is the thermal conductivity of the material, W/(m.K);
dT/dx is the temperature gradient.

Heat Transfer Model

1.2. Heat convection

The basic formula of calculating convective heat transfer rate is the Newton's law of cooling

$$q = hA\Delta T$$

Where:
q is heat-transfer rate;
h is convection heat transfer coefficient, W/(m^2.k);
A is area, m^2;
ΔT is temperature difference between fluid and surface, K.

Heat Transfer Model

1.3. Heat radiation

Based on the Stefan-Boltzmann law:

$$e_b(T) = \sigma T^4$$

Where:
Eb is the energy radiated per unit time and per unit area.
Σ is the Stefan-Boltzmann constant with value of 5.7 x 10-8 W/m2K4
T is temperature, K.

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1.4. Heat Balance Method for the electric bus

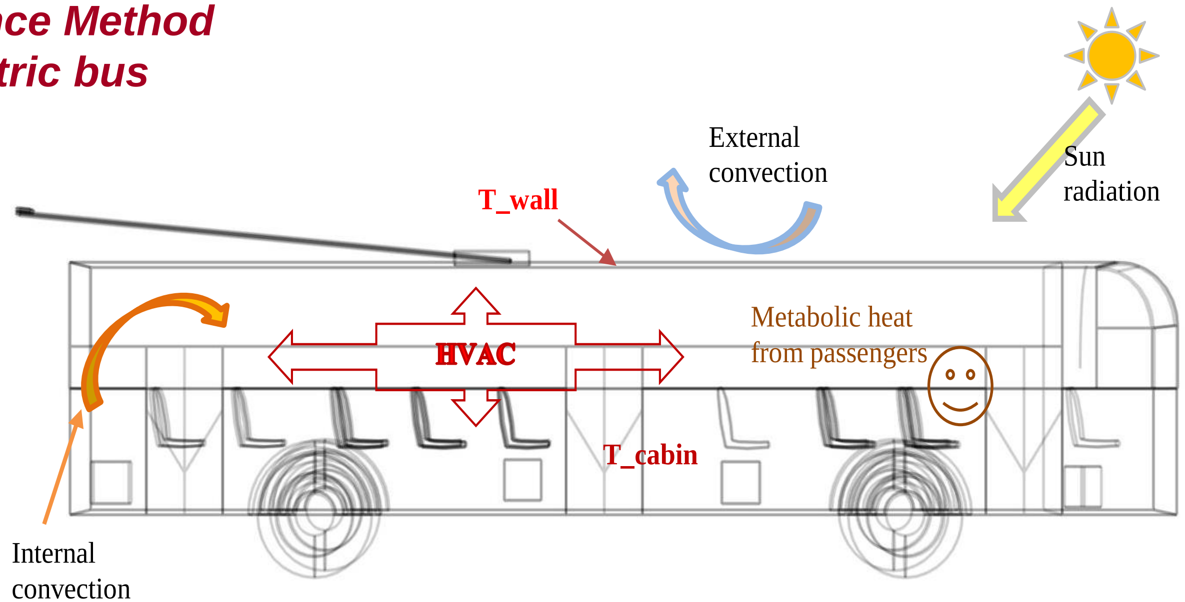

Fig. 1. Thermal processes into an electric buses.

There are 4 effects to be considered:

1. The sun that radiates heat through the windows of the bus. It is dependent on the radiation power of the sun, on the transmission factor of the glass, the area of the windows and the angle between the sunlight and surface of the glass.

2. Air refresh rate. This term is a value of fresh air flowing into the cabin, it is dominated by the airflow through the doors. This factor depends on whether the doors are opened and the temperature difference between the inside and outside air.

3. Wall and window insulation. Heat energy is also flowing through the walls and windows of the bus. A better insulated cabin enclosure will result in a reduced heat transfer between ambient conditions and the cabin climate. This factor depends on the temperature difference between inside and outside air and the insulation factor of the bus walls.

4. Passengers that generate heat inside the bus. Passengers generate heat through their metabolism system.

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CHAPTER 2.
DESIGNING OF THE INSIDE GEOMETRY MODEL OF THE ELECTRIC BUS

2.1. Geometry model of the real electric bus E321

The geometry of the electric bus is constructed as a basic geometry and is composed from:
-Passenger’ cabin;
-Driver’ cabin;
-Front, rear, and lateral walls of the bus;
-Windshield (front/driver window);
-Rear and lateral windows;
-Floor;
-Roof;
-Doors;
-Wheels;
-Passengers’ seats;
-Driver’s seat;
-Power collecting current system (on the roof);
-Electric air heat units (4 pieces) inside the passengers cabin;
-Heating block (inside the driver cabin).

Geometry of the real electric bus E321

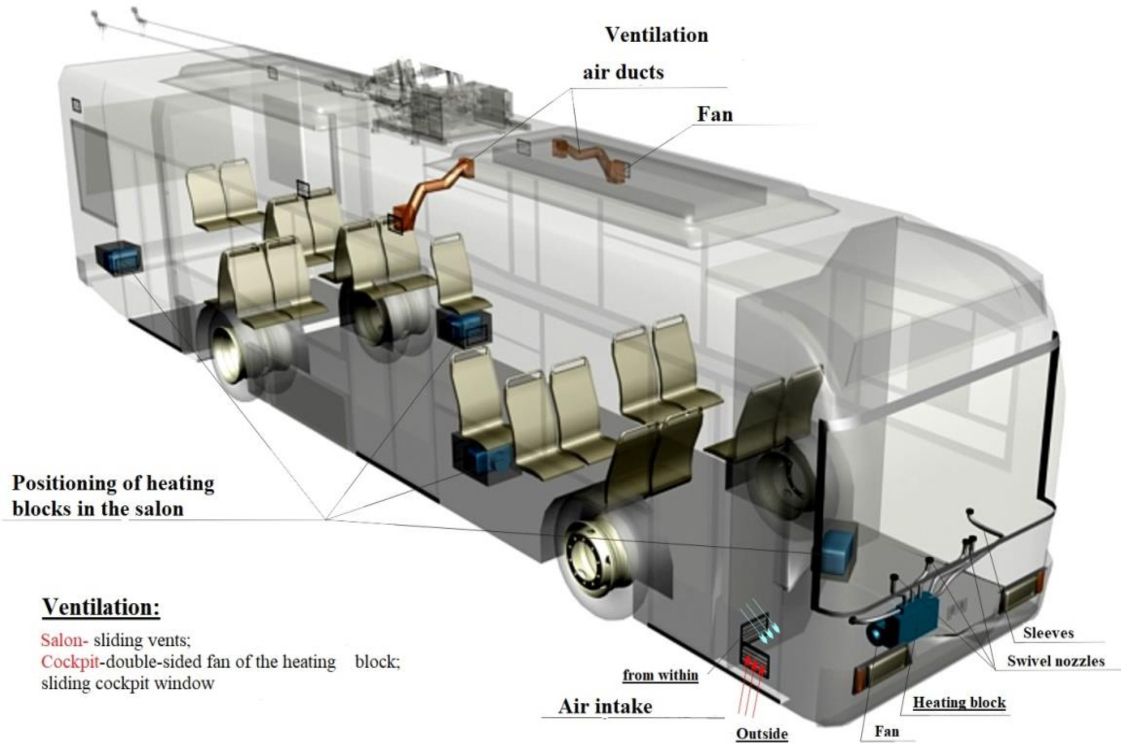

Fig. 2. The E321 BUS heating and ventilation System

Some of the traction equipment are mounted on the roof of the electric bus,, while the traction lithium-ion batteries are mounted on the back of the electric bus.

Position of heating blocks in the salon (passenger area) and the ventilation system of the electric bus used in the project is presented in a 3D representation in Figure 2.

Table 1
General characteristics *of the electric bus E321*

Passenger capacity, people	101
Number of seats	23
Unladen weight of trolley, ready for operation, kg	11,100
Maximum mass, kg	18,000
Mains voltage, V	550
The floor height above the road, mm	340
Number of doors	3
Length, mm	11,935
Width (without mirrors), mm	2,550
Continuous output of electric motor, kW	150
Maximum speed, km/h	60
Number of seats	26

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2.2. CAD model

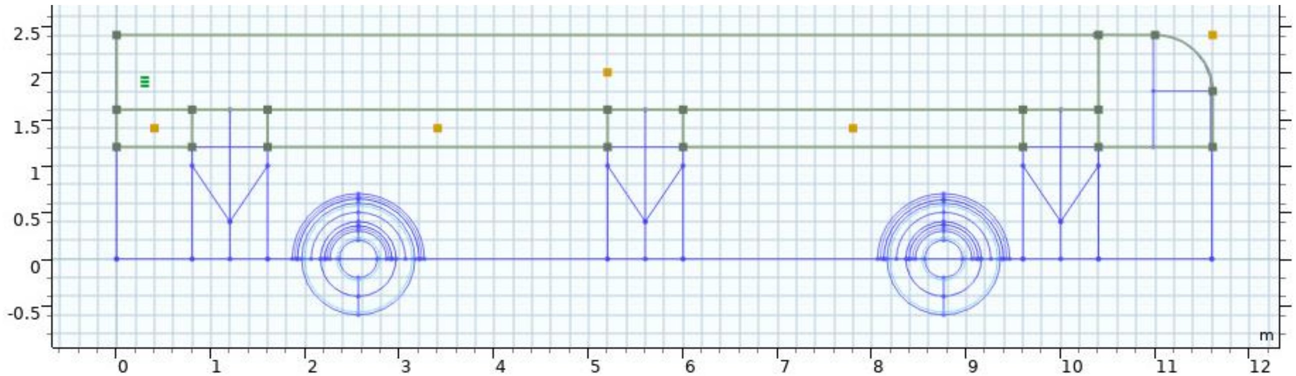

Fig. 3. 2D design of the bus.

The dimensions of the electric bus are designing into the geometry model according to the real dimensions of the real vehicle, an electric bus E321 used currently on public transportation in Kishinev, Republic of Moldova.

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2.2. CAD model

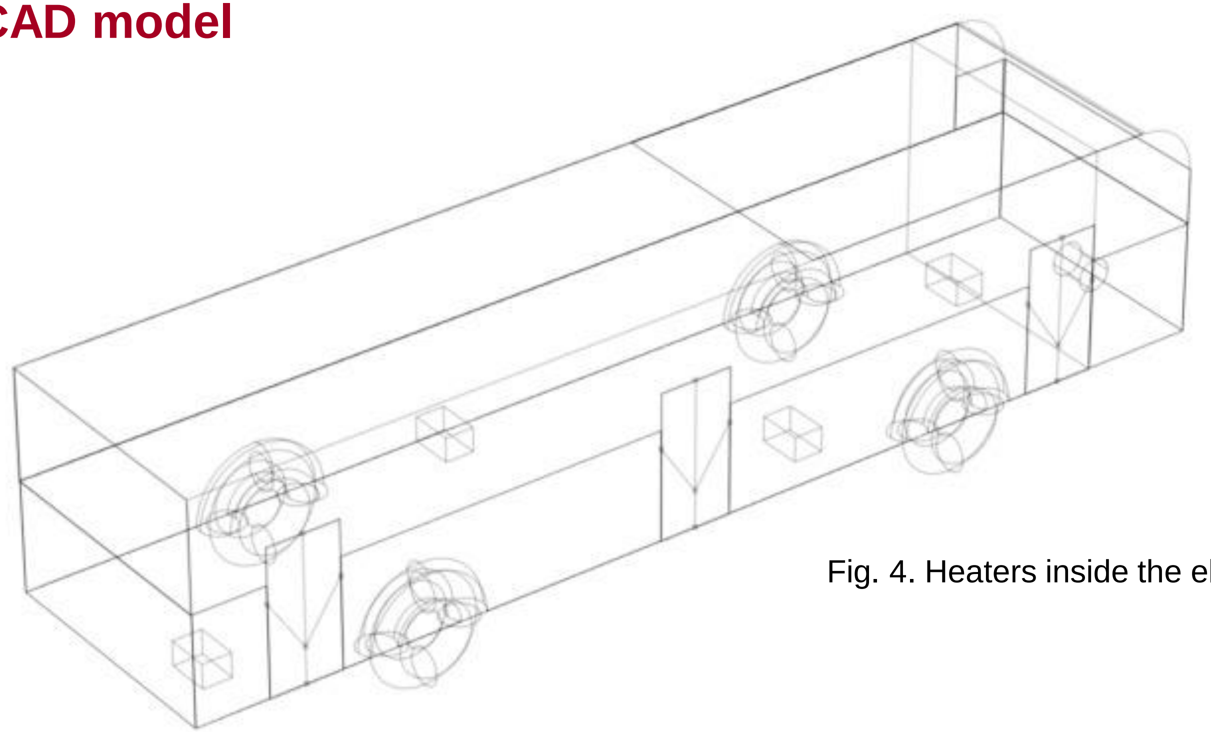

Fig. 4. Heaters inside the electric bus.

Having the main structure of the geometry model, the heaters can be designed inside the cabins.

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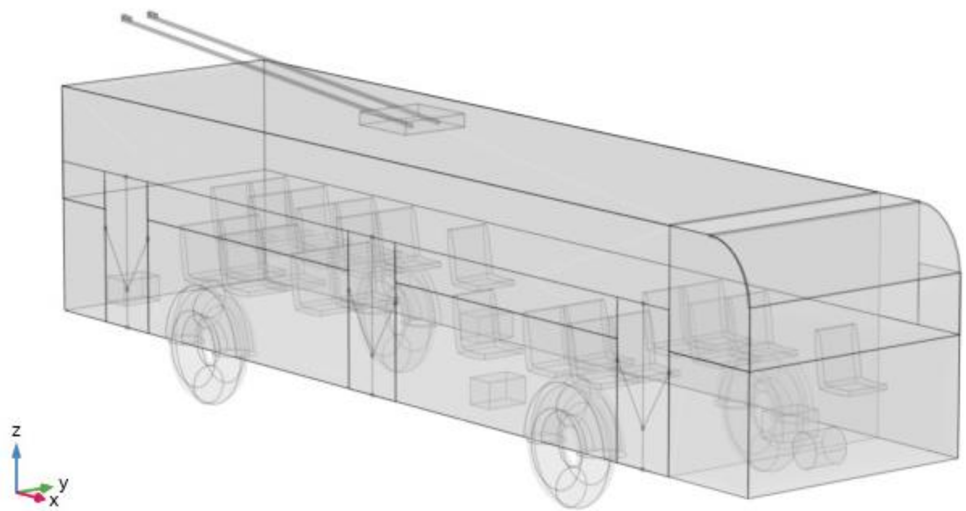

Fig. 5. The basic geometry model of the electric bus; transparency view.

The materials considered for the components of the bus for the model are:
-iron,
-glass,
-acrylic plastic,
-glass fiber and
-PMMA - polymethyl methacrylate.
The inside volume of the bus is modelled as fill with air.

2.3. SIMULATIONS AND RESULTS

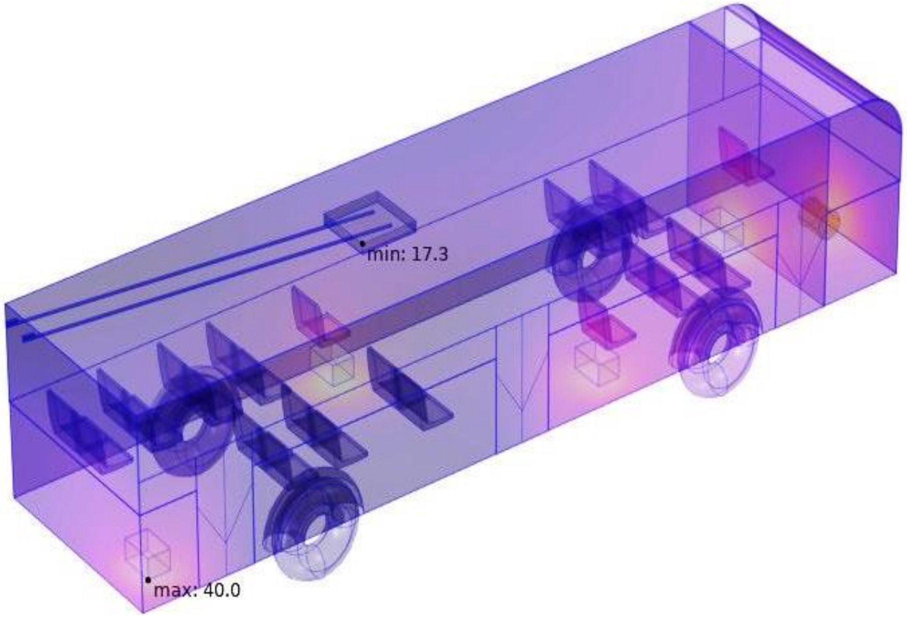

Fig. 6. Simulation results on the temperature distribution on the bus

Figure 6 shows the temperature distribution inside the electric bus with view from the right side of the vehicle.

The temperatures are estimated at the surfaces of the component of the bus.

It is to observe that the maximum temperature, as expected, is on the heaters (40 ºC), and the minimum temperature is on the exterior surface of the roof, next to the power collecting box system where are attached the trolleys (17.3 ºC).

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A comparative analysis between the temperature measurements inside the bus and the simulations results

Fig. 7.
Temperature measured with thermal image camera on the driver area on the bus

For the validation of the thermal model it were realised some experimental measures inside the electric bus.
The results of the simulations were compared with the measured temperatures.
The temperatures were measured in different areas inside the electric bus with a point-and-shoot infrared camera (thermal imaging camera FLIR).
The temperature measured on the driver area is 27.8 ^oC, a quite comfortable for the driver.

The simulated maximum temperatures inside the drivers' cabin are between 25.2 ^oC and 27.9 ^oC, which are quite close to the measured temperature, of 27.8 ^oC (Figure 7).

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CONCLUSIONS

1. The geometry of an electric bus indoor is designed considering the main components of the vehicle: passengers' cabin, driver's cabin, windows, walls, seats and the main materials according to the real bus.

2. To study the heat transfer into the electric bus, a computer aided design is used based on the heat transfer theory.

3. Thermal model and simulations are made for the heat transfer inside the electric bus.

4. The simulated data are compared with measurement data, and based on these data, it is to conclude that the thermal model of the electric bus can be validated and it can be used further for various thermal simulations.

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THANK YOU FOR YOUR ATTENTION!

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