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The 1st Scientific Seminar – Industrial

On the project "Improving the cross-border public transportation using electric buses supplied with renewable energy - ELBUS"

Project EMS-ENI code 2SOFT/3.1/54

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GENERAL OBJECTIVE of the project:

DEVELOPMENT OF THE CROSS-BORDER PUBLIC TRANSPORTATION USING ELECTRIC BUSES.

Specific Objective 1:

DEVELOPMENT OF THE ELECTRIC BUSES.

Specific Objective 2:

IMPROVING OF THE RANGE FOR THE ELECTRIC BUSES USING RENEWABLE ENERGY.

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ANALYSIS OF THE ELECTRIC BUS OPTIMAL FUNCTIONALITY

Activity 3.1. Analysis of the electric buses

Deliverable 3.1.1. Technical report related to the using of the electric buses

Activity 3.2. Analysis of the auxiliary loads

Deliverable 3.2.1. Automation system for auxiliary loads

Activity 3.3. Thermal model of the indoor climatic environment

Deliverable 3.3.1. Thermal model

Deliverable 3.3.2. Thermal map for the indoor climatic environment

Activity 3.4. Renewable energy for the batteries

Deliverable 4.1. Hybrid charging system design for electric buses with authonomus power source

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Activity 3.1. ANALYSIS OF THE ELECTRIC BUSES

The analyze of the optimal functionality of the electric bus had the next directions:

An overview related to the electric vehicles in general, and to electric buses, in particularly, with benefits of using of the electric power supply instead of traditional fuels and the impact on the environment.

A research and analysis regarding the functionality and the energetical aspects of the electric buses: the structure of the bus, the drive system, the auxiliary system and its equipment, efficiency, the traction motor.

Realization of a test bench (TUIASI) including an electric motor and generator as variable load.

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Outputs on the Activity 3.1. ANALYSIS OF THE ELECTRIC BUSES

1. The benefits of using of the electric power supply instead of traditional fuels and the impact on the environment.
2. **Perspectives for fully electric buses in the EU.**
3. Technical limitations of using the electric buses.
4. **Electric buses types to use in urban and interurban transportation**.
5. Electric buses technology configurations.
6. **The drive system and the optimization of the electric buses operating**.
7. The auxiliary equipment used on the electric buses: main equipment, energy consumption and optimization.
8. **Electric motor used to drive the electric buses**.
9. **Test bench achievement**: the drive system of the electric bus accomplished in the laboratory: it permits to study the operating drive system, the energy consumption, speed, braking time, energy to be recovered.
10. Electric buses operating at variable loads. Studies and experiments on the test bench in laboratory.

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Activity 3.1. ANALYSIS OF THE ELECTRIC BUSES

The benefits of using of the electric power supply instead of traditional fuels and the impact on the environment.

Within the European Union the road transport is the second largest producer of carbon dioxide (CO2), one of the greenhouse gases responsible for climate problems. Fully-electric buses have potential to significantly **reduce carbon dioxide emissions,** up to 75%.

Advantages that electric buses offer beyond the cost consideration:

- Increasing urban quality of life:
- **lower air pollution** and **lower noise** ,
- Attractive to the people,
- **Using renewable energy**,
- **Energy security** ,
- Stimulating European industry.

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Limitations of using the electric buses

Technological limitations:

- Limited range and Grid and charging infrastructure.

Limitations due to the lack of knowledge:

- The operational characteristics, and maintenance necessary;
- Strategies and techniques to optimize the design and implementation of an electric buses project;

Other :

- Difficulties for agencies in changing procurement practices: typically use rigid financial management models, low-risk procurement.
- Traditional procurement practices also do not allocate responsibilities for the new tasks associated with electric buses operations, such as maintaining the batteries and grid infrastructure.

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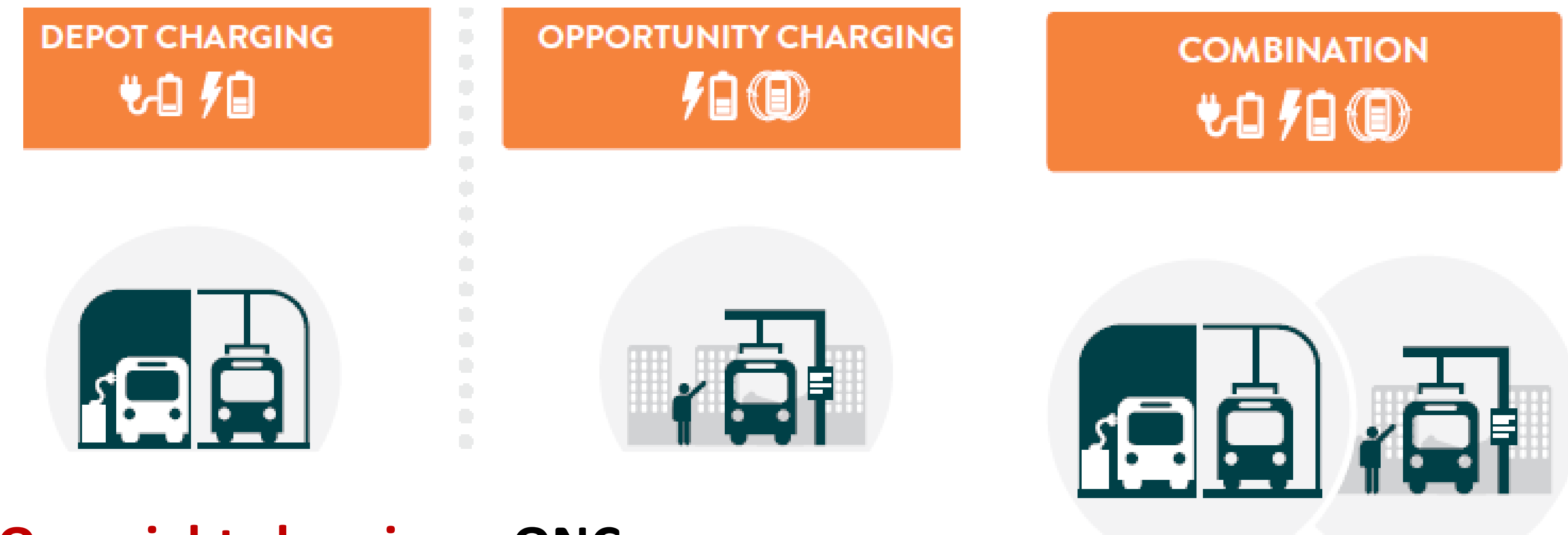
Electric buses types to use in urban and interurban transportation



Overnight charging – ONC.

Opportunity charghing - OC.

Combining depot charging and opportunity charging.

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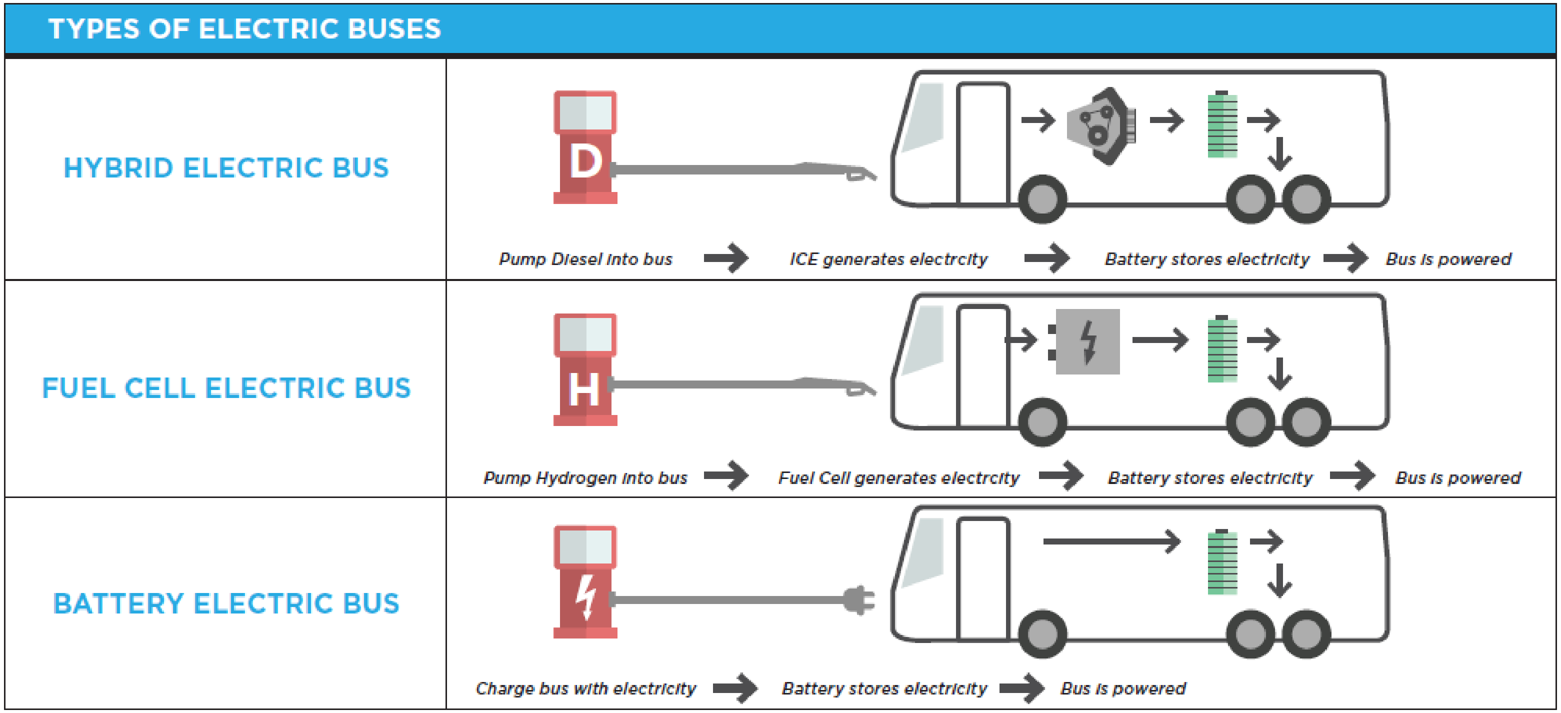
ELECTRIC BUSES TECHNOLOGY CONFIGURATIONS

- **HYBRID ELECTRIC BUSES (HEBs)**
- **BATTERY ELECTRIC BUSES (BEBs)**
- **FUEL CELL ELECTRIC BUSES (FCEBs)**



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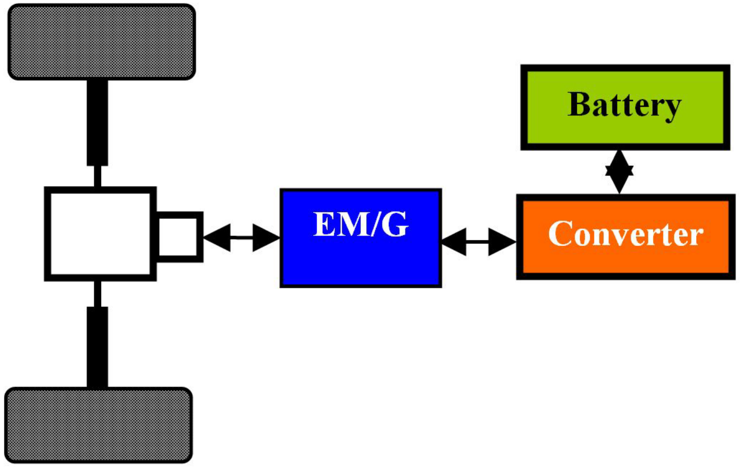
BATTERY ELECTRIC DRIVE SYSTEM FOR ELECTRIC BUSES



The main electric bus components:

-The drive motors,

-an Auxiliary Power Unit (APU),

-controllers and inverters,

-the energy storage device and

-other auxiliary systems, such as air conditioning and lighting.

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The drive system and the optimization of the electric buses operating

Battery Electric Buses (BEB)

Increasing the battery capacity results in an increased range, however this also increases the vehicle cost, increases weight, and decreases passenger capacity.

Overloading of the local electricity grid is another infrastructure challenge that arises through electric buses implementation, especially if large numbers of opportunity BEBs are used in one area.

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Electric motors used to drive the electric buses

They have frequent starts and stops, they need high acceleration rate for fast starting and capability to work in harsh environments.

Motor drives require high efficiency over a wide speed and torque region, high torque and power densities, fast dynamic response, simple construction, high reliability, regenerative braking capability, good controllability and low noise

- **DC motors**
- **Squirrel cage induction motors (IM motors)**
- **Permanent magnet brushless motors (PM)**
- **Switched reluctance machines (SRM)**

The auxiliary equipment used on the electric buses: main equipment, energy consumption and optimization

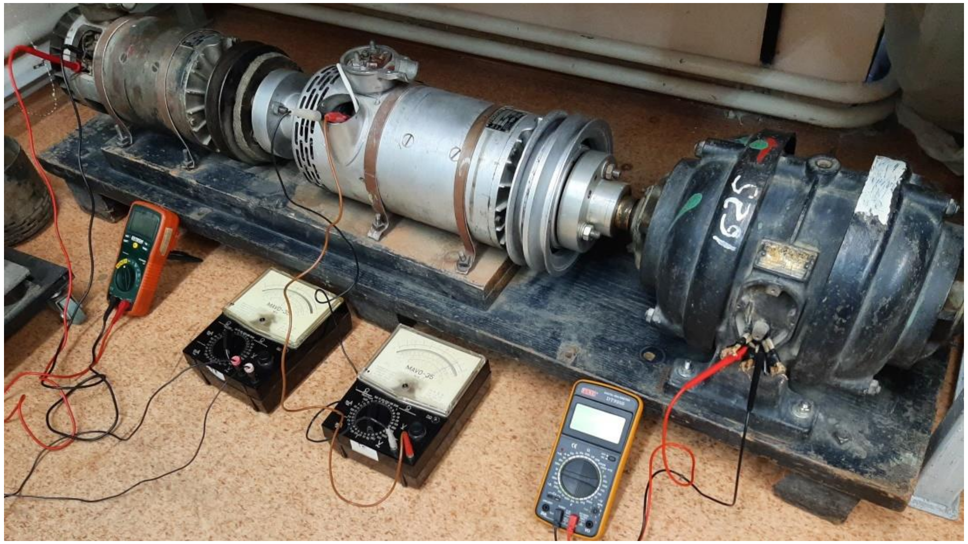
HVAC: **HEATING**, **Ventilation**, and **Air Conditioning**.

Other auxiliaries:

- Battery cooling,
- Air compressor,
- Steering,
- Doors drive,
- Lights.

ELECTRIC BUS TEST BENCH

An important aspect is to analyze the electric traction system for the electric bus at variable loads. The principles are studied in the laboratory on a test-bench including an electric motor and generator as variable load.



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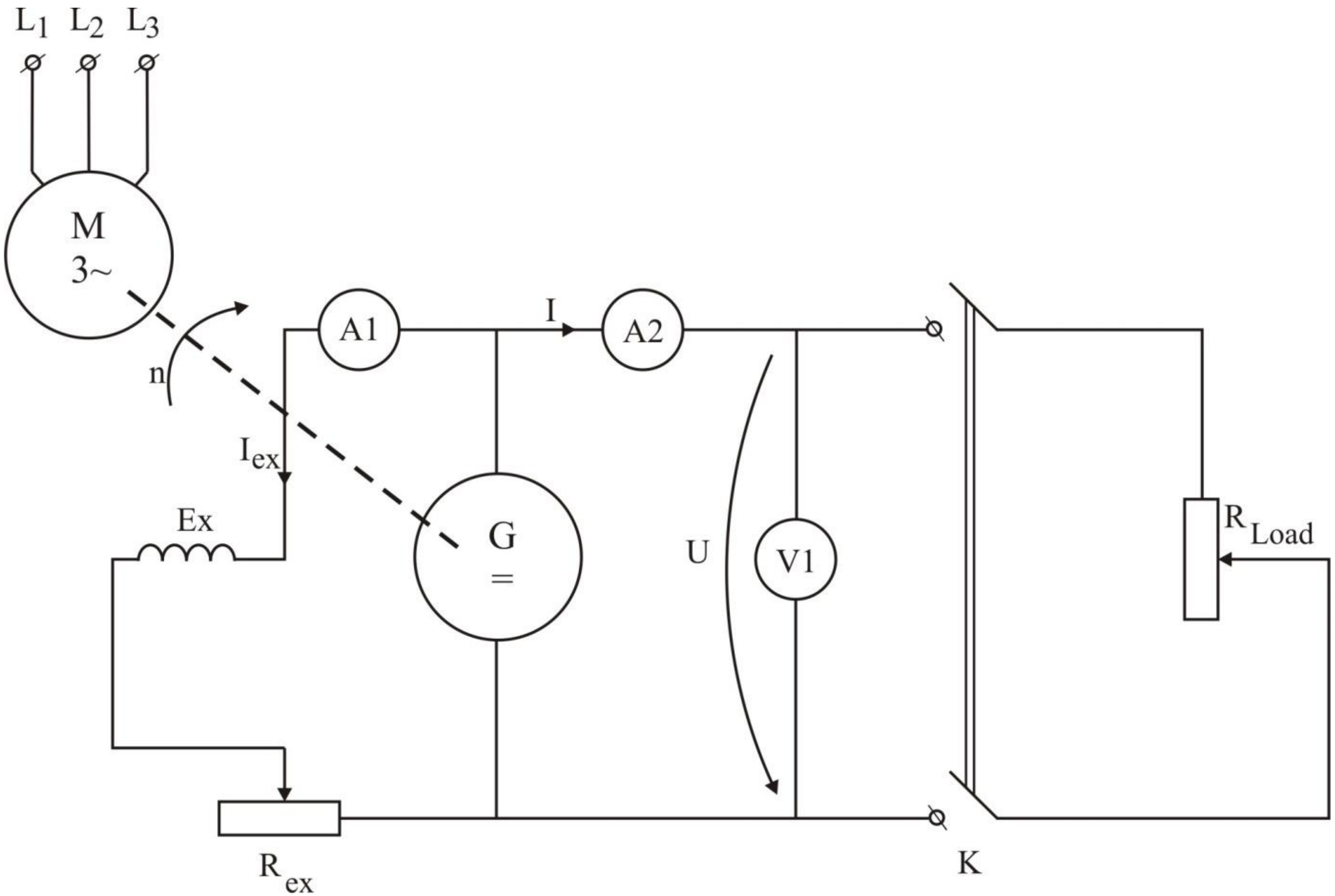

Electric diagram of the traction system drive structure.

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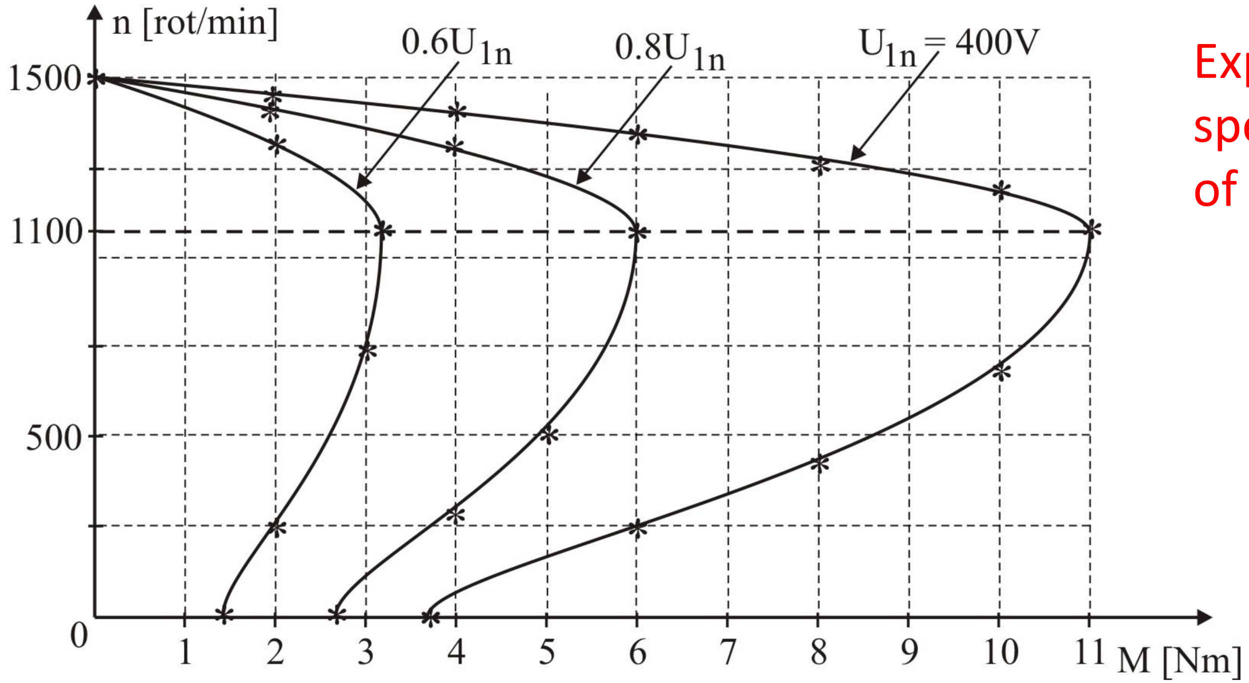
Torque speed characteristics of the three-phased AC motor

The torque speed characteristics are considered for the next supply voltages:

0.6 Un;

0.8 Un;

Un = 400 V.



Experimental torque speed characteristics of the AC motor.

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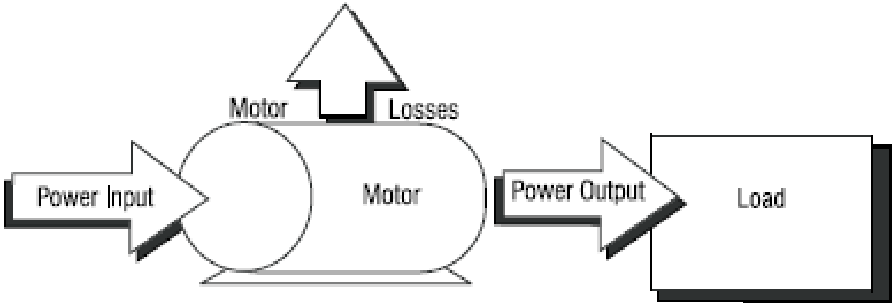
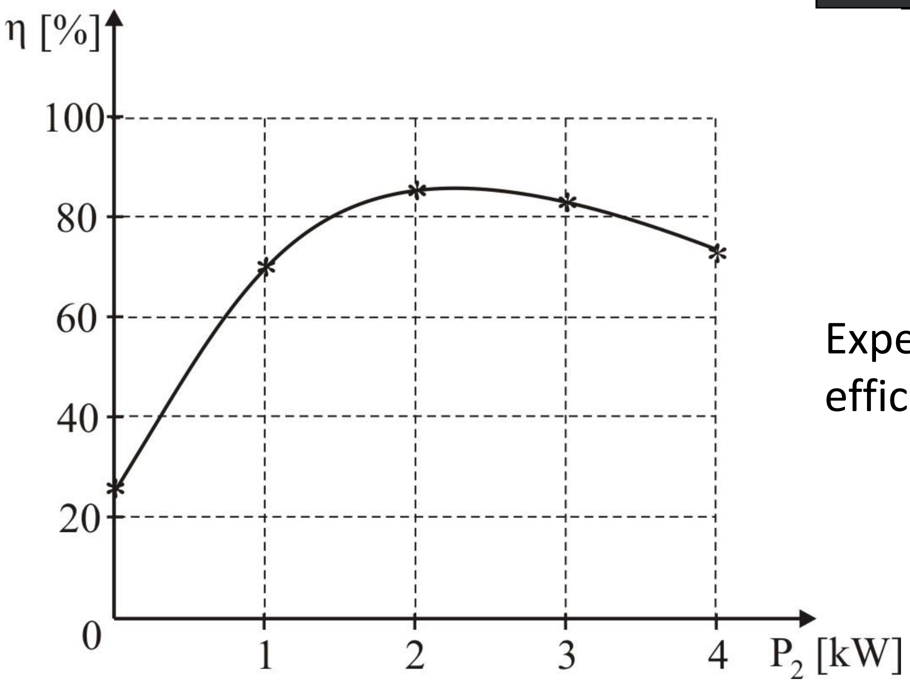
Efficiency of the three-phased asynchronous motor



Power configuration for an electric motor.



Experimental characteristic for the efficiency of the AC motor.

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Activity 3.2. ANALYSIS OF THE AUXILIARY LOADS

A research and analysis regarding the auxiliary loads on the electric bus in order to estimate and to improve their energy efficiency.

Study a heating/cooling system to be used on an electric bus from thermal efficiency point of view.

It will be developed an automation system based on PLC (Programmable Logic Controllers) for an optimal control of the heating/cooling devices.

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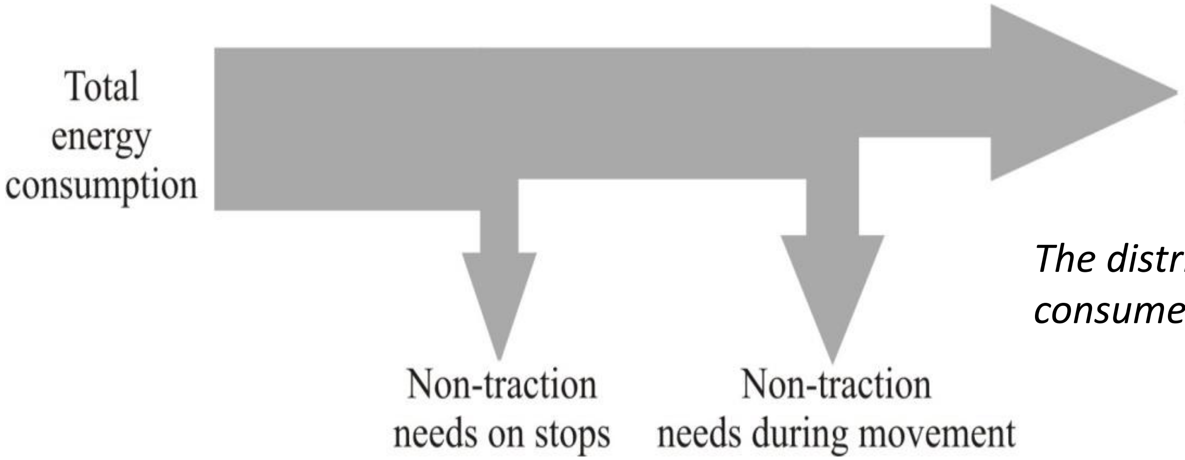
GENERAL ASPECTS ON AUXILIARY LOADS

- The fixed energy consumption auxiliaries, which are used both when the electric bus is standing and when it is running;
- The variable energy consumption auxiliaries, which depend on the fluctuant characteristics (e.g. number of the bus stations, number of traffic lights on the route, number of the curves, weather as sunny/cloudly, day/night, other traffic conditions).



The distribution of electric energy consumed by vehicles.

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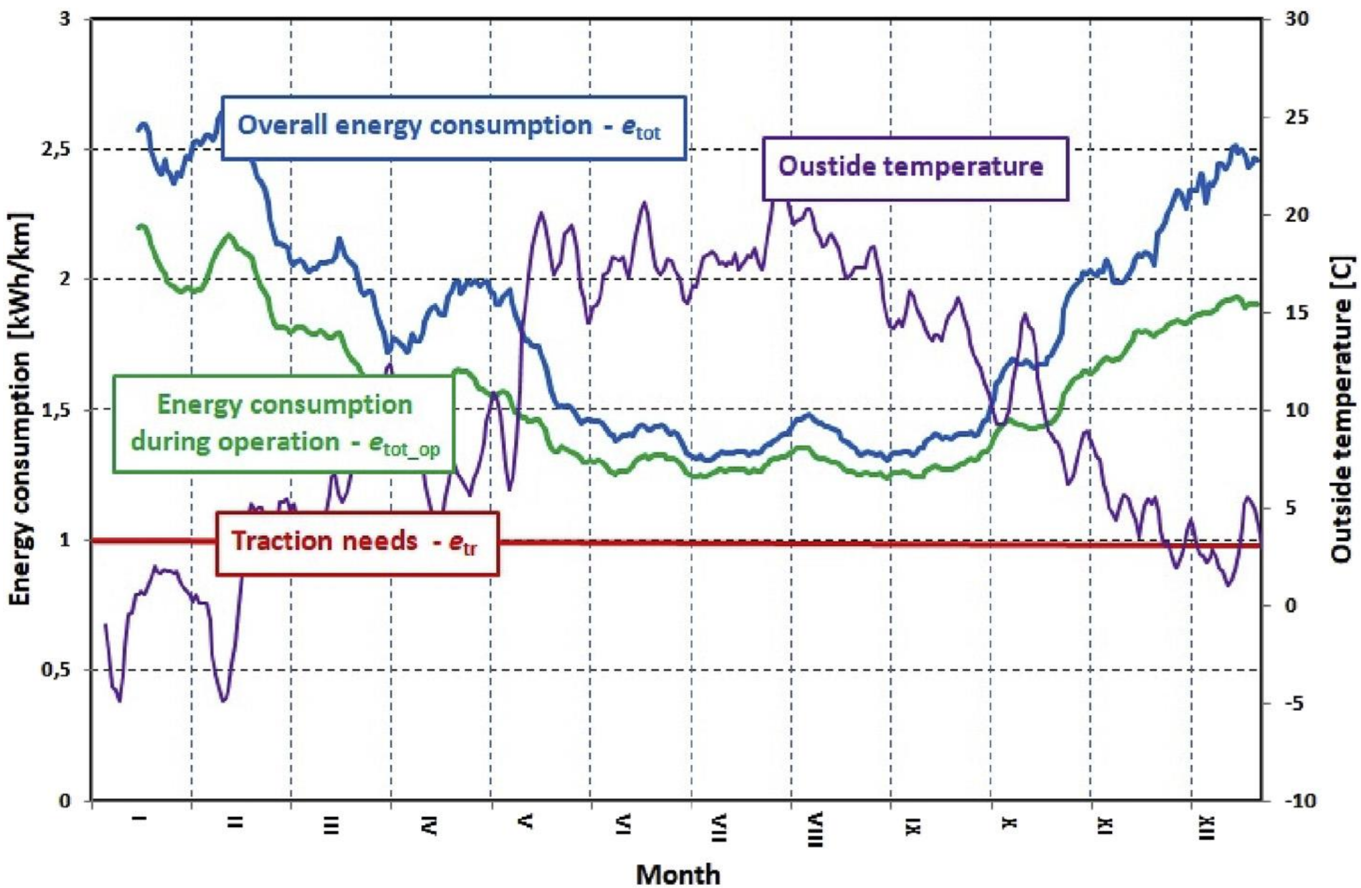
The values of average energy consumption and daily average outside temperature in annual scale



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COMFORT OF THE PASSENGERS AND THE AUXILIARY ENERGY DEMAND

What a person perceives as a comfortable temperature depends on many parameters:

1. **Air humidity**: humidity causes the temperature that is perceived by a person to be amplified.

2. **Air velocity**: if there is an air flow around the person, the heat energy transfer between the person and the ambient air increases.

3. **Radiation**: besides the cabin air being heated up by the sun, a person could also feel the direct effect of the radiating sun.

4. **Seasonal effects**: comfort is also closely related to temperature differences. If the outside temperature in the winter is 0°C, an inside temperature of 15°C might already feel warm. Instead, in the summer, this setpoint might be too low.

5. **Metabolism**: differences between persons in metabolism cause differences in the perceived comfort in temperature (body weight, gender and age).

ECO-Comfort

Optimization of the thermal system of electric vehicles is defined as the ECO-comfort functionality. This functionality can be summarized in two topics:

1. Dynamic temperature setpoint: A temperature setpoint can vary over the day to account for ambient temperature changes. Similarly, the same method can be applied between summer and winter conditions.

2. Pre-conditioning: Pre-conditioning means that the cabin climate is already controlled towards the desired temperature while the vehicle is still connected to the charger either in the depot or in route at terminal stops. This way, the initial required energy peak to control the temperature is taken directly from the grid rather than from the battery. This improves also the driving range of the vehicle.

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ENERGY MODEL FOR AN ELECTRIC BUS

The traction energy consumption is dependent on the sum of resistance forces *F*res, shown in Equation (1).

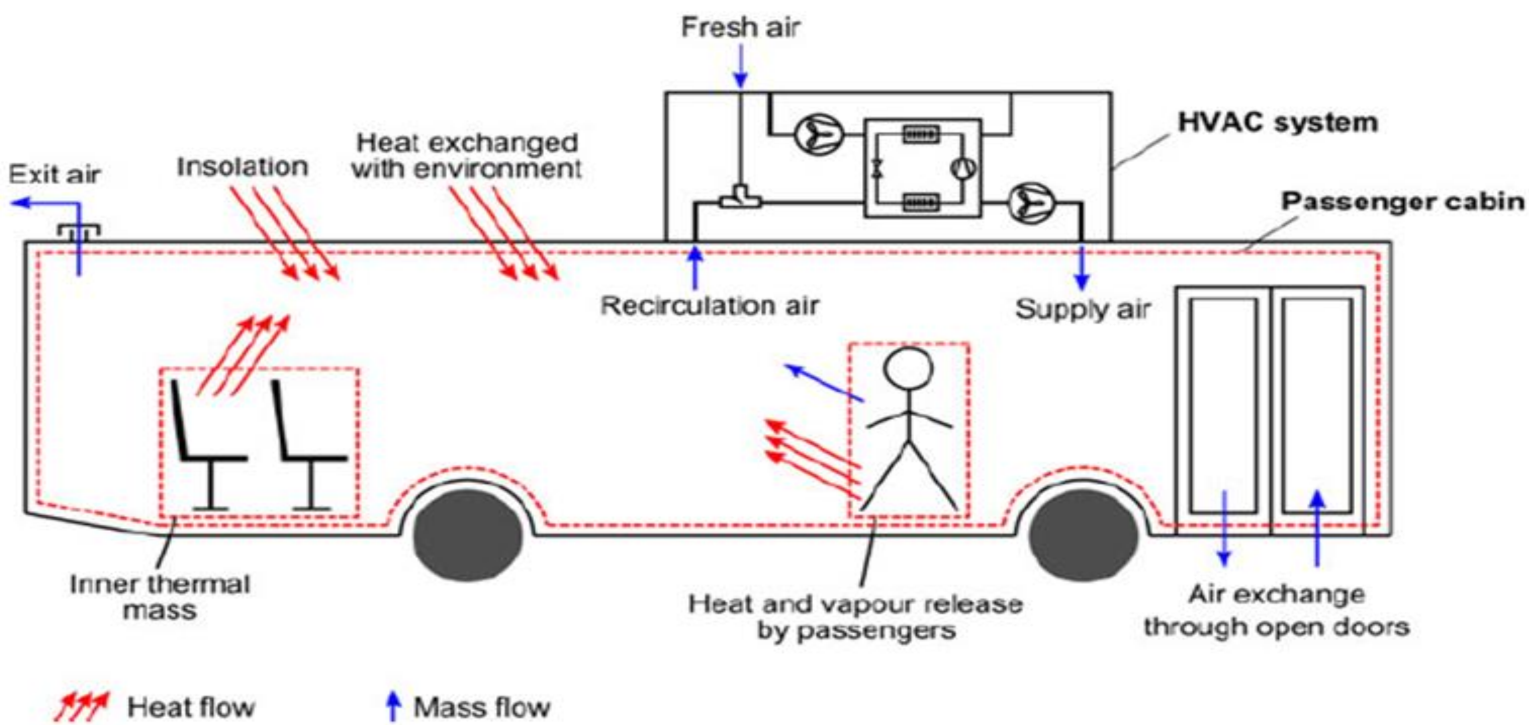
$$F_{res} = \lambda_m m\dot{v} + mgf_R \cos(\alpha) + \frac{1}{2}\rho_L c_W A v^2 + mg\sin(\alpha). \qquad (1)$$

The total required battery power *P*total:

$$P_{total} = \frac{F_{res}\vartheta}{\eta_{drive}} + P_{aux} \qquad (2)$$

Auxiliary power demand is mainly dependent on the electric power of the HVAC system *P*HVAC and to other components *P*others:

*P*aux = *P*HVAC + *P*others. (3)



Thermal model and the environment
heat exhange for an electric bus.

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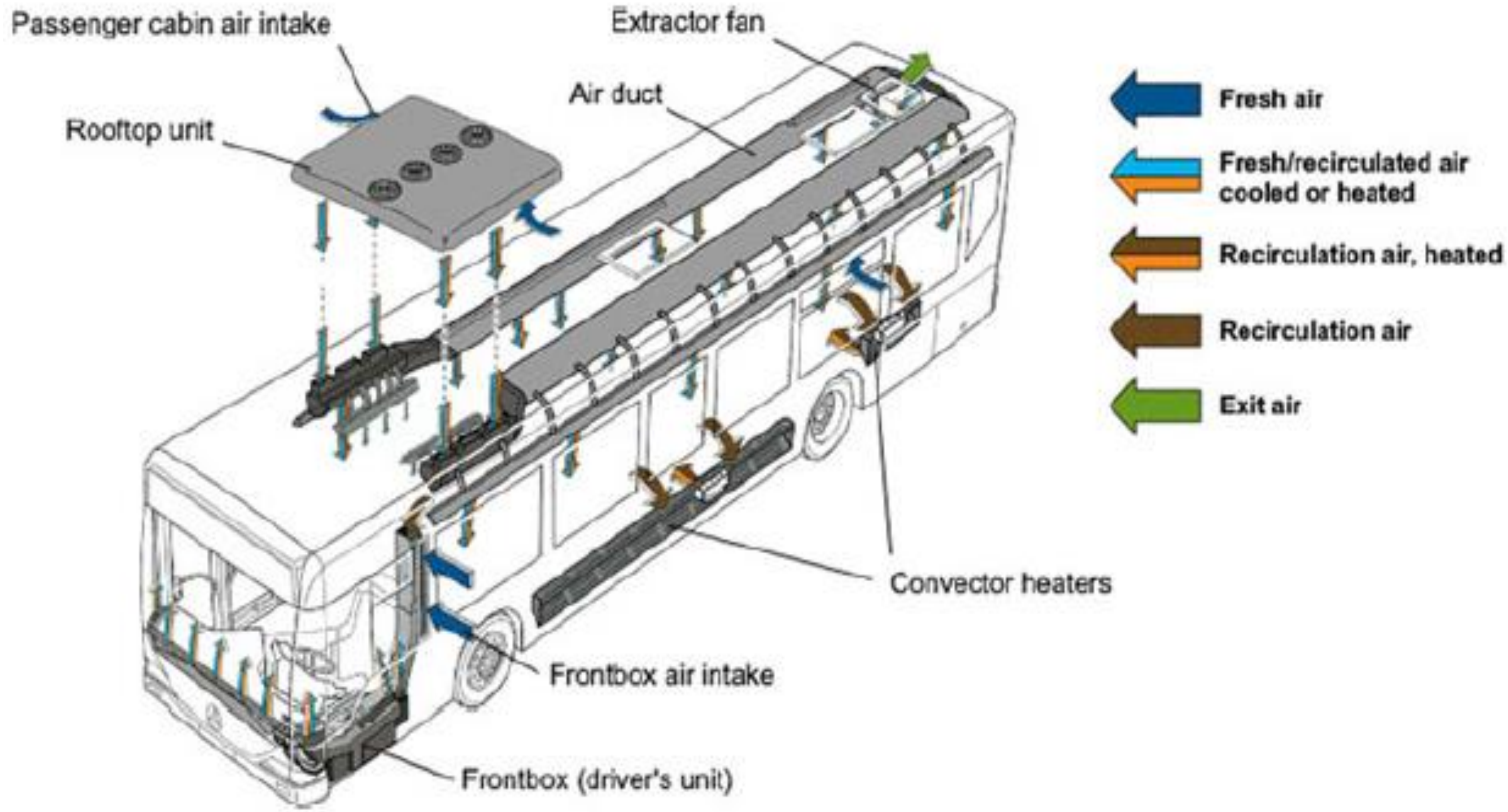
HEATING, VENTILATION AND AIR-CONDITIONING (HVAC) SYSTEMS



OTHER AUXILIARY LOADS

Lighting (indoor, outdoor)

Windows cleaning system and seat heating.

Audio system.

Opening and closing of door, windows and roof.

Anti-lock Braking System – ABS.

OVERALL ENERGY CONSUMPTION OF AUXILIARY SYSTEMS

Auxiliary systems	Part of traction battery energy, %
Climate control: – cooling; – heating.	 Up to 30% Up to 35%
Power steering	Up to 5%
Braking system	Up to 5%
Other (lights, media, locks etc.)	Up to 5%

The information presented in Table is more general and does not include all operational conditions of electric vehicles.

The **lightning, passenger information systems, and air compressor are responsible for 20-25%** of total energy consumption.

Under standard operating conditions, **the non-traction energy consumption is up to 1.2 kWh/km.**

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S7-1200 PROGRAMMABLE CONTROLLER

The S7-1200 controller provides the flexibility and power to control a wide variety of devices in support of your automation needs.

The compact design, flexible configuration, and powerful instruction set combine to make the S7-1200 a perfect solution for controlling a wide variety of applications.

The CPU combines a microprocessor, an integrated power supply, input and output circuits, built-in PROFINET, high-speed motion control I/O, and on-board analog inputs in a compact housing to create a powerful controller.

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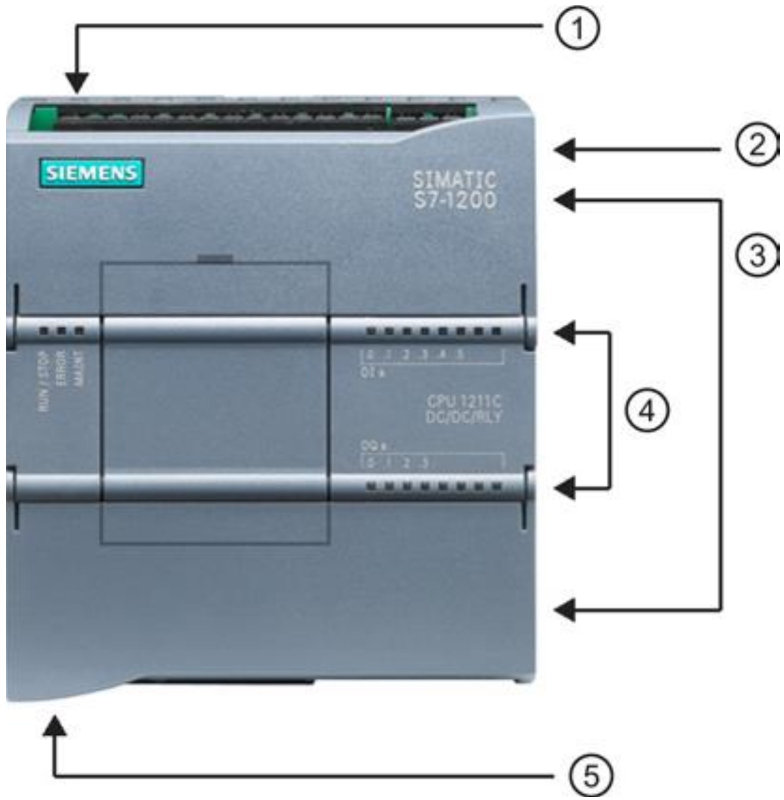

① Power connector.

② Memory card slot under top door.

③ Removable user wiring connectors (behind the doors).

④ Status LEDs for the on- board I/O.

⑤ PROFINET connector (on the bottom of the CPU).

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● Organization blocks (OBs) define the structure of the program. Some OBs have predefined behavior and start events, but the user can also create OBs with custom start events.
● Functions (FCs) and function blocks (FBs) contain the program code that corresponds to specific tasks or combinations of parameters. Each FC or FB provides a set of input and output parameters for sharing data with the calling block.
● Data blocks (DBs) store data that can be used by the program blocks.

Operating modes of the CPU:

The CPU has three modes of operation:

STOP mode,

STARTUP mode, and

RUN mode.

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Output 3.1. Increasing the energy efficiency of the auxiliary loads

First of all they were identified the auxiliary loads specific for an electric bus, that is: heating, cooling, various electric systems (lighting, doors, windows, windshield wiper, ventilation for the traction motors, battery cooling, air compressor, steering pump). Activity 3.2 in the project (Analysis of the auxiliary loads) extended the researches and results into the increasing of the energy efficiency of the auxiliary loads.

Output 3.2. Increasing the overall energy efficiency of the electric bus

The increasing of the overall energy efficiency of the electric bus was considered from various perspectives, such as: efficiency of the drive motors, efficiency of the battery charging, and to supply the auxiliary loads.

An automated model controlled with PLC have been started to be developed in order to implement and to control energy strategies on the auxiliary loads, having as final result an overall reduction of consumption by saving electricity to auxiliary consumers.

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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.

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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

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.

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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.

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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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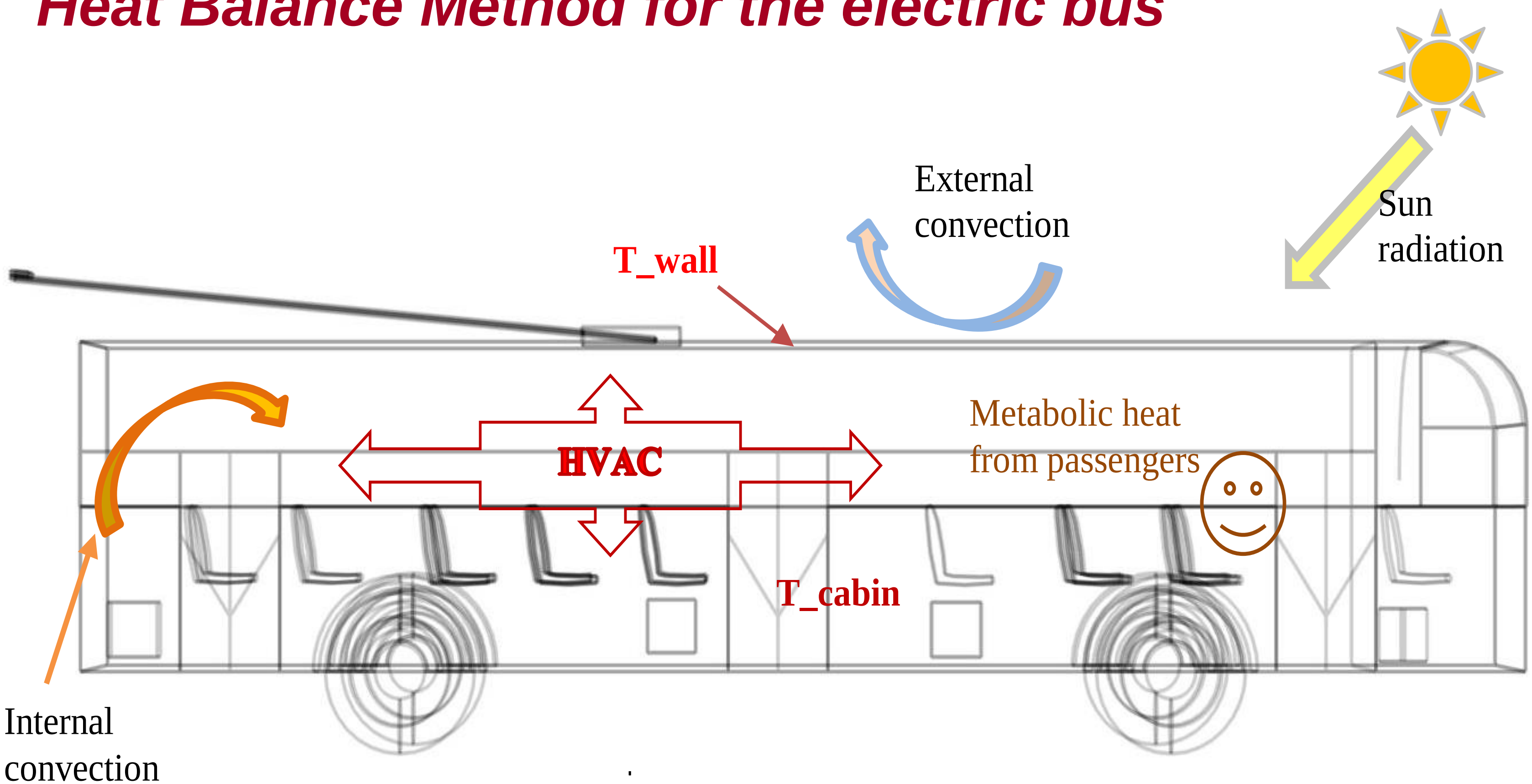
Heat Balance Method for the electric bus



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DESIGNING OF THE INSIDE GEOMETRY MODEL OF THE ELECTRIC BUS

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).

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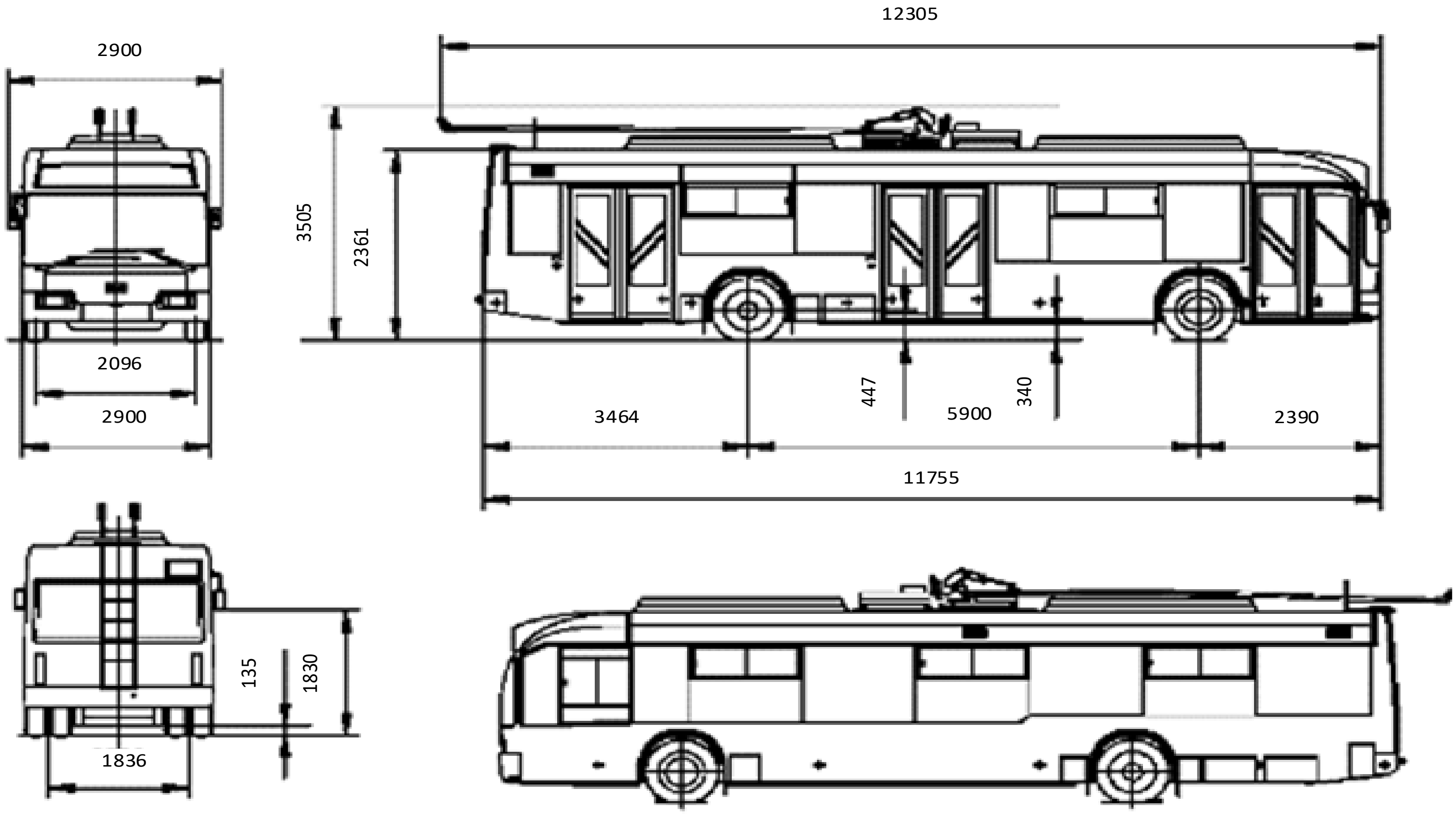
The main dimensions of the electric bus



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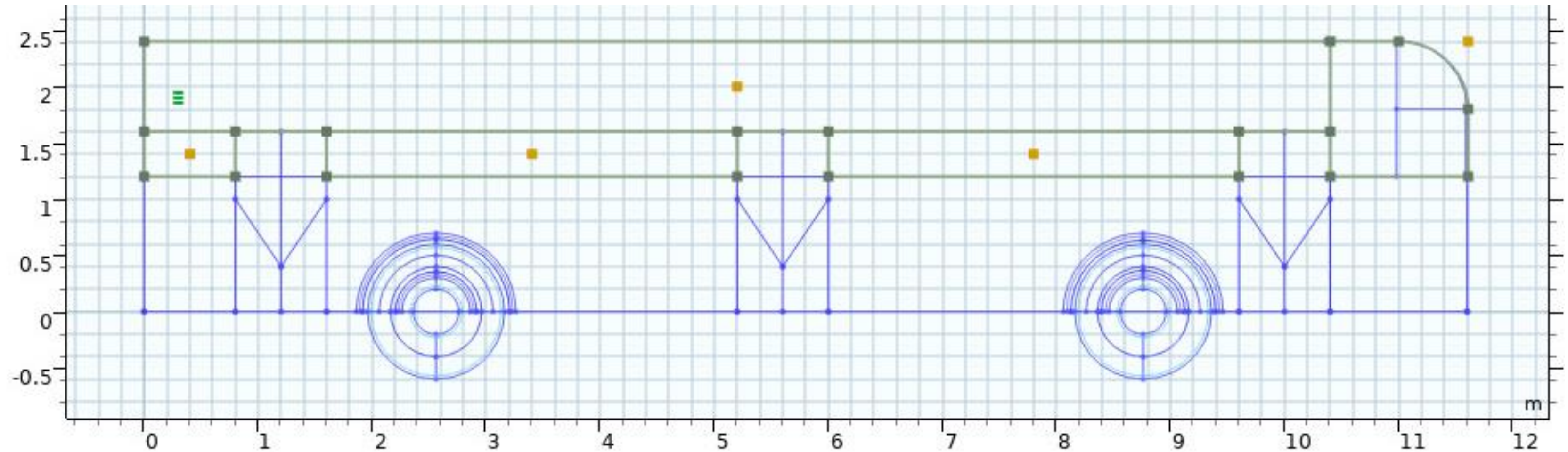
CAD model



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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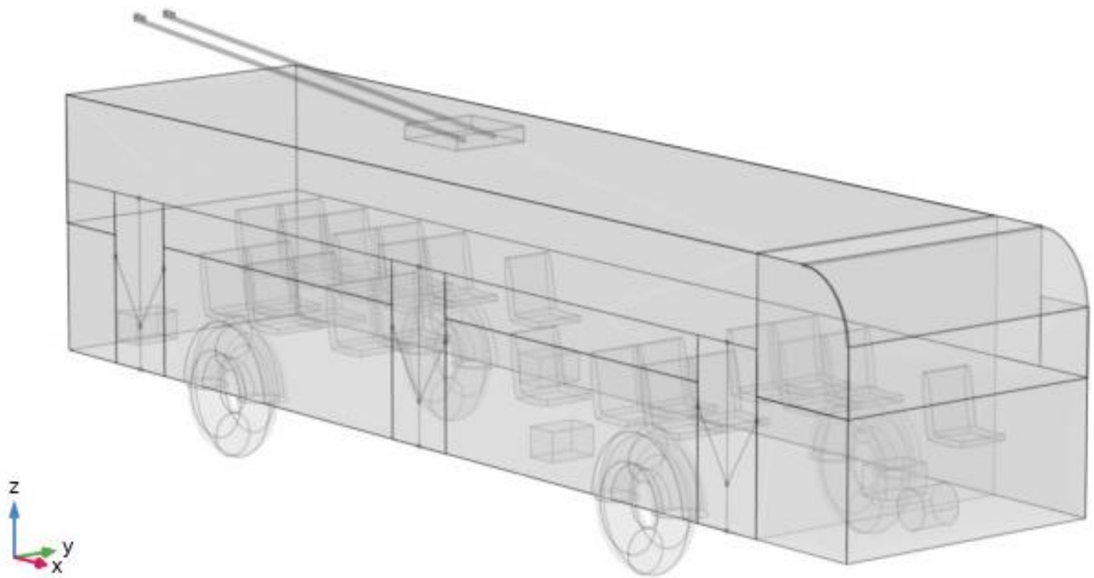

The basic geometry model of the electric bus; transparency view.

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.

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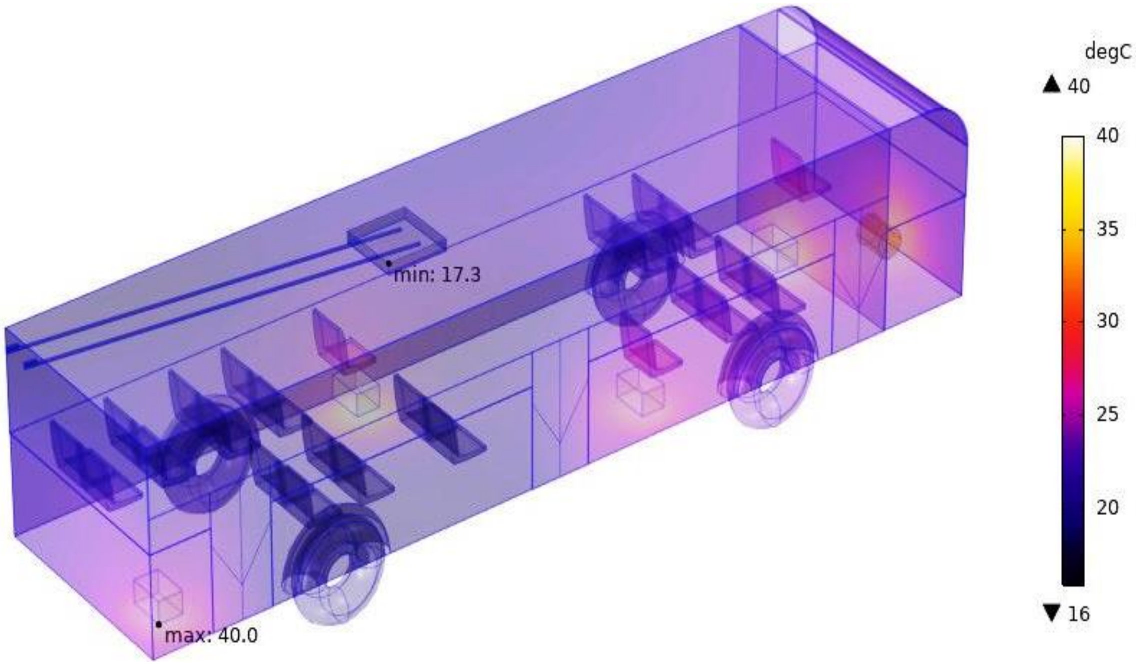
SIMULATIONS AND RESULTS



Simulation results on the temperature distribution on the bus

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 ^{o}C), 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 ^{o}C).

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Thermal Measurement in Electric Bus

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Temperature measured with thermal image camera

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

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 °C, a quite comfortable for the driver.

The simulated maximum temperatures inside the drivers' cabin are between 25.2 °C and 27.9 °C, which are quite close to the measured temperature, of 27.8 °C.

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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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ACTIVITY 3.4

RENEWABLE ENERGY FOR THE BATTERIES

- Photovoltaic panels
- Batteries parameters for the electric buses
- Hybrid charging system design for electric buses with authonomus power source

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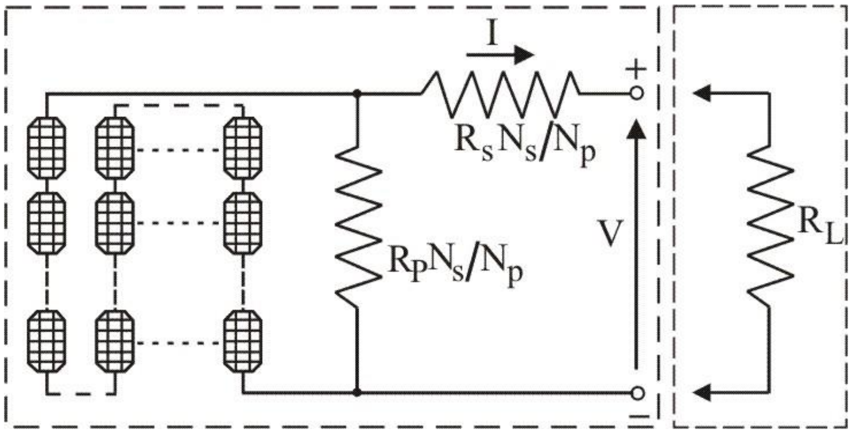
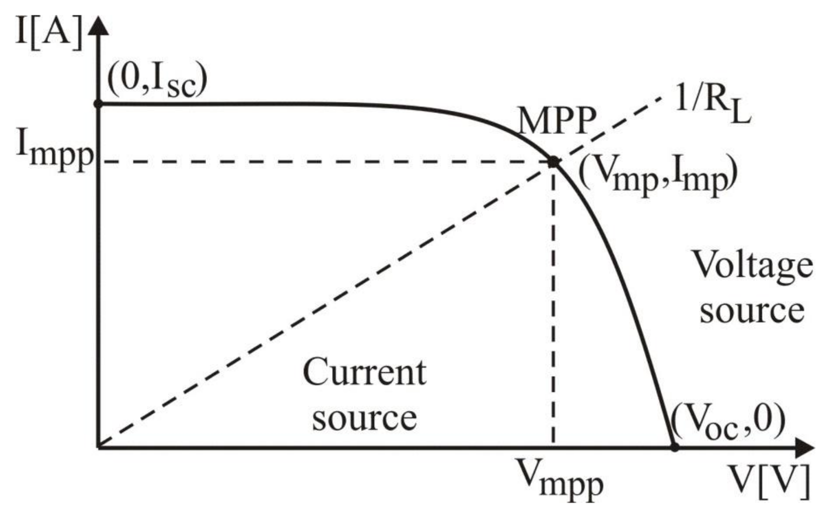
PHOTOVOLTAIC PANELS



The PV module equivalent circuit model.

Photovoltaic (PV) systems are largely used in producing electric energy for different applications, starting from low power systems (Kilowatts) to very large power systems (tenth of Megawatts).



Characteristics of a photovoltaic device.

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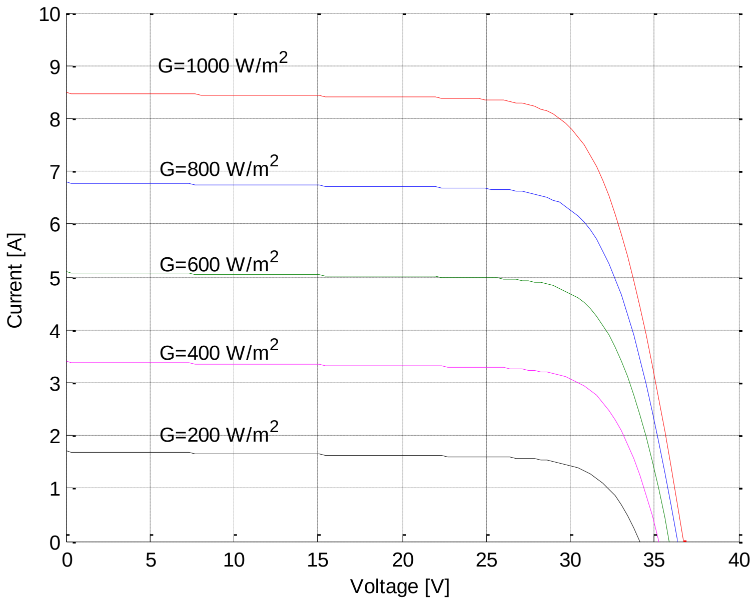
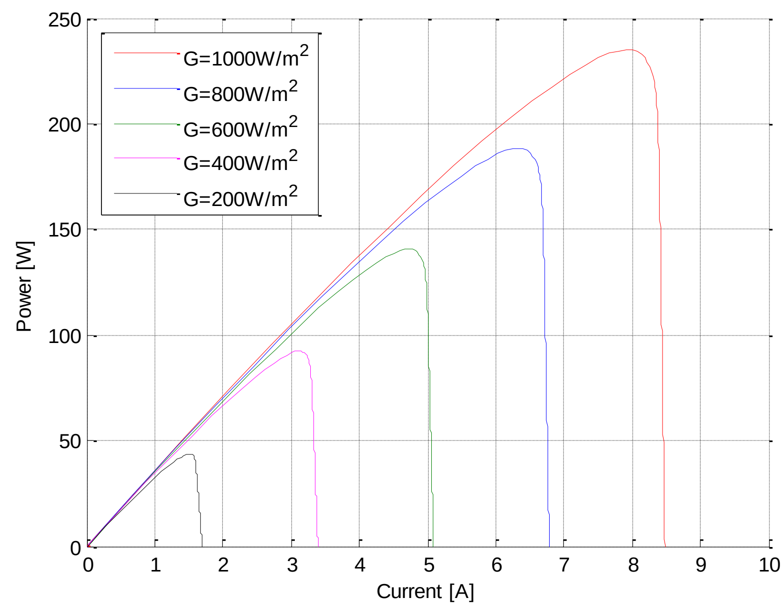


I-V curves for different solar irradiations



P-I curves for different solar irradiations

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IMPORTANT PRACTICAL PARAMETERS OF THE BATTERIES

The main parameters of the batteries are :

- ✓ Cell (battery) voltage;
- ✓ Capacity;
- ✓ State of Charge (SOC);
- ✓ Specific energy, specific density and specific power;
- ✓ Cycle life;
- ✓ Operating temperatures;
- ✓ Self-discharge rate;
- ✓ Recharge time;
- ✓ Battery efficiency;
- ✓ Charge efficiency;
- ✓ Memory effect;
- ✓ Depth of Dischrage (DoD);
- ✓ Battery geometry;
- ✓ Safety and environmental concerns;
- ✓ Cost.

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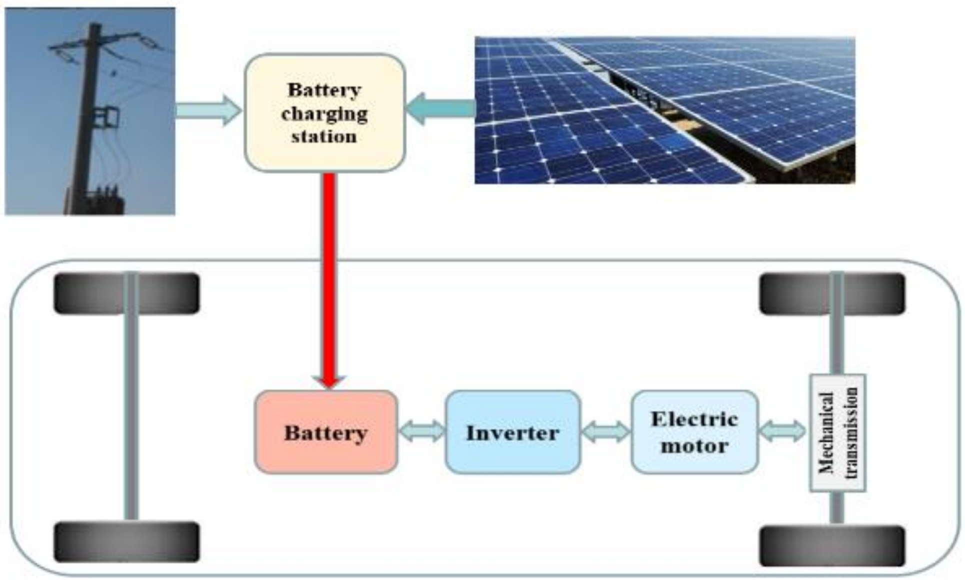
HYBRID CHARGING SYSTEM DESIGN FOR ELECTRIC BUSES WITH AUTHONOMUS POWER SOURCE



The EV charging station structure with hybrid power supply

Charging station of the trolleybuses

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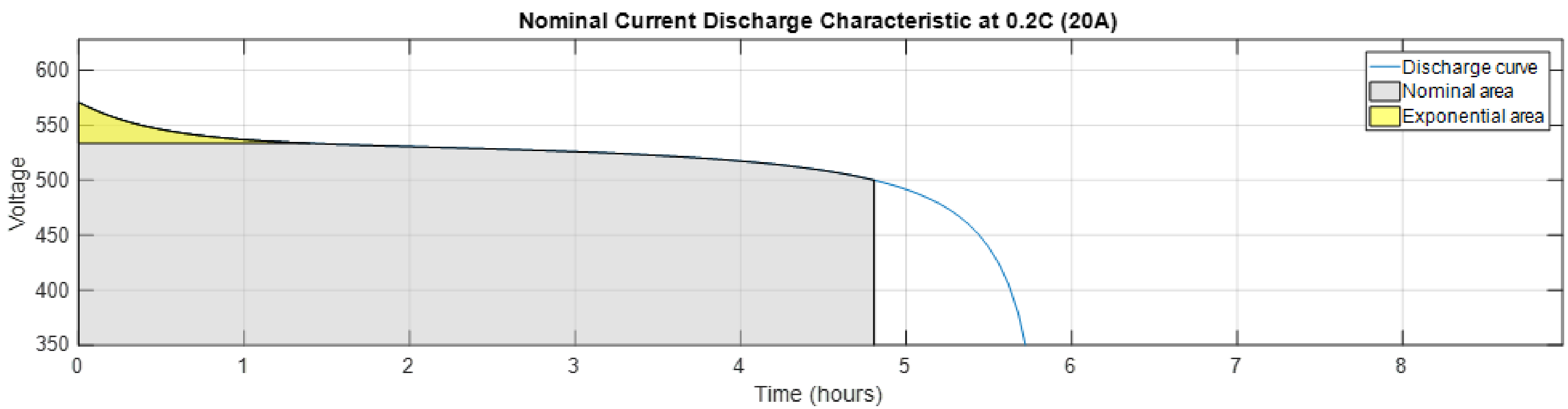
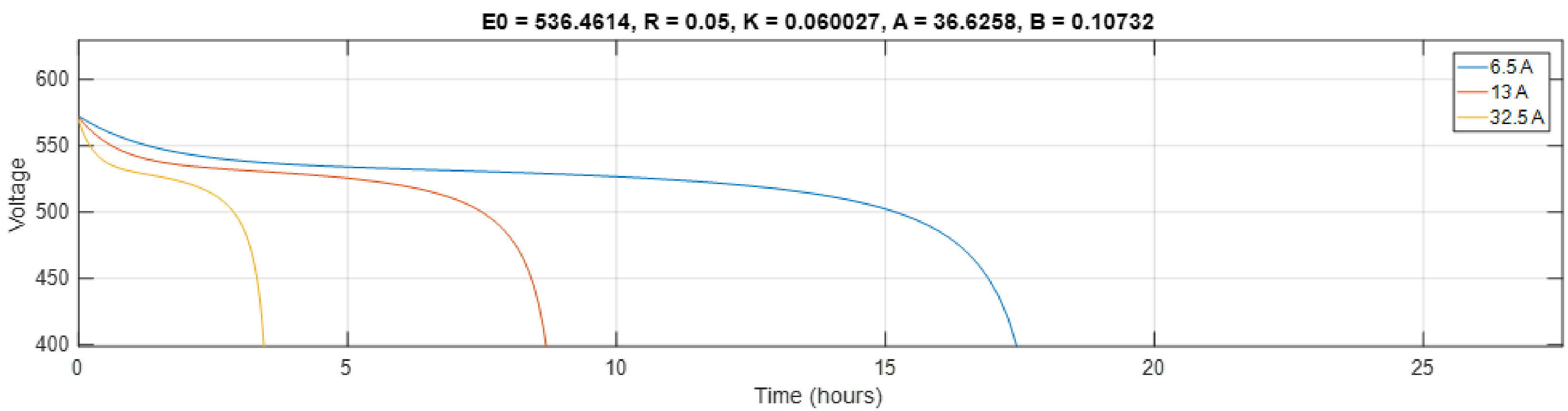
Characteristics of the e-bus battery





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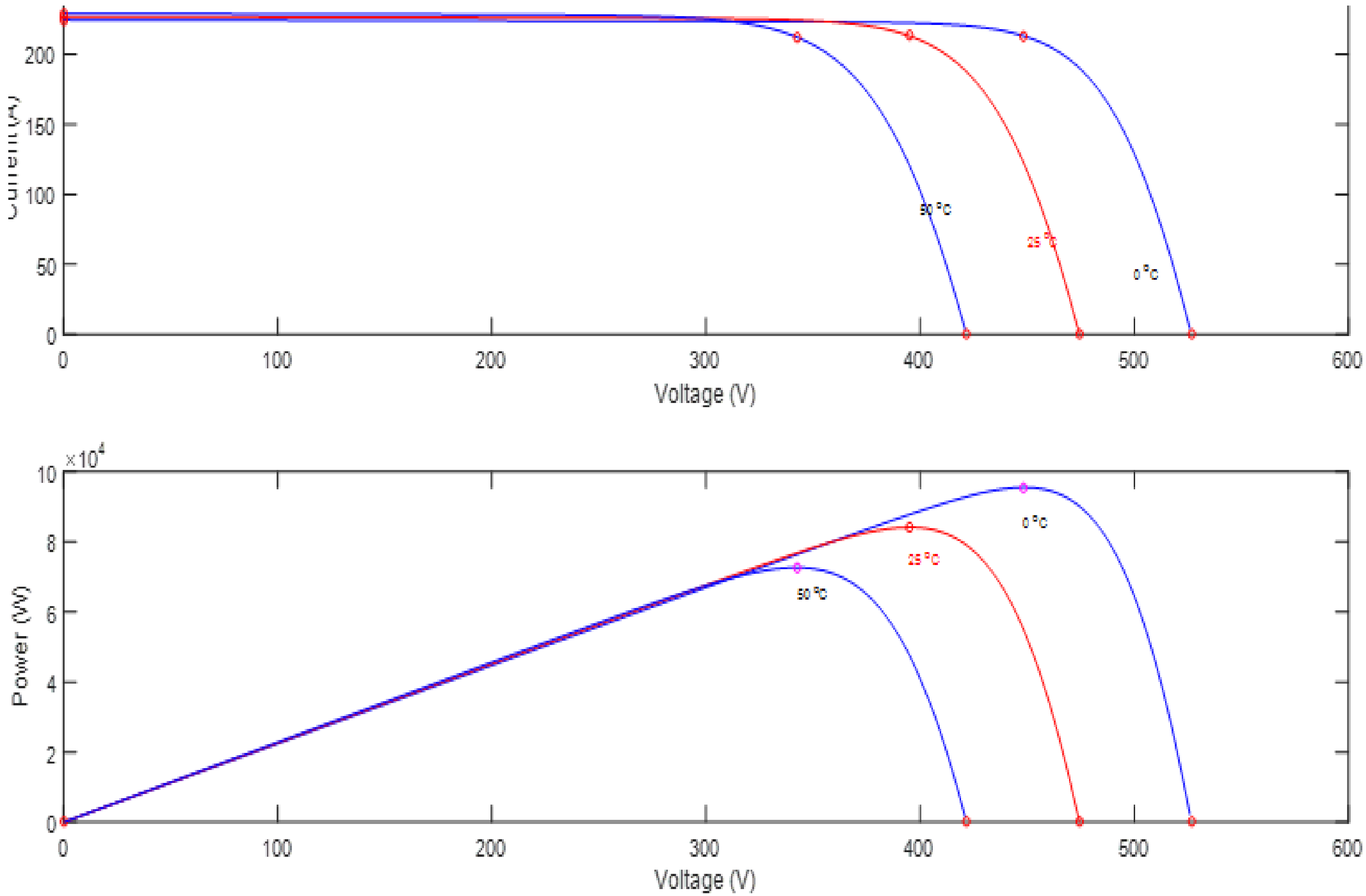
The V-I and P-V characteristics of the calculated photovoltaic park and the influence of the panel temperature on the maximum power point



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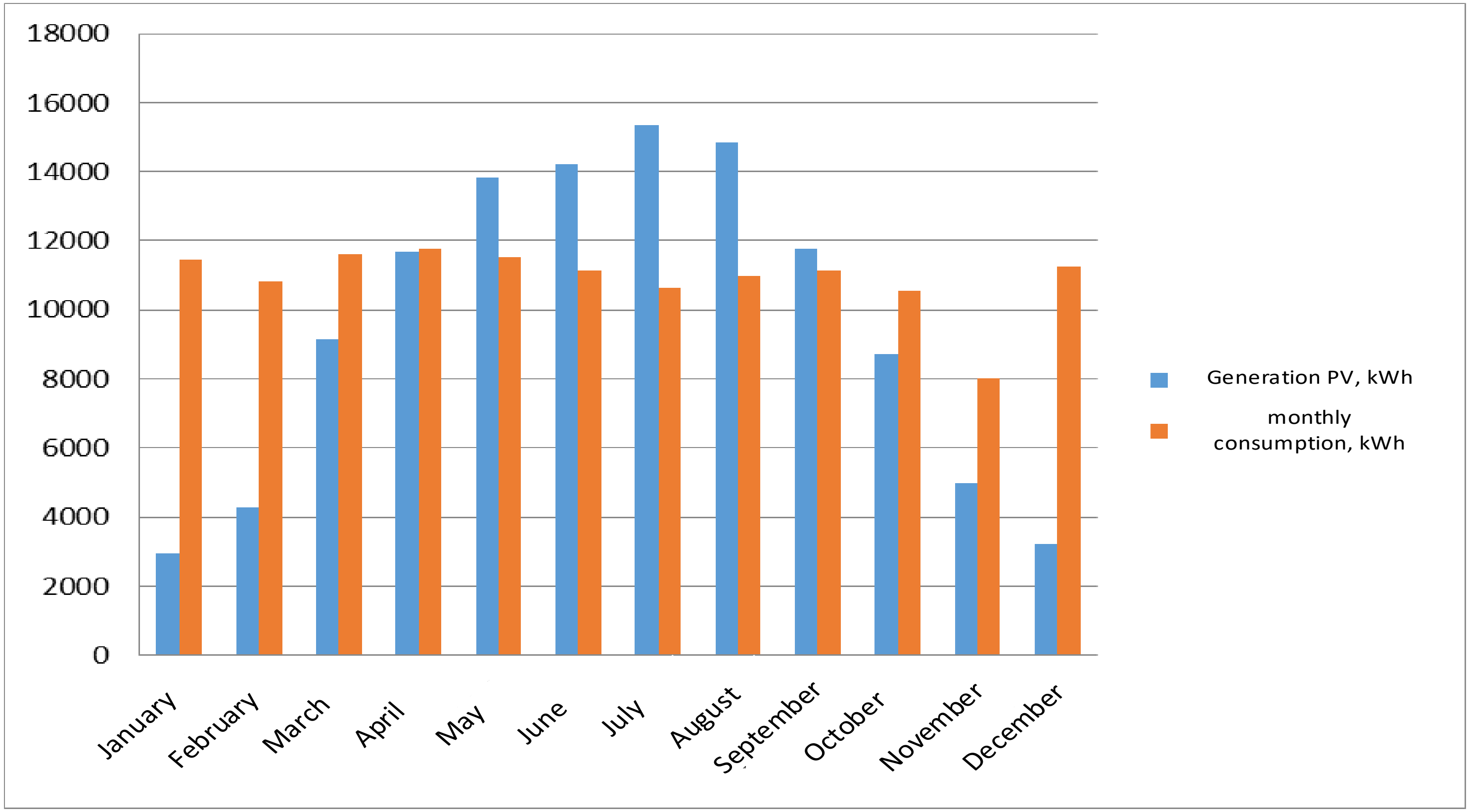

The energy production and consumption on each month of the photovoltaic plant integrated with charging station

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CONCLUSIONS

1. Following the analysis of the current state of the station in the Sângera town, an average of energy consumption about 320 [kWh/day] was estimated and this consumption depends on the route taken by the electric bus, and the season.

2. According to the analysis of the annual electricity consumption of the charging station currently located in the town. Bleeding, this being 130900 [kWh/year]. Based on these data, a park with an installed capacity of 90[kW] was calculated. The designed park provides both the charging station with electricity, and the surplus is injected into the network.

3. For energy injection into the network and for the charging station operation in autonomous mode, 3 Hybrid inverters of 30 [kW] were selected. The division of the entire park into 3 fields was dictated by the nominal power of these inverters.

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Scientific Results in Articles:

GEOMETRY DESIGN AND ANALYSIS OF AN ELECTRIC BUS FOR THE INTERIOR THER-MAL MODELLING

C Niţucă, G Chiriac, G Gabor, I Nucă... - Journal of Energy ..., 2021 - search.proquest.com

Sistem ogrevanja, prezračevanja in klimatizacije (HVAC) predstavlja glavno dodatno obremenitev za vse vrste avtobusov. Ker gre za sistem z največjo porabo energije pri električnem ...

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Aspects regarding the heating of electric buses

G Chiriac, DD Lucache, C Niţucă... - ... and Energy Systems ..., 2021 - ieeexplore.ieee.org

Heating the electric vehicles requires new challenges compared to thermal engine vehicles. Limited energy available from the traction battery needs new approaches for the heating ...

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A Hybrid Charging System Design for Electric Vehicles with Autonomous Power Source

..., A Moldovan, C Niţucă, G Chiriac... - ... and Energy Systems ..., 2021 - ieeexplore.ieee.org

The paper focuses on the development of hybrid battery charging systems for autonomous electric passenger vehicles. Aspects of elaboration and design methodology of the battery ...

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THANK YOU FOR YOUR ATTENTION!

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