City simulation software for modeling, planning, and strategic assessment of territorial city units

The project was supported by the Technology Agency of the Czech Republic (TACR), National Competence Center of Cybernetics and Artificial Intelligence, TN01000024.

29.01.2021

Version 1.1

Technical report

Project information

Project name: Technology Agency of the Czech Republic (TACR), National Competence Center of Cybernetics and Artificial Intelligence

Subproject Name: Artificial Intelligence for Smart Cities and Regions (T2.a)

Subproject Number: TN01000024/09

Subproject Leader: Prof. Dr. Ing. Miroslav Svítek, dr.h.c.

Nuber of Result: TN01000024/9-V1

Name of Result: City Simulation Software (CSS) for modeling, planning, and strategic assessment of territorial city units

Type of Result: S- Software

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1. Introduction

The **Smart Resilience City** concept is a new vision of a city as a digital platform and eco-system of smart services where agents of people, things, documents, robots, and other entities can directly negotiate with each other on resource demand principals providing the best possible solution. It creates the smart environment making possible self-organization in sustainable or, when needed, resilient way of individuals, groups and the whole system objectives.

Urban resilience is defined [1] based on the classical approach of Holling's resilience [2] as the ability of the system to continue to function with the change but does not necessarily remain the same. Picket [3] defines resilience as the ability of the system to adapt to changing conditions.

Chelleri [4] defines urban resilience not as the ability to return for basic condition, but as the ability to smoothly change the system, the ability to evolve to adapt. In the theory of complex systems, urban resilience is the ability to evolve [5]. According to Cutter[6], urban resilience is the ability to adapt to climate change and hazards.

From another perspective, a resilient city is a sustainable network of physical systems and human communities [7]. Mehmood [8] emphasizes the need to consider the city as a complex adaptive system to assess resilience. Linkov [9] notes the increasing complexity of systems and the need for a network-centric approach to addressing urban sustainability.

There are many definitions and they are contradictory. Therefore, in our work, we will adhere to the definitions of urban sustainability, urban resilience and urban transformation, which Elmqvist et al.[10] derived from their research:

- Urban sustainability - manage all resources the urban region is dependent on and enhance the integration of all sub-systems in an urban region in ways that guarantee the wellbeing of current and future generations, ensuring distributional equity.
- Urban resilience - the capacity of an urban system to absorb disturbance, reorganize, maintain essentially the same functions and feedbacks over time and continue to develop along a particular trajectory. This capacity stems from the character, diversity, redundancies, and interactions among and between the components involved in generating different functions.
- Urban transformation - a systemic change in the urban system. It is a process of fundamental irreversible changes in infrastructures, ecosystems, agency configurations, lifestyles, systems of service provision, urban innovation, institutions, and governance.

The city is a very complex system of social-ecological and social-technical networks [1]; a network of physical systems and human communities [7]. Therefore, Resilient city (RC) should be considered as a complex adaptive network-centric system of systems with a huge number of interconnections [8, 9].

Urban resilience is one of the key factors in smart city planning [11,12]. To ensure it, it is necessary to manage the flow of resources, paying special attention to their interrelationships, thus optimizing consumption [13]. Processes need to be planned in real-time. Smart Resilient City is characterized by the ability to produce knowledge, store it and learn. And to ensure high complexity, the Smart RC as the system of systems for better interaction should be developed based on common knowledge bases [14].

To implement these requirements in some papers it is proposed to use multi-agent technologies. Massei and Tremori [15] use intelligent agents to model urban responses to threats in a military context, with particular emphasis on human behavior. Brudermann and Yamagata [16] also use agents to model people's behavior, the main purpose is to study crowd behavior in case of an emergency. Mustapha et al. [17] are developing the multi-agent architecture for a disaster-resistant city. The approach of Rieger et al. [18] considers the use of multi-agent technologies and graph theory for urban resilience. In our work, we focus on the use of ontologies as a core element of storing the knowledge that can work along with multi-agent technologies. It is a network in which all nodes are accessible to each other [19] and is capable of self-organization and risk management [20].

The use of ontologies is the most promising method of ensuring urban interoperability [21]. In the sphere of transport ontologies for cargo transportation have been developed [22], for management in the iron ore industry [23]. In the field of ontology construction for the construction of energy-efficient buildings [24], risk management and quality control [25] have been developed. There is a platform [26] for ontological modeling of necessary domain areas. Ontologies have been developed to collect information from sensors of smart houses and cities [27].

Km4City[28] is the most comprehensive open ontology for smart cities, covering a large number of areas (e.g. weather, sensors, structures, transport, etc.) needed to reduce energy consumption and CO2 emissions.

However, there is currently no single ontology covering all sectors and no standardization and consistency [21].

As opposed to us, Trucco et al. [29] modeled the city using ontologies not for planning, but resilience assessment. Also, several other works are devoted to modeling the city to assess its resilience. Uribe-Perez and Pous [30] argue that a large number of connections in the city require a special architecture for modeling. They offer architecture with a service bus. Inspired by the human nervous system, they propose to give the service bus functions like a spinal cord for the simplest quickest reactions to events. This is a promising idea. In the future, it can be combined with the results of our work.

Cavallaro et al. [31] solve the problem of a huge number of connections in the city by using Hybrid Social-Physical Complex Networks. Their approach is convenient for assessing urban resilience; in our work, the idea of a hybrid network is implemented using ontologies for the convenience of subsequent planning.

To summarize we can say, that Smart Resilient City should be a network-centric system of systems, based on knowledge bases and ontologies as the most promising method of ensuring interoperability, should manage the flow of resources and all city services and be capable of self-organization, adaptability and risk management. It is also vitally important to have a full understanding of the current situation, as well as instruments for modeling "what if" scenarios.

In our work, we propose to create the Smart City architecture and framework resilient by design (here and after means the property of the framework) based on MAT, ontologies and digital ecosystem of services. Our architecture will allow both strategically and real-time to modeling and plan sustainable and resilience city behavior.

2. Smart City simulation software for modeling, planning and strategic assessment of urban areas (CSS)

2.1. System oriented description

The CSS conceptual architecture is shown in Fig. 1. The general idea of CSS is to combine existing modeling and simulation tools to make the online model of the whole urban area at least in the following sectors:

1) Micro-climate model;
2) Energy model;
3) Transportation model;
4) 3D model.

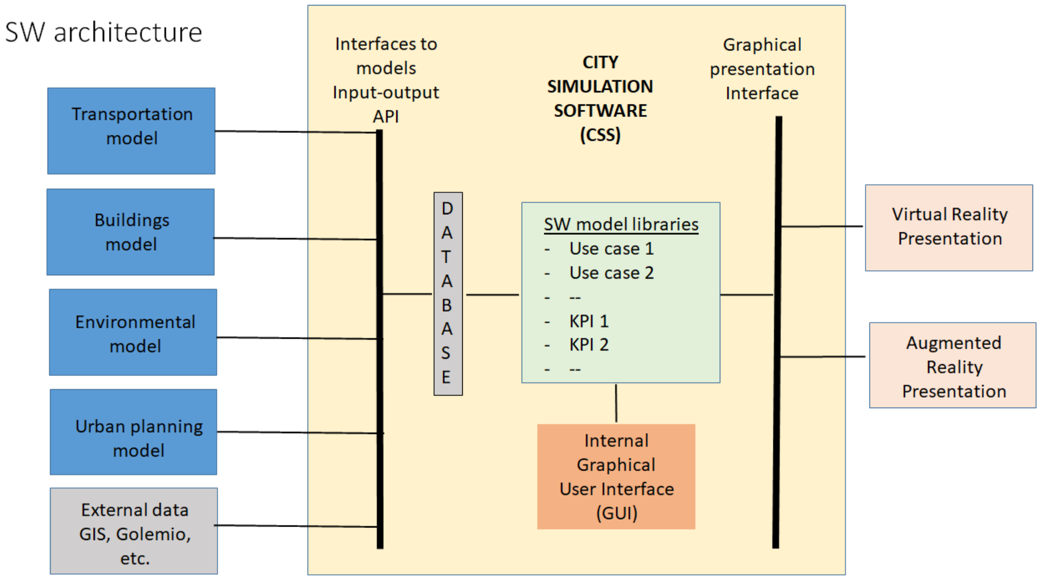


Fig. 1. Architecture of CSS

The results of CSS could be visualized in two different ways. Firstly, we use the equalizer in Fig.2 for showing the economic, environmental and social parameters assigned to each smart city components. Secondly, we can create a virtual model which is playing the role of the twin-model of the real city area. By virtual model, we can optimize economic, environmental and social parameters together with common synergies among different sectors (transport, environment, security, etc.).

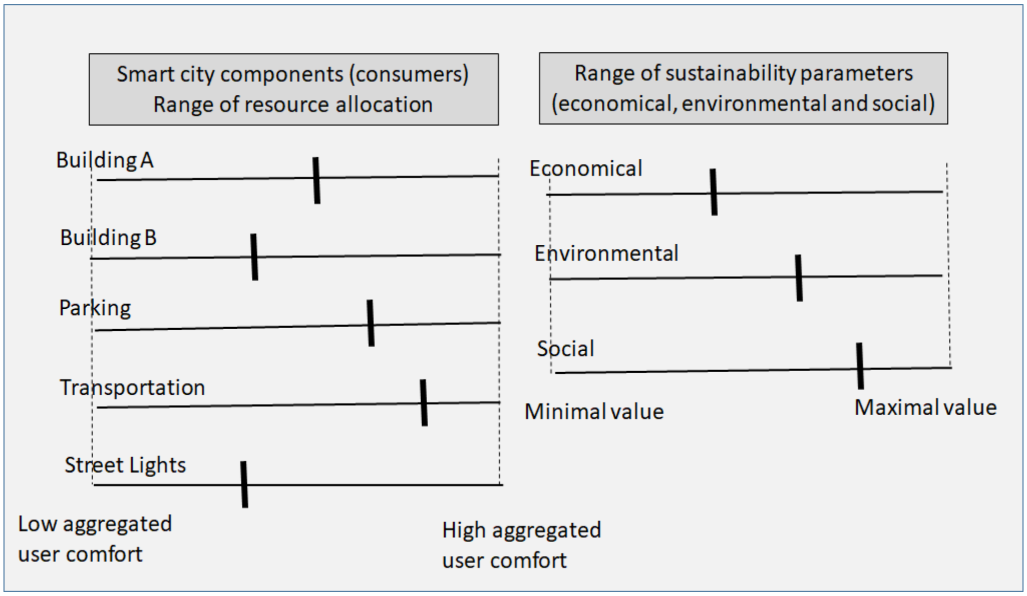


Fig. 2. City Equalizer

The mixture of models yields in the complex simulation of "what-if" critical situations.

2.2. Software description

City simulation software for modeling, planning, and strategic assessment of territorial city units (Smart city platform) enables the implementation of different smart city models created in different applications and products into one web-based platform that provides the complementary overview of the current situation of the section of the city or provide the results of what-if modeling of this area. The platform collects the heterogeneous data from different information sources to simulate possible city evolution strategies. Smart city platform enables to integrate the several existing simulation tools and models to very narrowly specialized issues to develop the holistic simulation of the whole territorial unit.

By using integrated mathematical models it is possible to simulate “ what-if” scenarios of future evolution. The platform collects the heterogeneous data from different information sources, provides the integration and enables to simulate possible urban unit evolution strategies and compute the appropriate set of KPIs - Key Performance Indicators. Smart city platform (CSP) provides the KPIs and results of simulations in a web-oriented platform.

The platform comprises the following components:

- Visualization components.
- R –Energy smart energy grid model.
- Synthetic population model.
- Environment model.
- Mobility model.

Technical description of every component are presented below.

3. R –Energy smart grid model

The main idea of the system is to model smart grid of any possible configuration (including supply networks) and provide real-time results of gas, water, and energy resource – demand model. This system has the following functions:

1) full monitoring of the supply networks;
2) efficient distribution of resources in the supply system;
3) matching of the produced number of resources with the consumed;
4) quick adaptation of networks to current events.

It is initially created as an adaptive p2p network of individual resources planners, and with recursive scalable deployment at any level (holonic approach). The multiagent approach in the development of the system ensure efficient distribution of resources in resource supply networks and increase the overall level of customer satisfaction, as well as ensure that production costs are adequate to the level of consumption by building coordinated production and supply plans for resources, taking into account all the parameters of consumers and suppliers.

3.1. System Architecture

Software is implemented as the following modules:

- multi-agent platform that includes an agent generator, agent dispatcher, adaptive planning module, agent inspector, and agent conversation log;
- module for configuration set up;
- integration module;
- ontology;

- reports module;
- User Interface (UI) modules.

The enlarged system architecture, which includes the main modules and components, is shown in Fig. 3.

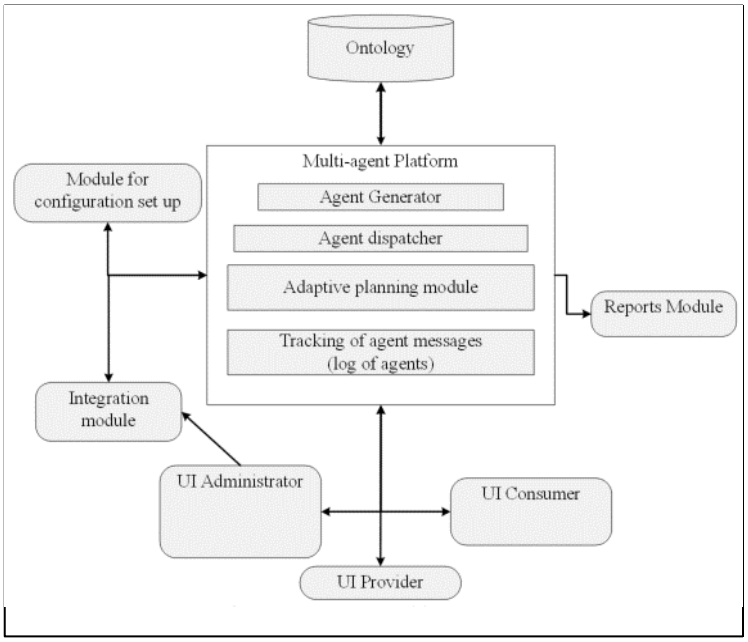


Figure 3- System Architecture

3.2. Ontology for describing resource supply networks

An ontology has been developed to describe the basic concepts of the subject area and the relationships between them. The ontology allows to describe objects and processes, the principals of supply, formation of demand and production of resources, taking into account the structure of networks, detalize and accumulate information about specific network objects.

Figure 4 shows the top level of the resource supply network management ontology, which includes three basic concepts corresponding to the objects of consumption, production, and distribution of resources ("Consumer", "Provider", and" Network", respectively).

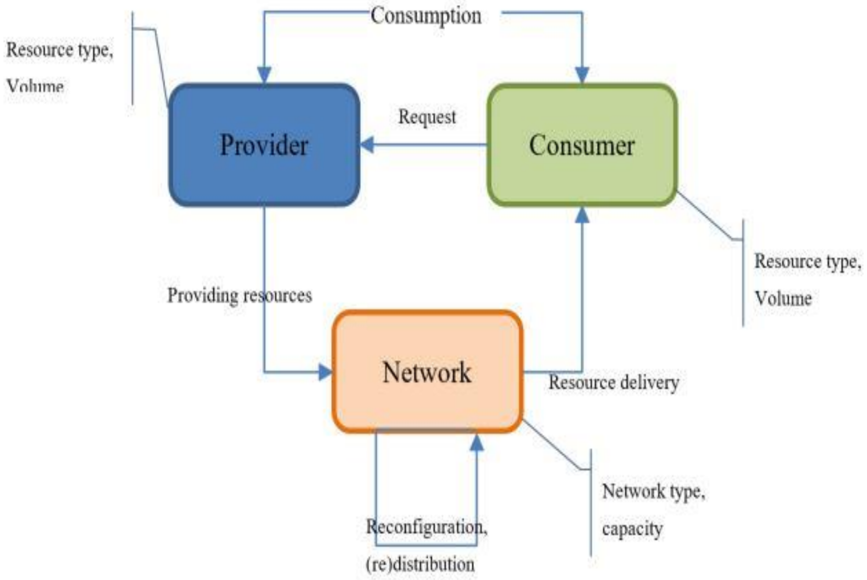


Figure 4- Basic ontology classes

Based on the use of the simplest basic ontological entities in conjunction with the almost unlimited possibilities of ontology to expand a network topology constructor allows take into account all their necessary parameters.

3.3. Software operation logic

Initially, the user sets the general configuration of resource supply networks through an automated workplace. This configuration is loaded into a multi-agent platform, where the agent manager maps each network object to a software agent that represents the interests of this object. Using the integration module, the real data is collected from the equipment of resource supply networks, as well as from existing information systems that perform network monitoring.

Consumers and suppliers using the appropriate user interface to set up the parameters of consumption and production of resources. After that, using the message transfer module, the agents representing the network objects begin negotiations, which, through biddings and concessions, are completed by reaching a consensus – that suits all parties. If this solution is not possible, software agents make recommendations to consumers about changes in the volume of demand or supply to suppliers, which are sent to users of the system via UI. With this form of communication, dialogue with the system continues until proposals are formulated that are acceptable to all parties in the scene. User can get access to various statistics. User access to system functions and data is determined by the access control module.

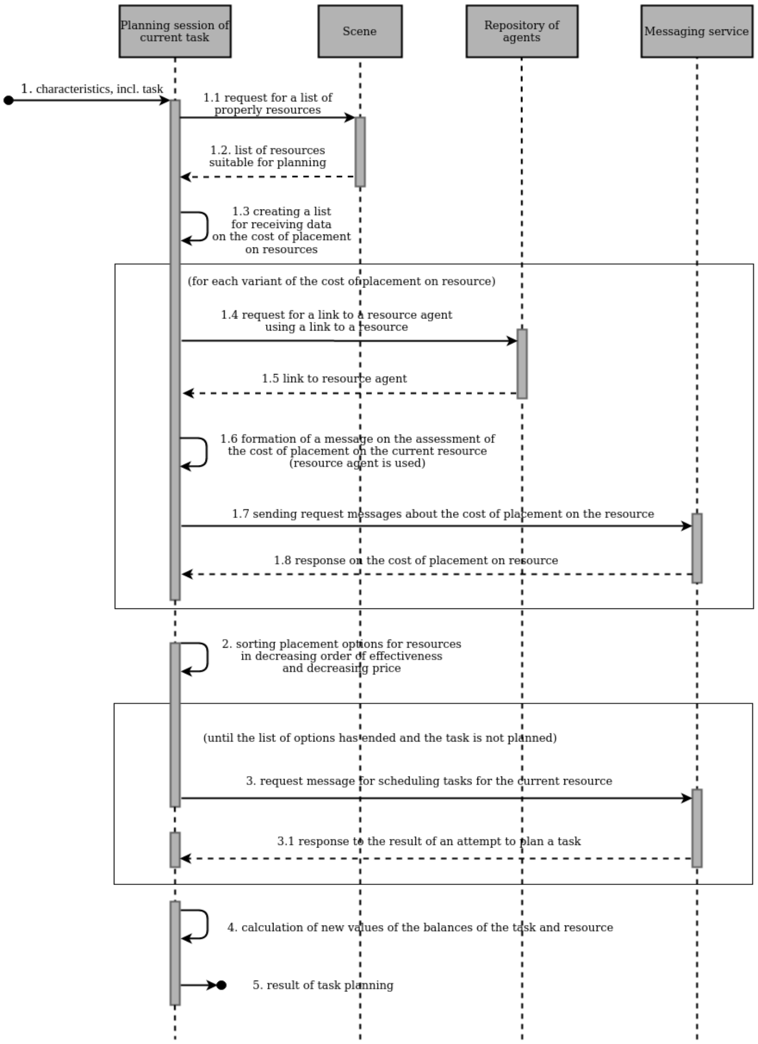
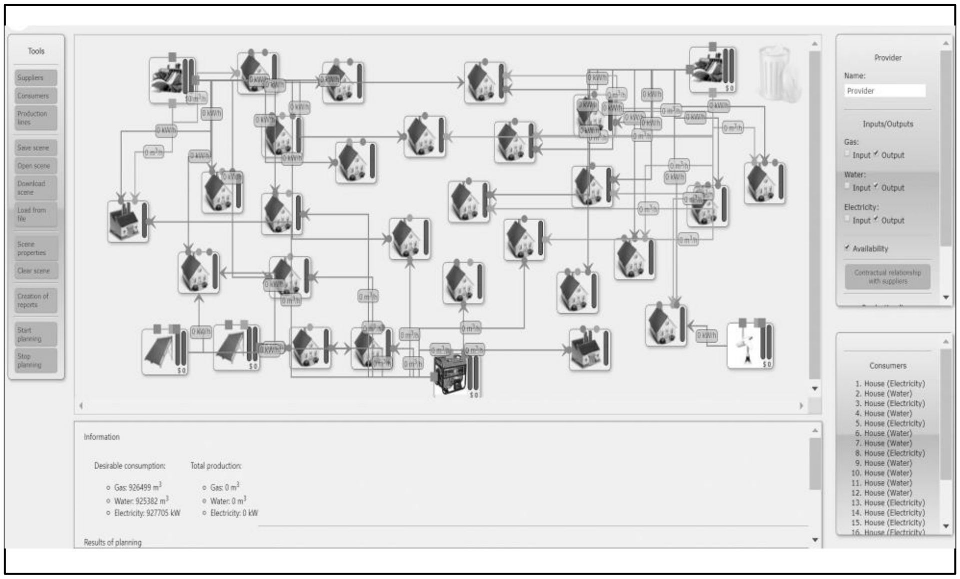


Figure 5 – Protocols of agent's negotiation

Users are provided with remote access to the system from any device that has an Internet connection (PCs, laptops, tablets, mobile phones). For this purpose, the Software user interface has been developed with a focus on web and cloud technologies. Fig. 6 shows the main window of the resource supply network designer.



Provider

Name: Provider

Inputs/Outputs

Gas:
☐ Input ☑ Output

Water:
☐ Input ☑ Output

Electricity:
☐ Input ☑ Output

☑ Availability

Consumers

1. House (Electricity)
2. House (Water)
3. House (Electricity)
4. House (Water)
5. House (Electricity)
6. House (Water)
7. House (Water)
8. House (Electricity)
9. House (Water)
10. House (Water)
11. House (Water)
12. House (Water)
13. House (Electricity)
14. House (Electricity)
15. House (Electricity)
16. House (Electricity)

Information

Desirable consumption:
- Gas: 926499 m^3
- Water: 925382 m^3
- Electricity: 927705 kW

Total production:
- Gas: 0 m^3
- Water: 0 m^3
- Electricity: 0 kW

Results of planning

Figure 6 – Software User Interface

4. Mobility model

Transportation system (TS) is the core element of every city. To define different ways of possible cooperation between services the transport model of the city was created. Within the overall system, we can perceive it as a subsystem with certain input values and output KPIs [16].

Inputs cover:

- (IP) RG: Road geometry (incl. nodes, sections, parking etc.);
- (P) TD: Travel demand (incl. origin-destination (OD) matrices for particular vehicle classes);
- (IP/P) TC: Traffic control (signal plans, traffic signs, etc.);
- (P) PT: Public transport (lines, bus stops, time schedules);
- (P) TD_VRU: Travel demand for pedestrians and cyclists;
- (P) SP: Simulation and model parameters (acceleration, gap acceptance, etc.); and
- (-) CD: Data for calibration (travel times, queue length etc.).

The simulation process has several stages. During the first stage, a basic model is created. This is a model of the existing situation. In order to ensure that the model corresponds to the reality, a calibration process must take place. Here, the parameters of the model are modified till the behavior in the model corresponds to the real work situation. Typically, travel times or for example queue length are used for this comparison. After we have a calibrated model, different alternative scenarios can be evaluated.

The list of inputs above also consists of specification whether the given group of parameters is implicit (denoted - IP), or whether they can be used as parameters (denoted - P). Some scenarios require implicit changes in the model (typically changes in road geometry such as different number of traffic lanes, changes from signal control to round about etc.), some just changes in input parameters (for example changes in travel demand as a result of certain policies, changes in public transport, changes in the number of pedestrians, time shift of the demand and others). Using different policies (for example support of car sharing etc.) has direct influence on the OD matrices. This is a way how different subsystems can influence each other.

With all of this said, the transportation model is addressed by the remaining agents (sub-systems) in the following way:

$$O_i^S = TM(t, p, ip) \tag{1}$$

The output of certain scenario, *S*, depends on the inputs, *p*, and input parameters, *ip*, at a given time *t*.

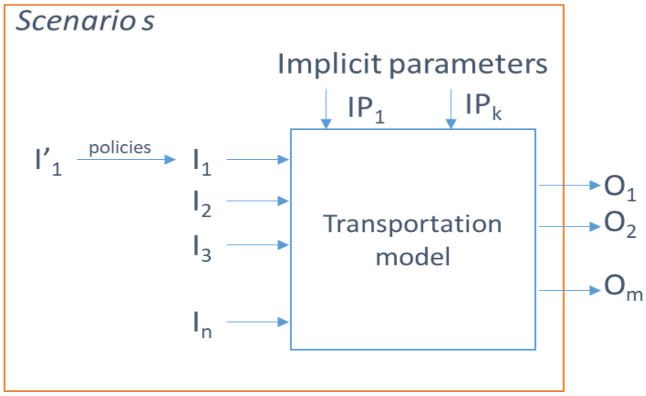


Fig. 7. Scenario oriented Transportation Model

Typically, the performance of the system (i.e. output or KPIs) cover the cost of given situation (scenario) and its influence on the environment (emissions, fuel consumed, and others), but also for example characteristics such as travel time or the delay of the vehicles in the network.

One of the biggest questions is the dealing with the required level of details. There are different approaches to actual transportation modeling [17], mainly:

(1) Travel demand modeling and approaches based on activities

(2) Microscopic traffic modeling

(3) Macroscopic traffic modeling

With respect to the environment, the model can be perceived as a black box with input and output variables. The other subsystems must not know about its internal behavior. There are however some issues that cannot be dealt with on an aggregated level. The two most important are discussed below:

Dynamic behavior – transportation is rather complex system with many dependencies. For example, simple variables such as travel time (TT) are not constant. This is a dynamic parameter and its value depends on several parameters, but mainly the actual travel demand, D.

$$TT(t) = f(t, D) \tag{2}$$

Interactions among different elements – several approaches (such as highway capacity manual) allow analytical description of the behavior on a single network element, for example road segment or an intersection. They however do not offer modeling of interactions among such elements. For example, unsuitable control algorithm or too high travel demand can lead to a situation that a queue caused by first intersection influences not only speed on the given road section, but can cause the fact that vehicles cannot clear the adjacent intersection.

Travel is derived from the need to participate on activities – most modeling approaches focus on interactions among the vehicles, but do not take into consideration the fact that transportation is derived from the need to participate in activities. Modeling of human decision process is a prerequisite to allow modeling of impact of different policies and incentives.

In order to provide sufficient level of details and realistic behavior, microscopic simulation model is the preferred solution for MAS. It is able to deal with the first two challenges described above. Even the microscopic models however have some limitations. First of all, they do not allow modeling of human decisions. Changes in the destinations are not part of the model and must be dealt with prior to the simulation. It does not react to changes in attractiveness of certain parts of the network etc.

The size of the assessed area greatly influences what software tools can or should be used. However, unless the area is an entire city, so called microscopic mobility modelling should be the preferred tool to use. At microscopic level of mobility simulation, the model goes into the detail of individual vehicles (size, type, engine capabilities etc.), infrastructure geometry (both horizontal and vertical if need be) and driver’s behaviour (car following models, critical gaps, aggressive behaviour, law negligence etc.). This level of detail enables to include more information about geometry comparison and changes in policies. To put it in contrast, for macroscopic mobility models, there could be model of grater area with much less effort, however, the level of detail would drop significantly as it would be solely a graph theory task. Assuming this tool would be mostly used for burrows or smaller urban units, microscopic modelling should be the option to choose with the possibility to change to macroscopic modelling, should the need arise.

4.1. Model Inputs

In order to create the mobility model in a suitable depth and precision, there are several inputs that need to be included and measured:

- Infrastructure geometry (maps or project documentation).
- Traffic control information (traffic lights plans, public transport preferences, pedestrian crossings etc.).
- Desired functions of urban units (city or area master plan).
- Driver behaviour (state statistical data, city-wide psychological surveys on driver behaviour etc.).
- Traffic flow description (traffic surveys – traffic flow volume, directional volumes, velocity, traffic mix etc.).
- Public transport plans and timetables (including the bus/tram stops locations).
- Pedestrian flow description (either throughout the area or for individual or important pedestrian crossings).
- Development prognosis (demographical development, car ownership etc.).
- Other information about infrastructure (parking spaces distribution, parking management policy, law enforcement policy etc.).

Through the inputs above, it should be possible to sufficiently understand the area to be modelled. It is, however, beneficial to include someone familiar with the area in the process of creating the model and evaluating the findings. The goal is mainly to avoid wrong conclusions.

4.2. Model creation

For the purposes of the project use case, SUMO (Simulation of Urban Mobility) software was used as a microscopic mobility model tool as the area was small enough for the benefits of microscopic modelling to outweigh the increased effort needed to create the model. The used interface for model creation also enables rather flexible environment for third-party access and allows for remote access through remote system or database. SUMO operates through XML commands. The core file consists of XML code. However, the infrastructure can also be built through user friendly graphic interface similar to PTF Vissim. Moreover, the infrastructure can also be built partially through an automated process of raster analysis of orthophoto map of the area and later adjusted. The necessary steps needed to create a functioning model are listed below:

1) Data collection (inputs from previous chapter).
2) Infrastructure creation (it is necessary to balance accuracy and effort).
3) Traffic organization and control (traffic lights, traffic signs, lines etc.).

4) Drivers behaviour description (possible to use standard description included with less accuracy).
5) Trip generation (O-D matrix for each trip).
6) Individual trip details (what vehicle was used, individual driver behaviour etc.).
7) Iteration over several simulation runs to decrease the effect of extreme situations.
8) Model correction (based on output analysis).

4.3. Model outputs

The goal of mobility modelling process is to define the modelled area and individual scenarios through Key Performance Indicators (KPIs). As the model describes a network of roads, the best way to describe such network is to individually evaluate different segments. Individual segments may vary in lengths (length is determined by the needs of the model), therefore, the values of any KPI needs to be indrawn to length (e. g. mg/h/km – microgram per hour per kilometer). This then enables not only to compare the networks by value but also a visual comparison (assigning colour gradient to value scale). The scenarios can then be compared based on individual KPIs such as in the figure below (Figure 8). Visualization of individual vehicles passing through the model can also be used to give context and scale to the model.

The heatmap output might, however, require deeper inspection of the values or the map itself. For a more complicated network, simple visual comparison might not suffice. For this purpose, additional tools have been developed. First allows for combination of all KPIs and recalculation of the heatmaps to a heatmaps that visualizes how often set limits (thresholds) for each KPI are breached – more can be read in an article written about this subject (R. Dostál, O. Přibyl and M. Svítek: City Infrastructure Evaluation using Urban Simulation Tools, 978-1-7281-6821-0/20/$31.00 ©2020 IEEE). The second tool is mostly based on the first tool, but to further this combination of KPIs, if the values (that can be presented in percentages) are then averaged, we can get one global KPI, that describe the area from the perspective of mobility. The crucial aspect is how thresholds are set. It is also necessary to go over all the data (from each time period for every segment) and analyze the values. Should there be some extreme values, further inspection is needed.

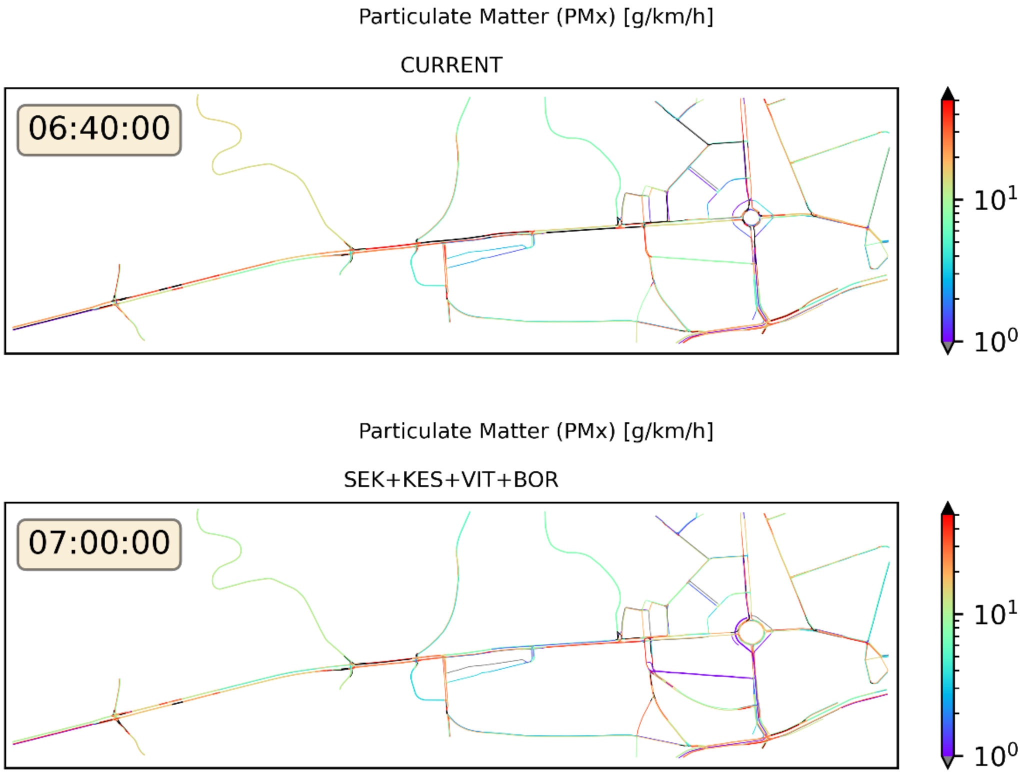


Figure 8: PMx Emission comparison for 0 case scenario and full development scenario

4.4. Implementation within the interface software

For each scenario, it is possible to visualize different KPIs for different models at once. For the mobility model, it is possible to see the change through the day of individual KPIs based on what KPI is chosen to be visualized, as shown in the figure below (Figure 99). The goal is to provide a simple a easily manageable software interface for the customer, so that they can easily compare every scenario what whatever aspect (model & KPI) they choose. As the easiest to read approach to transportation and mobility is through a heatmap, this is the approach that has been chosen. For deeper knowledge, further inspection of individual values can prove to be beneficial for the customer – but the ability to compare becomes gradually more difficult.

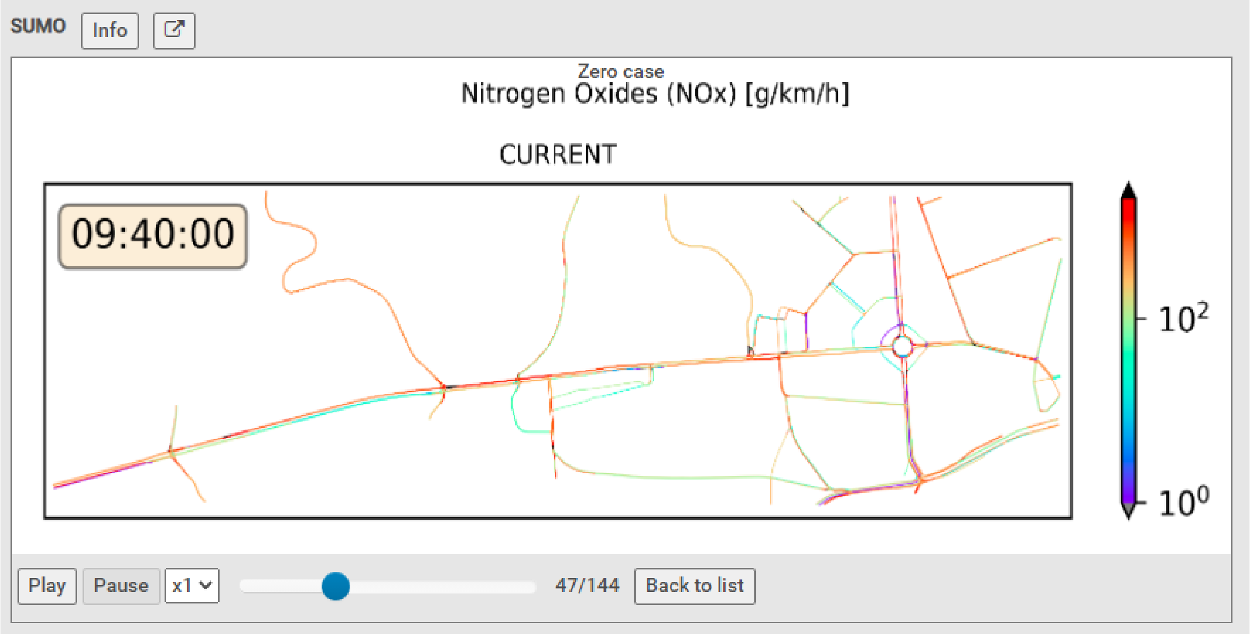


Figure 9: Mobility model implementation in interface software

5. Synthetic population and trip generator model

Synthetic population is the artificial population of individuals that resemble the real population. The differences in parameters of synthetic and real population are minimal. The synthetic population however does not match the real population on the level of individuals, because the synthetic population was created by sampling from joint distributions of real population parameters or created by probabilistic matching of various micro-samples or micro-censuses. Another reason for not one-to-one correspondence of synthetic and real population are the privacy protection concerns.

The synthetic population was created for selected pilot area in Prague 6, but it is naturally scalable to the whole area of Prague municipality. The synthetic population contain the buildings, residents, households, job, visitors and demanded trips. The structure of synthetic population is defined in the table below.

Agent/Entity	Characteristics
Building	Floor spaces classified by functions
	Num. of floors
	Outbound/Inbound residential trips by purpose, transportation mode, time
	Outbound/Inbound work-trips by transportation mode, time

	Inbound visitors’ trips by transportation mode, time
	Number of residents
	Number of jobs
	Number of visitors
Residents	Individuals by age and gender
	Number of trips per day
	Purpose of the trip
	Departure/arrival time of residential trip
	Affiliation to a household
Households	Number of household members by age category and gender
	Number of children
	Number of economically active
	Number of retired household members
Jobs	Transportation mode choice
	Transportation arrival time
	Transportation departure time
Visitor	Purpose of the trip
	Transportation mode choice
	Transportation departure time

5.1. The user interface

The interactive web-based map application based on ArcGIS Pro software provides users with basic information on synthetic population. The user interface presents following information:

- Dominant function of a building
- The number of trips related to a building
- The proportion of residential and non-residential trips
- The number of residents in the area
- The proportion of trips by purpose
- The proportion of trips by transportation mode

Figure 10 – SP User Interface

5.2. The procedure of synthetic population creation

Generating households in buildings: Completing data on buildings with data on households by probabilistic (fuzzy) matching of records from General Census 2011 data (SLDB 2011) with the records of flats from Register of Buildings (RSO).

Generating individual residents in the building: Individual residents are generated from data on households in buildings, each resident has age and gender.

Generating gross floor spaces by use of buildings: The floor spaces are attributed to buildings based on their number of floors and the area of their footprints. The use of buildings was determined by land use data of Prague and Register of Buildings (RSO). The mix-use buildings were disaggregated to elementary uses and HPP was equally divided among them.

Generating the number of non-residential trips by buildings: For each non-residential use the number of trips generated per unit of HPP was calculated. For that purpose, the Normative indicators provided by EDIP were used.

Generating the number of jobs in buildings: For each non-residential use the number of jobs per unit of gross floor space per day was calculated. The normative indicators provided by EDIP were used for that purpose. For specific uses such as public institutions the Annual reports were used.

Generating number of visitors in buildings: For each non-residential use the number of visitors per unit of floor space and per day was calculated. The normative indicators provided by EDIP were used for that purpose. For specific uses, such as public institutions, the Annual reports were used.

Timing of non-residential trips: The time of the trip is attributed to each inbound trip to building. It is done separately for work trips (table 1) and trips of visitors; Data: Travel survey „Česko v pohybu“.

Transportation mode of non-residential trips: The transportation mode is attributed to each inbound trip to buildings of non-residential use. It is done separately for work trips and trips of visitors, see table 2. Data: Travel survey „Česko v pohybu“.

The number of trips per day made by residents: For each person in building the number (0, 1, 2, 3, 4) of outbound trips per day is attributed based on gender and age, see table 3. Data: Travel survey „Česko v pohybu“.

Attributing the purpose of the trips: The purpose of the trip is probabilistically attributed to each trip generated in previous step based on age and gender of the person doing the trip. Calculated for inbound and outbound trips, see table 4. Data: Travel survey „Česko v pohybu“.

Timing of residential trips: The time of the trip is probabilistically attributed to each trip based on the purpose of the trip. Calculated for inbound and outbound trips, see table 5. Data: Travel survey „Česko v pohybu“.

The transportation mode of the trips: The transportation mode is probabilistically attributed to each trip based on age of the person doing the trip and based on purpose of the trip, see table 6. Data: Travel survey „Česko v pohybu“.

key	PE	BI	UT	BU	RW	CD	CC	OT
0	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
1	0,0000	0,0000	0,0000	0,0000	0,0036	0,0000	0,0000	0,0055
2	0,0000	0,0000	0,0000	0,0011	0,0036	0,0000	0,0000	0,0000
3	0,0000	0,0000	0,0000	0,0023	0,0000	0,0000	0,0000	0,0055
4	0,0000	0,0000	0,0000	0,0125	0,0000	0,0000	0,0015	0,0000
5	0,0048	0,0000	0,0016	0,0649	0,0036	0,0000	0,0031	0,0164
6	0,0167	0,0099	0,0047	0,1731	0,0250	0,0182	0,0201	0,0437
7	0,0335	0,0000	0,0233	0,2773	0,0714	0,7318	0,1316	0,0656
8	0,0466	0,0099	0,0638	0,2249	0,0893	0,1182	0,1331	0,0984
9	0,0430	0,0000	0,1260	0,0809	0,1464	0,0341	0,1068	0,0601
10	0,0633	0,0000	0,1633	0,0273	0,1393	0,0273	0,0944	0,0601
11	0,0394	0,2277	0,0684	0,0148	0,0964	0,0068	0,0681	0,0219
12	0,0346	0,4158	0,0715	0,0245	0,0536	0,0182	0,0588	0,0219
13	0,0585	0,0990	0,0529	0,0359	0,0893	0,0136	0,0387	0,0437
14	0,0490	0,0495	0,0544	0,0148	0,0679	0,0114	0,0743	0,0601

15	0,1004	0,0000	0,0840	0,0091	0,0500	0,0136	0,0898	0,0929
16	0,1326	0,0396	0,0980	0,0074	0,0500	0,0023	0,0789	0,0929
17	0,1063	0,0594	0,0949	0,0114	0,0607	0,0023	0,0511	0,1202
18	0,1111	0,0495	0,0575	0,0085	0,0214	0,0023	0,0186	0,0820
19	0,0800	0,0198	0,0264	0,0046	0,0036	0,0000	0,0186	0,0601
20	0,0490	0,0198	0,0078	0,0017	0,0107	0,0000	0,0077	0,0219
21	0,0131	0,0000	0,0016	0,0011	0,0071	0,0000	0,0015	0,0109
22	0,0131	0,0000	0,0000	0,0006	0,0036	0,0000	0,0031	0,0109
23	0,0048	0,0000	0,0000	0,0011	0,0036	0,0000	0,0000	0,0055

Tab. 1, Timing of non-residential trips: the probability that the non-residential trip will be effectuated at certain time of day. Trip purpose: BY: housing, VO: free time, ST: eating, NA: shopping, PR: work, PC: business, VZ: education, ZA: arranging, OS: other, key: the time of starting the trip.

key	PE	BI	UT	BU	RW	CD	CC	OT
BY	0,2971	0,0095	0,4144	0,0129	0,0132	0,1924	0,0530	0,0076
NA	0,4423	0,0032	0,3157	0,0032	0,0016	0,1619	0,0689	0,0032
OS	0,3182	0,0057	0,3636	0,0284	0,0170	0,1705	0,0795	0,0170
PC	0,0809	0,0037	0,1618	0,0037	0,0221	0,6581	0,0551	0,0147
PR	0,1444	0,0113	0,4582	0,0292	0,0376	0,2792	0,0322	0,0078
ST	0,7400	0,0000	0,1500	0,0000	0,0000	0,0900	0,0200	0,0000
VO	0,5262	0,0195	0,2838	0,0146	0,0146	0,0853	0,0463	0,0097
VZ	0,4439	0,0000	0,3699	0,0263	0,0286	0,0310	0,0979	0,0024
ZA	0,2206	0,0063	0,3921	0,0206	0,0190	0,2603	0,0762	0,0048

Tab. 2, Transportation mode of non-residential trips: the probability that the non-residential trip of given purpose will be effectuated by certain transportation mode (PE: pedestrian, BI: Bicycle, UT: urban transit, BU: bus, RW: railway, CD: car driver, CC: car co-driver, OT: other). Key: trip purpose: BY: housing, VO: free time, ST: eating, NA: shopping, PR: work, PC: business, VZ: education, ZA: arranging, OS: other, key: the time of starting the trip.

gender	key_vek	p0	p1	p2	p3	p4
M	Y	0,02	0,67	0,28	0,02	0,01

Z	Y	0,02	0,65	0,31	0,01	0,01
M	M	0,05	0,70	0,20	0,04	0,01
Z	M	0,06	0,63	0,24	0,06	0,01
M	O	0,04	0,72	0,21	0,03	0,00
Z	O	0,05	0,66	0,26	0,04	0,00

Tab. 3, The number of trips per day made by residents: probability of the given number trips (p0: 0; p1: 1; p2: 2; p3: 3; p4: 4) effectuated by certain person based on his/her gender (M; Z) and age (Y: 0-18, M: 19-59, O: 60+) of the person.

key	BY	VO	ST	NA	PR	PC	VZ	ZA	OS
M_19	0,066	0,241	0,008	0,046	0,436	0,029	0,116	0,037	0,021
M_30	0,093	0,127	0,003	0,048	0,553	0,052	0,007	0,079	0,038
M_40	0,067	0,118	0,010	0,040	0,586	0,034	0,003	0,111	0,030
M_50	0,080	0,080	0,015	0,070	0,565	0,080	0,010	0,080	0,020
Z_19	0,115	0,191	0,007	0,104	0,347	0,010	0,125	0,069	0,031
Z_30	0,069	0,190	0,003	0,114	0,363	0,016	0,007	0,212	0,026
Z_40	0,071	0,132	0,003	0,094	0,459	0,044	0,003	0,165	0,029
M_15	0,083	0,262	0,000	0,012	0,083	0,024	0,452	0,060	0,024
M_0	0,040	0,246	0,006	0,034	0,011	0,000	0,611	0,040	0,011
Z_0	0,036	0,237	0,000	0,041	0,000	0,000	0,604	0,053	0,030
M_60	0,058	0,169	0,013	0,169	0,357	0,026	0,000	0,162	0,045
M_70	0,038	0,265	0,011	0,341	0,070	0,011	0,000	0,243	0,022
Z_60	0,052	0,194	0,009	0,259	0,246	0,022	0,000	0,190	0,030
Z_50	0,103	0,113	0,000	0,097	0,508	0,031	0,000	0,097	0,051
Z_70	0,068	0,208	0,019	0,358	0,034	0,000	0,000	0,272	0,042
Z_15	0,054	0,378	0,000	0,054	0,014	0,000	0,486	0,000	0,014

Tab. 4, Attributing the purpose of the trip: probability of the purpose of given trip: BY: housing, VO: free time, ST: eating, NA: shopping, PR: work, PC: business, VZ: education, ZA: arranging, OS: other, key is composed of gender (M; Z) and age (0-14; 15-18; 19-29; 30-39; 40-49; 50-59; 60-69; 70+) of the person.

key	BY	VO	ST	NA	PR	PC	VZ	ZA	OS

0	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
1	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,012
2	0,000	0,000	0,000	0,000	0,002	0,011	0,000	0,000	0,000
3	0,000	0,000	0,048	0,000	0,004	0,000	0,000	0,000	0,012
4	0,000	0,003	0,000	0,000	0,030	0,022	0,000	0,005	0,012
5	0,000	0,005	0,000	0,003	0,100	0,056	0,003	0,009	0,093
6	0,005	0,035	0,000	0,010	0,262	0,133	0,061	0,052	0,058
7	0,027	0,051	0,000	0,043	0,276	0,200	0,812	0,197	0,116
8	0,005	0,068	0,000	0,079	0,173	0,133	0,067	0,150	0,140
9	0,014	0,056	0,000	0,173	0,058	0,122	0,015	0,108	0,093
10	0,009	0,075	0,000	0,206	0,020	0,100	0,009	0,103	0,047
11	0,059	0,019	0,333	0,081	0,006	0,078	0,006	0,049	0,035
12	0,036	0,023	0,143	0,043	0,013	0,033	0,012	0,056	0,012
13	0,018	0,049	0,048	0,046	0,017	0,022	0,006	0,042	0,023
14	0,081	0,075	0,000	0,038	0,010	0,022	0,000	0,063	0,058
15	0,158	0,115	0,000	0,046	0,006	0,033	0,006	0,061	0,070
16	0,212	0,106	0,143	0,071	0,005	0,033	0,000	0,040	0,047
17	0,176	0,112	0,048	0,084	0,009	0,000	0,003	0,031	0,093
18	0,104	0,108	0,143	0,043	0,006	0,000	0,000	0,023	0,035
19	0,050	0,061	0,048	0,025	0,002	0,000	0,000	0,002	0,023
20	0,014	0,024	0,048	0,008	0,001	0,000	0,000	0,002	0,012
21	0,032	0,007	0,000	0,003	0,002	0,000	0,000	0,005	0,000
22	0,005	0,007	0,000	0,000	0,000	0,000	0,000	0,000	0,012
23	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,000	0,000

Tab. 5, Timing of residential trips: probability of effectuating the trip of given purpose in certain time; trip purpose: BY: housing, VO: free time, ST: eating, NA: shopping, PR: work, PC: business, VZ: education, ZA: arranging, OS: other, key: the time of starting the trip.

key	PE	BI	UT	BU	RW	CD	CC	OT
M_BY	0,435	0,000	0,367	0,056	0,079	0,051	0,011	0,000
M_NA	0,545	0,006	0,210	0,000	0,000	0,204	0,036	0,000

M_OS	0,288	0,015	0,394	0,000	0,030	0,227	0,045	0,000
M_PC	0,039	0,000	0,195	0,000	0,013	0,688	0,052	0,013
M_PR	0,147	0,015	0,476	0,012	0,015	0,289	0,036	0,010
M_ST	0,615	0,000	0,231	0,000	0,000	0,077	0,077	0,000
M_VO	0,475	0,028	0,252	0,006	0,025	0,150	0,037	0,028
M_VZ	0,319	0,000	0,528	0,000	0,014	0,125	0,014	0,000
M_ZA	0,328	0,008	0,278	0,004	0,000	0,344	0,033	0,004
O_BY	0,565	0,000	0,283	0,022	0,043	0,065	0,022	0,000
O_NA	0,578	0,004	0,295	0,004	0,000	0,070	0,049	0,000
O_OS	0,552	0,000	0,276	0,000	0,034	0,103	0,034	0,000
O_PC	0,000	0,000	0,455	0,000	0,000	0,364	0,182	0,000
O_PR	0,187	0,007	0,515	0,000	0,007	0,224	0,045	0,015
O_ST	0,727	0,000	0,273	0,000	0,000	0,000	0,000	0,000
O_VO	0,577	0,023	0,206	0,023	0,023	0,086	0,063	0,000
O_VZ	0,125	0,125	0,125	0,125	0,125	0,125	0,125	0,125
O_ZA	0,242	0,005	0,452	0,016	0,011	0,151	0,118	0,005
Y_BY	0,417	0,000	0,500	0,000	0,083	0,000	0,000	0,000
Y_NA	0,500	0,000	0,389	0,000	0,000	0,000	0,111	0,000
Y_OS	0,600	0,100	0,100	0,100	0,000	0,000	0,100	0,000
Y_PC	0,000	0,000	0,000	0,000	0,000	1,000	0,000	0,000
Y_PR	0,200	0,000	0,500	0,000	0,100	0,100	0,100	0,000
Y_ST	1,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Y_VO	0,526	0,045	0,278	0,000	0,023	0,023	0,105	0,000
Y_VZ	0,611	0,000	0,261	0,007	0,000	0,004	0,113	0,004
Y_ZA	0,333	0,000	0,238	0,000	0,000	0,000	0,429	0,000

Tab. 6, The transportation mode of the trip: probability of the trip of given purpose and effectuated by person of given age being effectuated by certain transportation mode; key composed of age of the person (Y: 0-18, M: 19-59, O: 60+) and trip purpose (BY: housing, VO: free time, ST: eating, NA: shopping, PR: work, PC: business, VZ: education, ZA: arranging, OS: other). Transportation mode (PE: pedestrian, BI: Bicycle, UT: urban transit, BU: bus, RW: railway, CD: car driver, CC: car co-driver, OT: other)

5.3. The scenarios

The synthetic population can be used for various purposes: the generated trips constitute the transportation demand which can input into transportation models, the occupation of buildings can be very useful for energy demand modelling or the analyzing how the users of the area are changing during the day. To test the usage of the model, several scenarios was defined:

1) Scenario – COVID19

The COVID19 scenario evaluate impact of COVID19 impact on frequency and structure of trip generation.

It is assumed that the impact of the COVID19 lockdown influences especially the trips related to work (PR), education (VZ) and eating (ST). The trips of these purposes dramatically decreased and affects especially children, women of working age.

Apart from trip purposes the COVID19 impacts the modal split of trips (especially of public transport) and timing of the trip when the trips are more equally distributed during the day.

Bellow, we can see the map depicting the distribution of trips in COVID19 scenario.

Figure 11 – COVID19 scenario.

Other three scenarios are based on proposed large-scale developments located in the area of interest. These scenarios evaluate the impact of changes in parameters of buildings in the area (increase/decrease in floor spaces in use categories, location/removal of individual buildings). Description of changes in terms of common attributes allows to evaluate local as well as global impact on synthetic population: e.g., transportation demand or current residents within same computational model. The floor spaces are categorized according to following uses:

CODE	FUNCTION (CZE)	FUNCTION (ENG)	
B	bydlení	residential	
D	doprava	transport	

I	neznámé	unknown	
L	lesy	forestry	
N	zeleň	greenery	
O	občanská vybavenost	public	
P	produkce	industry/logistics	
R	rekreace	recreation	
S	služby	services (commercial)	
T	technická infrastruktura	technical infrastructure	
V	veřejný proctor	public space	
X	bez využití	unused	
Z	zahrady	gardens	

Table 7 – Floor spaces

This categorization method is based on current authoritative Planning Materials procured by Institute of Planning and Development in Prague and therefore is compatible and compliant with any area within Prague.

The scenarios demonstrate the impact of new development on synthetic population as presented bellow

2) Scenario Bořislavka

The commercial center “Bořislavka” is currently under construction. The administrative and retail center encompasses 34 655 sqm of GFA (gross floor area), which provides amenities/capacity of approximately 1443 commuters and 2431 daily visitors. Most of these trips are served from existing subway station on subterranean levels.

“Bořislavka” development increases transportation demand by administrative workers that are more car-leaning compared to visitors of commercial uses.

Figure 11 – Bořislavka scenario.

3) Scenario Dejvice Center

“Dejvice Center” scenario offers large retail spaces with higher visitor turnover which is favorable for public transit and pedestrian modes. “Dejvice Center” is mixed-use building assembly with administrative, retail, cultural and educational uses. Total capacity of the development is 47 232 sqm GFA. The global impact of the development is not significant as the increase of floorspaces in the area of interest is less than 1% of total floor spaces.

Figure 12 – Bořislavka scenario.

4) Scenario Bořislavka and Dejvice Center

This scenario demonstrated the combined impact of both developments.

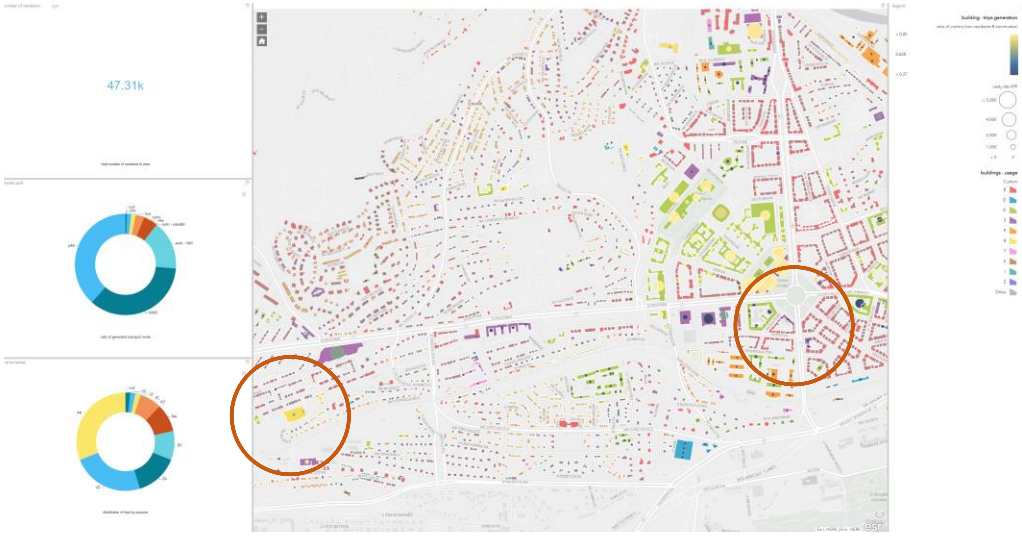
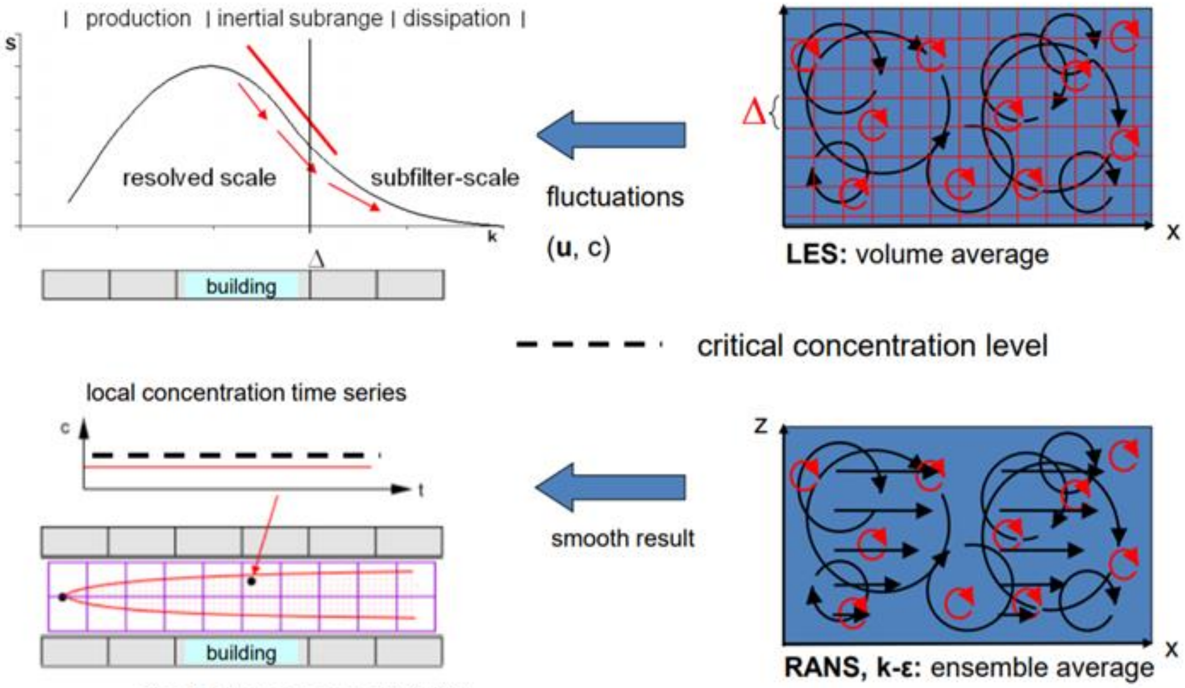


Figure 13 – Bořislavka and Dejvice Center scenario.

6. Environmental model

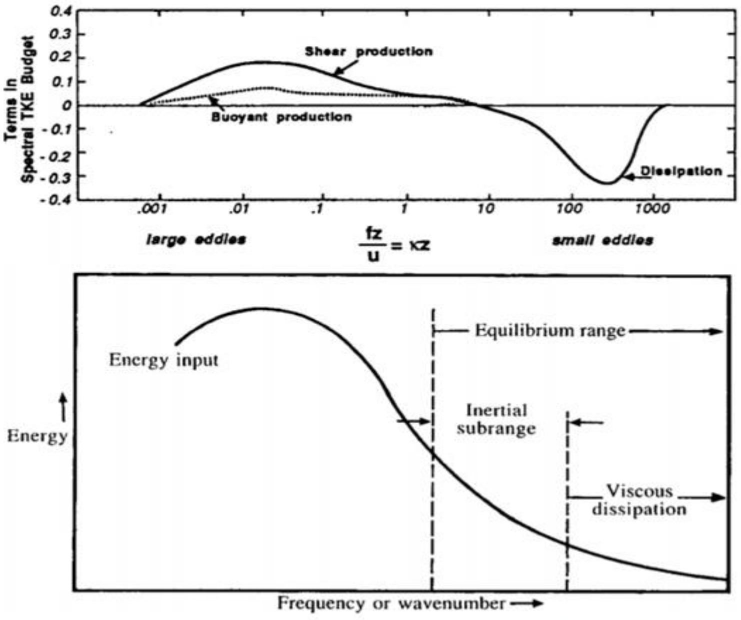
6.1. PALM modelling system

PALM is an advanced and modern meteorological model system for atmospheric and oceanic boundary-layer flows, originally Raasch & Schröter [50] in 2001, recently Maronga et al. [47, 48]. It has been developed as a turbulence-resolving large-eddy simulation (LES) model that is especially designed for performing on massively parallel computer architectures. The model PALM is based on the non-hydrostatic, filtered, incompressible Navier-Stokes equations in Boussinesq-approximated form (an anelastic approximation is available as an option for simulating deep convection). For basic principles of LES and the role of turbulence see Figures 14 and 15, for equations see Figure 27 in Appendix 2. Since PALM 5.0, the model contains several components for urban applications, named PALM-4U (PALM for urban applications). PALM-4U allows the use of the model for various urban applications ranging from the environmental meso- to the microscale. However, from a technical point of view, PALM-4U are special components that have been developed to suit the needs of modern academic urban boundary layer research and practical city planning related to the urban microclimate and climate change. Most important modules in PALM-4U for urban application are radiative transfer model (RTM; see Krč et al. [46]) and Building Surface Model (BSM, formerly USM; see Resler et al. [51]). Both of these modules have been designed and developed, in cooperation with developers in Germany, by a team of the Institute of Computer Science of the Czech Academy of Sciences ICS CAS. For example, of a simulation of street canyon with and without BSM (or USM that time) see Figure 28 in Appendix2. More information about the PALM modelling system is available at the project website (https://palm.muk.uni-hannover.de/trac; PALM-4U: https://palm.muk.uni-hannover.de/trac/wiki/palm4u).



after Schatzmann and Leitl (2001)

Figure 14 - Large-Eddy Simulation: basic principles (PALM 2020 tutorial [55])



Stull (1988); Garratt (1992)

Figure 15 - Large-Eddy Simulation fundamentals: The role of turbulence (PALM 2020 tutorial [55])

6.2. Simulation flowchart

Simulation structure and its integration to the entire project is displayed using flowchart diagram on Figure 16. Central gray segment is the PALM modelling system without any special modification due to the current TAČR - NCK; for a simplified PALM flowchart see Figure 25 and for PALM-4U components see Figure 26, both in Appendix 2. Light orange components (in Figure 16) are the data drivers and the pre-processing module which have been modified for environmental simulation of the project scenarios and domain. Green components are brand new parts of the software, just created for the project: new post-processing with its visualization and KPIs submodules and API server created by the environmental team for project integration. Dotted white segments correspond to other project work packages (WPs).

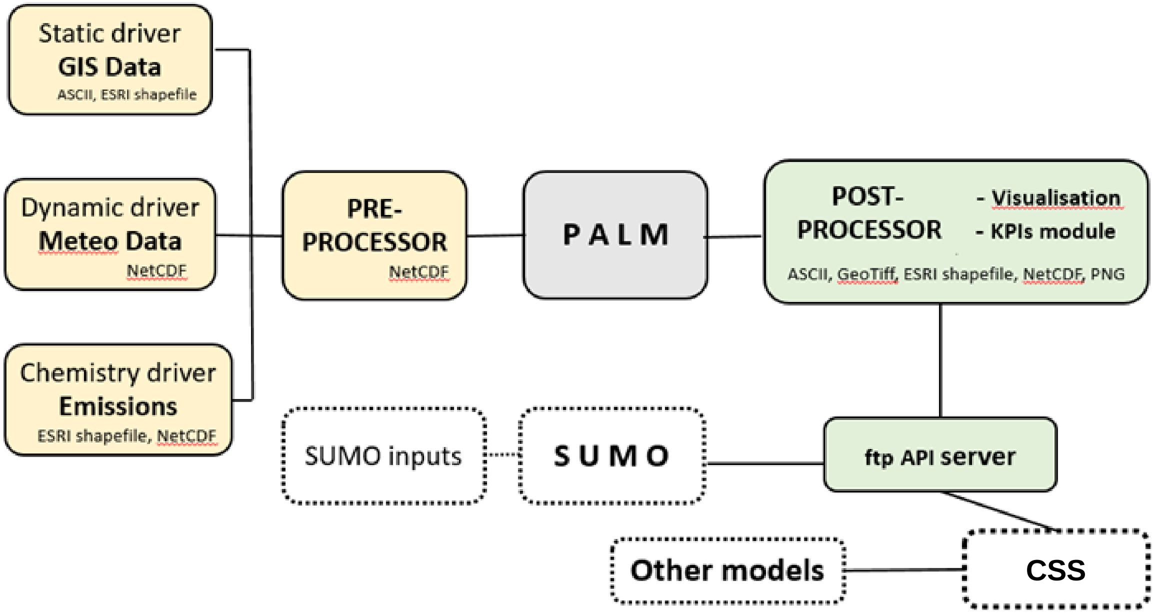


Figure 16 - Simulation and project flowchart

6.3. Study area

The study area is located in the north-west part of the center of Prague, capital city of the Czech Republic (Figure 17). The model was configured in two nested domains. The outer/parent domain measures 6,048 × 3,600 m, height approx. 3,000 m, at a spatial resolution of 12 m with the vertical stretching from 250 m to 24 m. The purpose of such a domain is to allow proper simulation of turbulent flow including convection effects and description of the orography of the area. The parent domain includes highly complex terrain in its north-west and south-west parts. The nested child simulation domain, used for the next analysis, has the horizontal extent of 3,360 × 1,440 m, height 250 m, at its spatial resolution is 3 m. Its purpose is to model the area of interest at a resolution that permits representation of the processes in city landscape including street canyons. The child domain may be described as a densely built-up area with specific urban conditions created by a Evropská boulevard. The east domain border is close to the traffic circle (Vítězné náměstí), the west border is close to the new administrative Bořislavka centre.

The simulation with current status of modelled domain will be marked as a “base case” simulation (or “base case” only). For the following analysis provided by the rest of our project team the term “Zero scenario” is usually used.

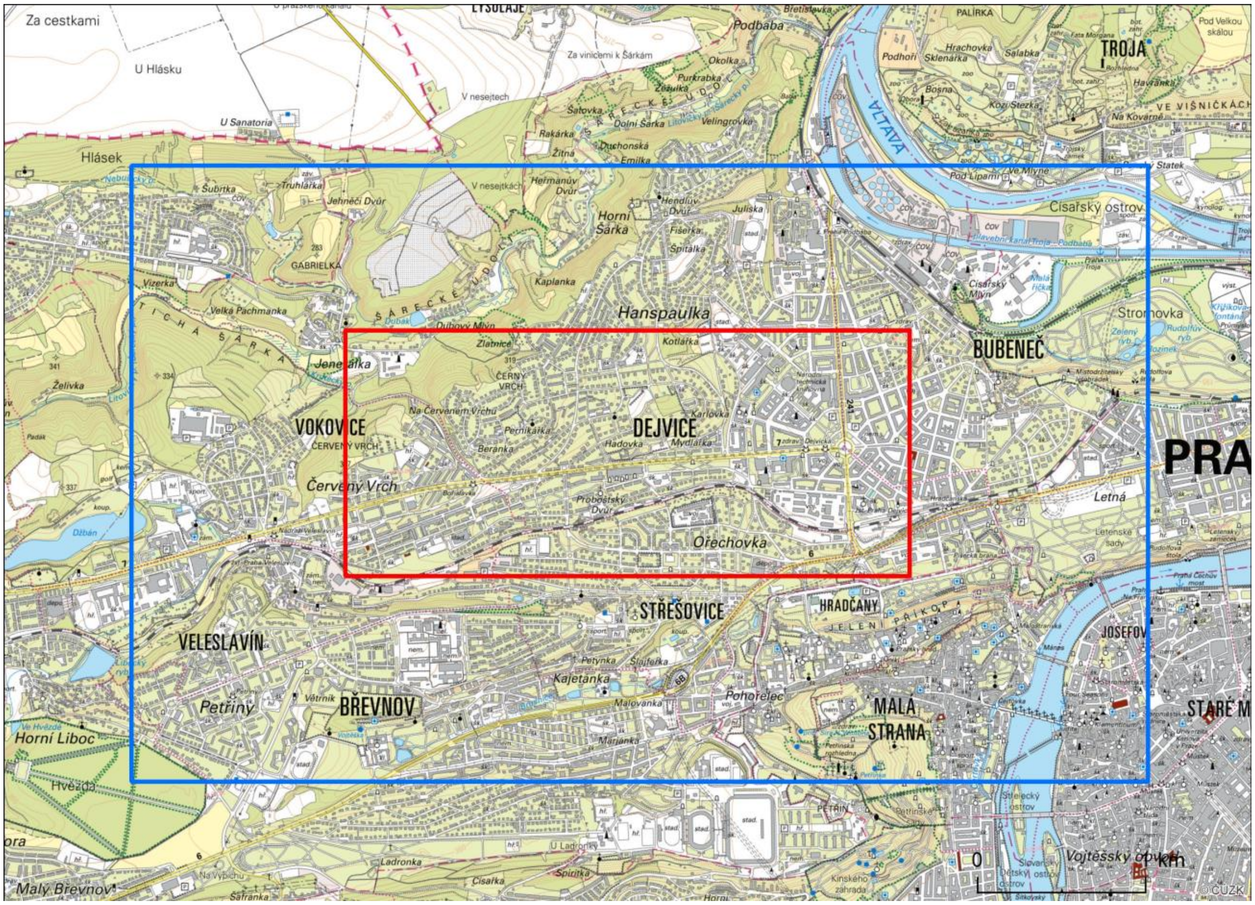


Figure 17 - Location of the parent (blue) and child (red) domains in Prague-Dejvice

6.4. Scenarios

Beside the base case simulation several scenarios were simulated. Each scenario was discussed in detail; final selection was based on the current pandemic situation in combination with planned developer projects. In total, 5 scenarios were approved.

For each of the project scenarios (Zero, Kulaťák, Sekyra building, Bořislavka centre, Quarantine case and General scenario) input data have been prepared. most of these modifications were implemented to the static driver. Simulations have been set up, tuned and performed and results obtained for any of the scenarios.

1) Zero scenario

This scenario simulates a current situation in the domain defined below. It is the “base case” for described PALM simulations.

2) Sekyra building

This scenario includes two new buildings on the Vítězné náměstí; a new building of CIIRC (it was already built) and planned Sekyra building. Input data for a scenario were provided by the Institute of planning and development of Prague.

3) Kulaťák

The Kulaťák scenario contains a planned complete reconstruction of the square Vítězné náměstí and with a new transport bypass KES near the current railway. Same as for the previous scenario, data were provided by the Institute of planning and development of Prague.

4) Bořislavka Centre

Third scenario is focused on the new complex of administrative buildings near Bořislavka tube station. The project documentation was not freely available, so data were processed using visualization by ICS CAS.

5) Quarantine case

Fourth scenario is dealing with decrease of emission concentration during the Spring 2020 COVID-19 quarantine. Detailed description of emission data corrections is below.

- point emission sources - decrease about 40 % (smaller plants and companies were closed, larger ones were limited, but not closed);
- main roads - decrease about 55 % (people drive less, but not so much, because of shopping; other roads are mostly in populated areas, so we gave up to commute to work and to the family, otherwise it is based on main roads);
- other roads - decrease about 65 % (similar to the above, only one is a larger street, so the fee is reduced by limited public transport, transport to work from suburban areas and transportation; probably one of the most accurate estimates);
- road in tunnel - decrease about 65 % (based on an estimate from Blanka tunnel complex);
- water traffic - decrease about 85 % (during the COVID-19 pandemic all boats stay in marines, except houseboats and recreational craft);
- railway traffic - decrease about 22 % (estimate based on limited public transport and cancelled train connections);
- local building heating - increase about o 12 % (it is an estimate according to the supplied amount of energy; total supply = industry + households; overall, consumption was lower

due to subdued industry, but household consumption increased because there were more people at home - an estimated increase is 10-15 %).

List of websites used for emission modification is in Appendix 1.

6) The General scenario

Last scenario, The General scenario, is a combination of cases 2-5 together. Modification of emissions in the new bypass were problematic, as a result estimated values multiplied by factor from the 4th scenario were applied.

6.5. Input data

Input data for a PALM were defined using PALM Input Data Standard (PIDS) “drivers” (for more details see https://palm.muk.uni-hannover.de/trac/wiki/doc/app/iofiles/pids). Basically, drivers contain all information about the modelled domain. Those drivers were processed using an input data pre-processor developed on ICS CAS. More detailed description of used drivers is in the following paragraphs.

1) Static driver

BSM and LSM require the input of a number of material input parameters to resolve the energy balance equations. These parameters provide details of the surface in terms of albedo, emissivity, roughness length, thermal conductivity, and capacity of the skin layer, and volume in terms of thermal capacity and volumetric thermal conductivity. Similarly, RTM requires detailed descriptions of the albedo and emissivity of surfaces. When operating at the high resolution involved in the test case herein (3 m), ground surfaces and the nature of walls and roofing materials become very heterogeneous. Any bulk parameter setting would therefore be inadequate. Detailed settings of these parameters, wherever possible, were the only option. To obtain these data, a supplementary, on-site data collection campaign was conducted to create a database of fine geospatial data. This included information concerning wall, ground, and roof materials, colours, roughness, and window fraction, which were used to estimate surface and material properties. Each surface was described in terms of material category, albedo, and emissivity. Categories were assigned parameters estimated on the basis of surface and storage material composition and thickness. Parameters of LSM surface layers were assigned according to the properties of the corresponding PALM LSM category. BSM materials utilized a special set of categories and their parameters; the first two layers were inferred from the properties of the material near the surface, which may differ from the rest of the volume.

Moreover, each tree was described by its position and vertically-stratified leaf-area density (LAD). The trunk and crown were measured separately; estimated perimeters and heights were available for each tree, while crowns were categorized by shape. LAD decreases towards the center of the crown as a result of the higher branches-to-leaves ratio that occurs there due to the decreased solar radiation available.

Building heights were available from the Prague 3D model, maintained by the Prague Institute of Planning and Development. All descriptions of surfaces, materials, trees, and their properties were collected in GIS formats and then pre-processed into the PALM-4U input files (according to the PALM input data standard) corresponding to the particular domain set-up.

2) Chemistry driver

Air pollution sources for our particular case are dominated by the local road traffic. Annual emissions totals were based on the traffic census 2016 conducted by the Technical Administration of Roads of the City of Prague – Department of Transportation Engineering (TSK-ÚDI). Emissions itself were prepared by ATEM (Studio of ecological models; http://www.atem.cz) using MEFA 13 model. Emissions from streets not included in the census were available in a grid with 500m spatial resolution. These emissions were distributed between the streets not covered by the census according to their parameters. Particulate matter (PM) emissions included resuspension of dust from the road surface. Time disaggregation was calculated using a Prague 2018 transportation yearbook (TSK-ÚDI [57]) and public bus timetables. This time disaggregation was the same for the primary emissions (exhaust, brake wear etc.) as well as for resuspended dust.

Traffic data were supplemented by emissions from stationary sources from the Czech national inventory REZZO: point sources correspond to the year 2017 [56] (the latest year available at the time of model input preparation). Residential heating was based on 2017 inventory and rescaled to 2018 multiplying by the ratio of degree days DD(2018)/DD(2017); DD(r) is the sum of the differences between the reference indoor temperature and the average daily outdoor temperature on heating days. Residential heating emissions were available on elemental dwelling units - urban areas with average area 0.5 km^2, and were spatially distributed to building addresses, where local heating source is registered, proportionally to the number of flats. Time disaggregation of point source emissions was based on monthly, day-of-week and hour-of-day factors (Builtjes et al.,[38] available also in Denier van der Gon et al. [39]). Residential heating emissions were distributed to days according to the standardized load profile of natural gas supply for the households, which use it for heating only (Novák et al. [49]). Daily variation of residential heating emissions was taken from Builtjes et al. [38].

3) Dynamic driver

The dynamic input data contain the primary source of boundary meteorological conditions from regional models. Initial and boundary meteorological conditions for the parent domain of the PALM simulations were obtained from the WRF model (Skamarock et al., [53]), version 4.0.3. The WRF model was run on three nested domains with horizontal resolutions of 9 km, 3 km and 1 km and 49 vertical levels. The inner domain has 84 × 84 grid points in the horizontal direction. The configuration was standard but parameterizations have been chosen so as to decrease possible discrepancies which might arise from boundary conditions.

Air quality simulations that served as chemical initial and boundary conditions were conducted using the chemistry transport model (CTM) CAMx version 6.50 (ENVIRON [41]).

WRF and CAMx outputs were then post processed to the PALM dynamic and chemistry driver. The data were transformed between coordinate systems and a horizontal and vertical interpolation was applied. As the coarse-resolution model terrain would not match the PALM model terrain exactly, the vertical interpolation method included terrain matching and the atmospheric column above the terrain was gradually stretched following the WRF hybrid vertical levels as they were converted to the fixed vertical coordinates of the PALM model. The interpolated airflow was adjusted to enforce the mass conservation.

Emission data for Prague used in the CAMx model were the same as described in the next chapter. Other emission inputs are described in detail in Ďoubalová et al. [40].

6.6. PALM set-up

PALM model system version 6.0 revision 4508 [48] was utilized for this validation study. It consists of the PALM model core and embedded modules and of PALM-4U components which have been specifically developed for modelling urban environments. The following urban canopy related PALM and PALM-4U modules were employed in this study: the land surface model (LSM, Gehrke et al [44]; to be submitted to GMD) was utilized to solve the energy balance over pavements, water- and other natural-like surfaces, the building surface model (BSM, formerly USM, see Resler et al. [51] from 2017) was used to solve the energy balance of building surfaces (walls and roofs). The BSM was configured to utilize an integrated support for modelling of fractional surfaces (Maronga et al. [48]). Dynamic and thermodynamic processes caused by resolved trees and shrubs were managed by the embedded plant-canopy model (PCM). Radiation interaction between resolved scale vegetation, land-surface, and building surfaces was modelled via the radiative transfer model (RTM, Krč et al. [46]; submitted to GMD, in review). Down-welling shortwave and longwave radiation from the upper parts of the atmosphere, which were used as boundary conditions for the RTM, were explicitly prescribed from stand-alone Weather Research and Forecasting model (WRF; see Sect. with dynamic driver description) simulation output for the respective days rather than modelled by e.g. the Rapid Radiation Transfer Model for Global Models (RRTMG). This way, effects of mid- and high-altitude clouds on the radiation balance were considered in the simulations. It is needed to note that without applying the RRTMG some physical processes such as vertical divergence of radiation fluxes leading to heating / cooling of the air column itself were missed, which may become especially important at night time. However, sensitivity tests with RRTMG applied revealed that the effect on night time air temperature was negligible in our simulations. In addition to the meteorological component, the embedded online chemistry model (Khan et al. [45]; to be submitted to GMD) was applied to model concentrations of NO_X, PM_{10}, and $PM_{2.5}$. Chemical reactions were omitted in this case to simulate purely passive transport of the pollutants. For a human thermal comfort estimation, the PALM biometeorological module (Fröhlich and Matzarakis [42]) was used.

This project does not include campaigns for collecting of the observations suitable for direct validation of the modelling results. From that reason, the general design of the simulations including their configuration and input data preparation followed the methods and approaches developed and validated inside the Dejvice validation campaign (see Resler et al.[52], submitted to GMD, in review). As the general configurations of the simulations follow similar principles and the domains cover similar type of the urban canopy, it ensures that the simulations done here provide reasonable and reliable results suitable for assessment of environmental impacts of the studied adaptations.

PALM simulations have high computer time requirements. To enable this, parallel computation is used for such simulations; 880 processor cores have been used for PALM simulation of any of the project scenarios. All simulations were performed on the available ICS CAS in-house HPC infrastructure, in particular, the simulation of the PALM model utilized the resources of the cluster Ariel. Despite this powerful parallel computation, the necessary computation time is 1-5 times larger, than is the simulated time. The simulation time is not constant, it variates during the simulated period. It also depends on the meteorological situation of the simulated period. In average, every 24-hours simulation of any scenario took about 2-3 days' computation time for simulation, not including preparation runs and calibration of PALM to the specific scenarios.

6.7. Result processing

The model outputs are given in the form of net cdf binary files with respect of PALM output data standard (for more details see https://palm.muk.uni-hannover.de/trac/wiki/doc/app/runtime_parameters). These files were processed to the form of outputs intended for presentation; maps and animations. ICS CAS provided following variables for further analysis:

- Universal Thermal Climate Index (UTCI);
- $PM_{2.5}$ concentrations;
- PM_{10} concentration;
- Nitric oxide (NO) concentration;
- Nitrogen dioxide (NO_2) concentration;
- Tropospheric ozone (O_3) concentration.

Maps were exported for each time step during the entire 24 - hour simulation time period. Considering the 10-minutes time step thus there are 144 images for each variable listed above.

We have to distinguish, here, road traffic emissions just on the place where they are produced; thus road lanes of roads in the child domain, same as the pollutant concentrations including other traffic emissions (railway, ships and boats, tunnel upcast emissions etc.) from the parent domain.

Moreover, in both domains existing other emission sources: local heating, local emission sources (small plants or companies, large parking lots etc.). All these source emissions are affected and formed by the terrain, city thermal convection, vertical shape of landscape, plant canopy, and of course wind and other simulated air flows. Resulting concentrations, same as their effect, are finally spatially spread over the entire area, mainly but not only close to principal roads and sidewalks along them, but also to streets in living areas and to urban greenery (parks, yards, gardens etc.).

Modelling results can be presented with the following example; newly planted trees have a significant effect on UTCI values. Suggested position and parameters (height, crown size, type of tree etc.) of trees in Vítězné náměstí plays an important role in future mitigation of thermal discomfort. As we can see on Figure 18, in the night-time trees mitigating slightly the thermal discomfort. In the morning phase, which is represented by Figure in the middle, is the mitigating effect of trees higher. Moreover, in noon and early-afternoon time mitigation effect reaches maxima; UTCI differences between squares with and without trees can reach up to 10 °C during summer heatwave. Alternatively, we can see the same effect on differential images, where blue colour shows temperature decreasing, while red colour temperature increasing in comparison with the base case, and white colour shows no difference, see Figure 19. In both the image versions we can see that added trees keep warm after sunset and during night, while cold during sunny and hot days.

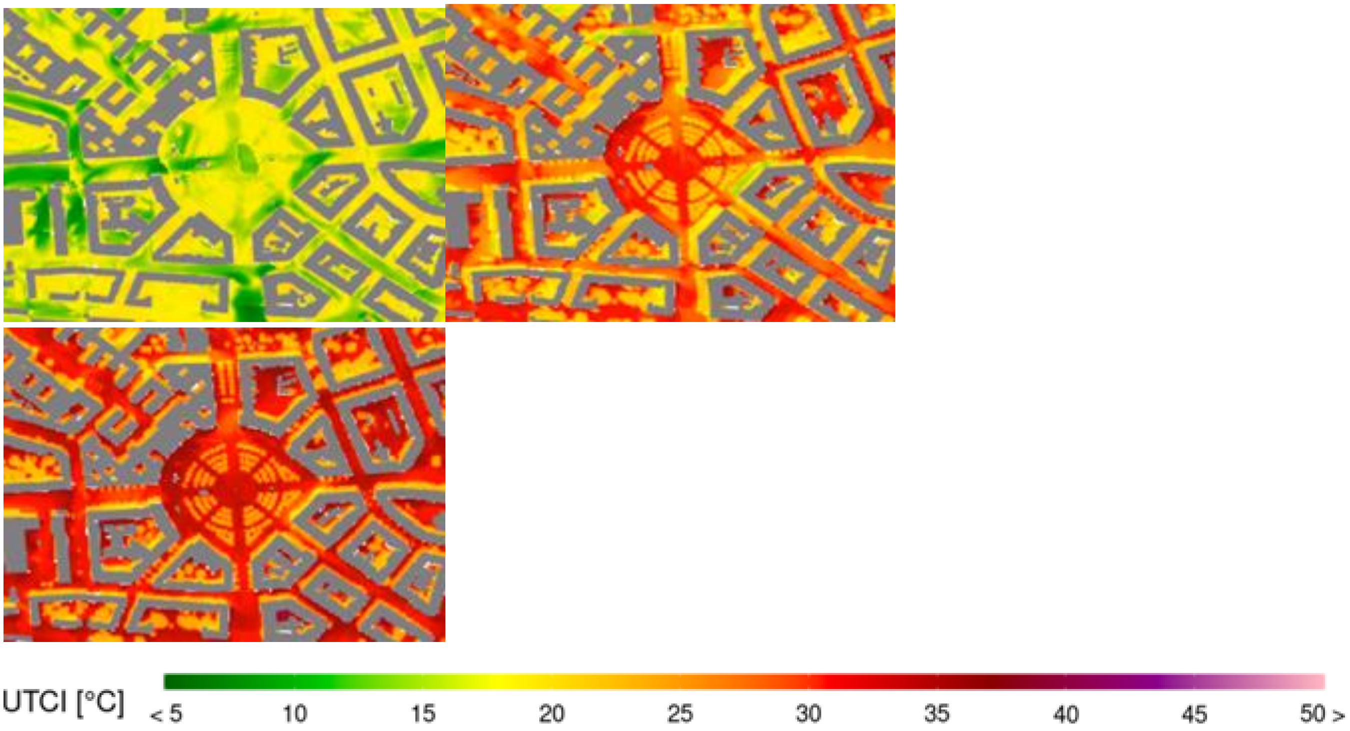


Figure 18 - Thermal accumulation kept by plant canopy; screenshots from General Scenario, UTCI, time 01:30, 8:30 and 10:30, absolute temperatures.

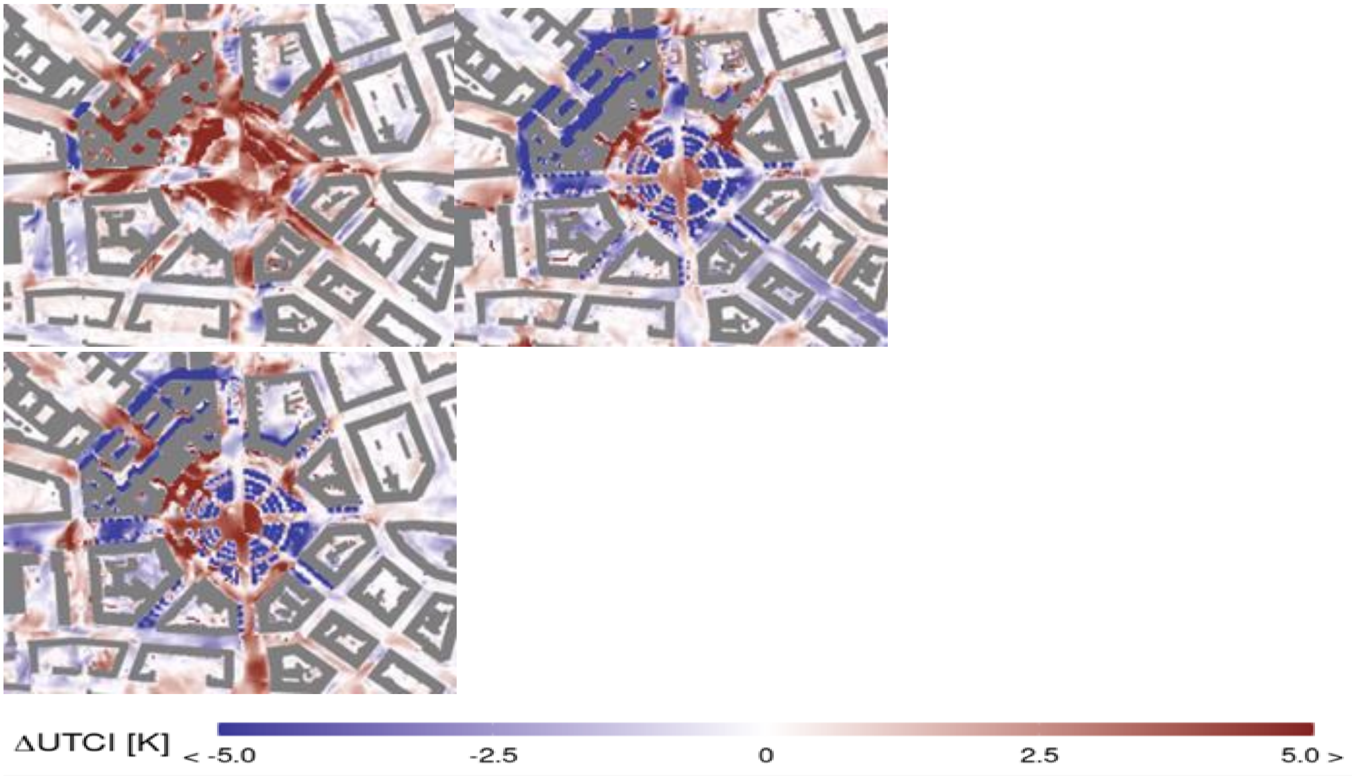


Figure 19 - Thermal accumulation kept by plant canopy; screenshots from General Scenario, UTCI, time 01:30, 8:30 and 10:30, thermal differences in comparison with the basecase.

However, it is important to analyze urban structures as a complex system. It can be demonstrated in the following example; Figure 20 shows absolute values of concentration of PM_{10} from the planned bypass of Vítězné náměstí (see description of KES and Vítězné náměstí). For analogous differential values, see Figure 21. The combination of densely planted street and heavy transport can increase another one (usually completely different or opposite) parameter. Planted trees will mitigate thermal discomfort on pavements near new road with heavy transport. On the other hand, an increase of PM_{10} concentrations probably will have a more important impact on human health. Not only close the road, but also in nearby surroundings.

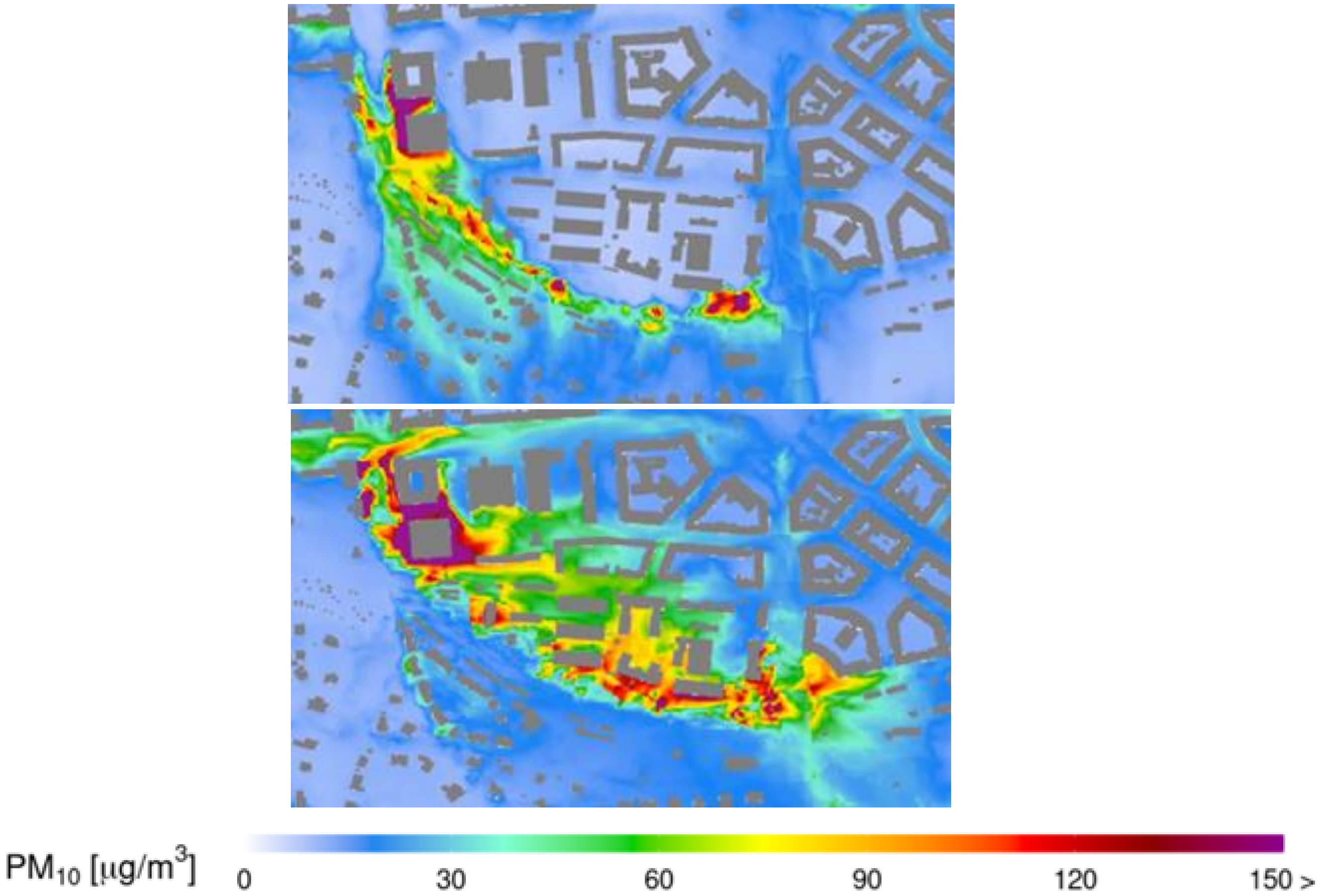


Figure 20 - Wind effect to PM10 concentration; screenshots from Kulaťák scenario, PM10, time 19:00 and 20:00, absolute concentrations values.

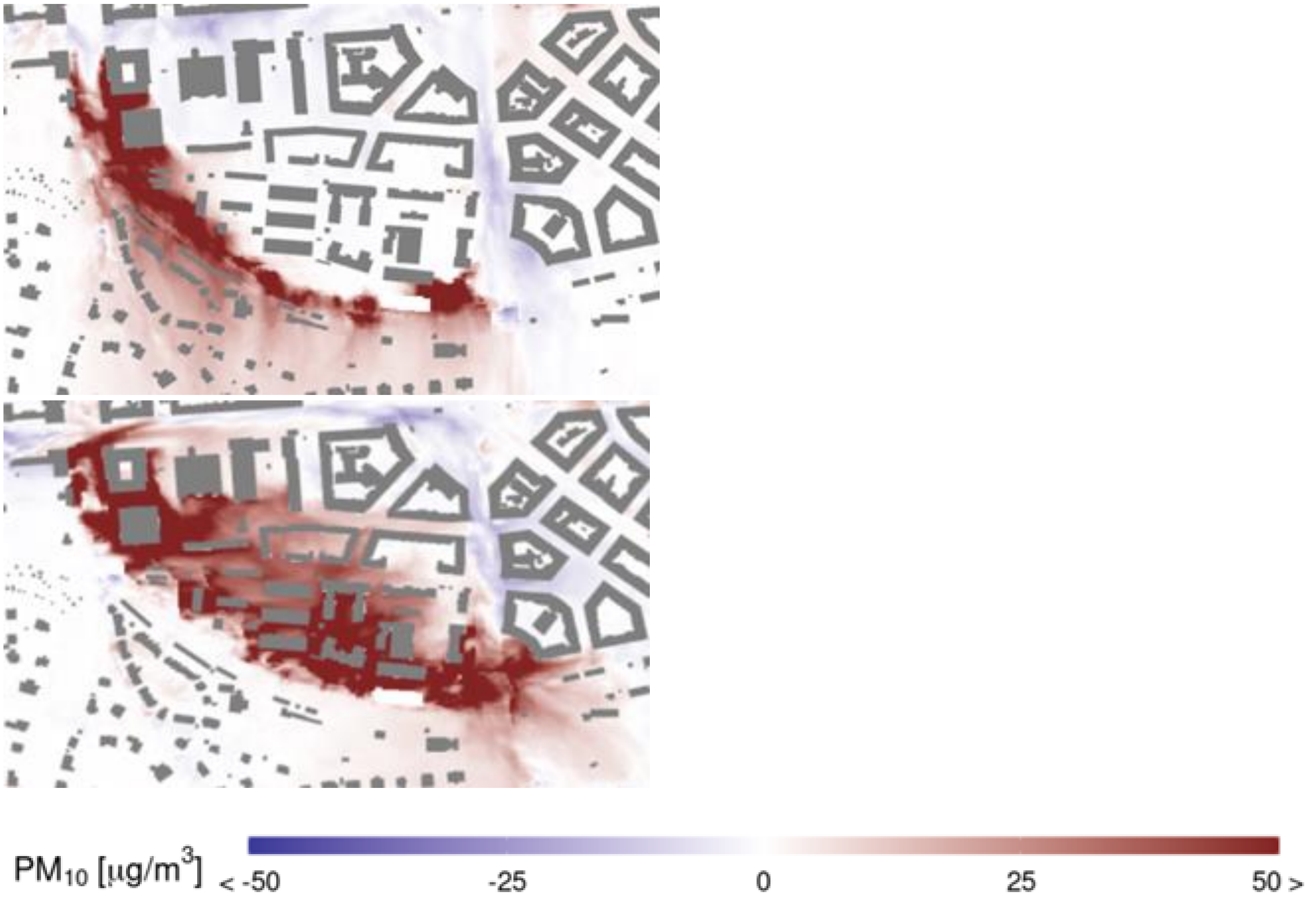
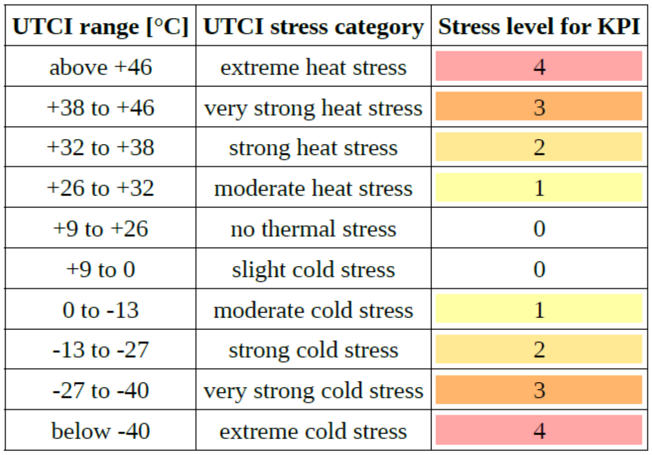


Figure 21 - Wind effect to PM10 concentration; screenshots from Kulaťák scenario, PM10, time 19:00 and 20:00, differential concentration values.

6.8. Environmental Local KPIs

6.8.1. Description of Local KPIs

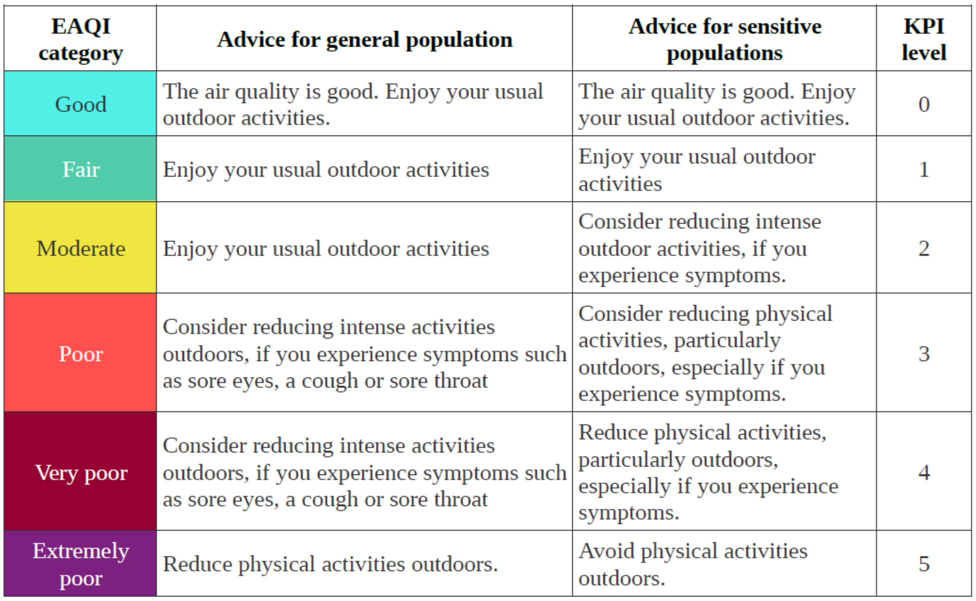
There are two KPIs: thermal comfort which correspond to the Universal Thermal Climate Index (UTCI) and air quality which is aggregated from particular resulting concentrations. Thermal comfort has six degrees of thermal cold and heat stresses (no, slight, moderate, strong, very strong and extreme), with five numeric values from 0 to 4, see the following table:



UTCI range [°C]	UTCI stress category	Stress level for KPI
above +46	extreme heat stress	4
+38 to +46	very strong heat stress	3
+32 to +38	strong heat stress	2
+26 to +32	moderate heat stress	1
+9 to +26	no thermal stress	0
+9 to 0	slight cold stress	0
0 to -13	moderate cold stress	1
-13 to -27	strong cold stress	2
-27 to -40	very strong cold stress	3
below -40	extreme cold stress	4

Table 8 Universal Thermal Climate Index (UTCI)

For air quality we use the European Air Quality Index (EAQI, see https://www.eea.europa.eu/themes/air/air-quality-index) as defined by the European Environment Agency (http://www.eea.europa.eu/), which is a successor to the Common Air Quality Index (CAQI). The EAQI specifies six index categories for each pollutant. For each category, we assign a level for the purpose of KPI calculation via spatial and temporal aggregation. For each point in time and space, we take the PM$_{2.5}$, PM$_{10}$, NO$_2$ and O$_3$ concentrations and we select the maximal degree for these pollutant concentrations. There are six EAQI categories (good, fair, moderate, poor, very poor, extremely poor, with six numeric values from 0 to 5. See the Table 9:



EAQI category	Advice for general population	Advice for sensitive populations	KPI level
Good	The air quality is good. Enjoy your usual outdoor activities.	The air quality is good. Enjoy your usual outdoor activities.	0
Fair	Enjoy your usual outdoor activities	Enjoy your usual outdoor activities	1
Moderate	Enjoy your usual outdoor activities	Consider reducing intense outdoor activities, if you experience symptoms.	2
Poor	Consider reducing intense activities outdoors, if you experience symptoms such as sore eyes, a cough or sore throat	Consider reducing physical activities, particularly outdoors, especially if you experience symptoms.	3
Very poor	Consider reducing intense activities outdoors, if you experience symptoms such as sore eyes, a cough or sore throat	Reduce physical activities, particularly outdoors, especially if you experience symptoms.	4
Extremely poor	Reduce physical activities outdoors.	Avoid physical activities outdoors.	5

Table 9 European Air Quality Index (EAQI)

Data for local KPIs were provided using NCK PALM data API (see below).

6.8.2. Spatial and temporal aggregation

For each scenario, we take the spatial and temporal average of the calculated KPI levels. The spatial averaging is performed uniformly for the pavements and roads of the Evropská domain environmental KPI area, same for all scenarios, see Figure 22. The area covers Evropská boulevard up to Bořislavka Metro Station, street Jugoslávských partyzánů up to square Náměstí Interbrigády and Vítězné náměstí including the area in the direction to Šolínova street (Sekyra building area).

The temporal averaging is uniform for the whole duration of the simulation of each scenario.

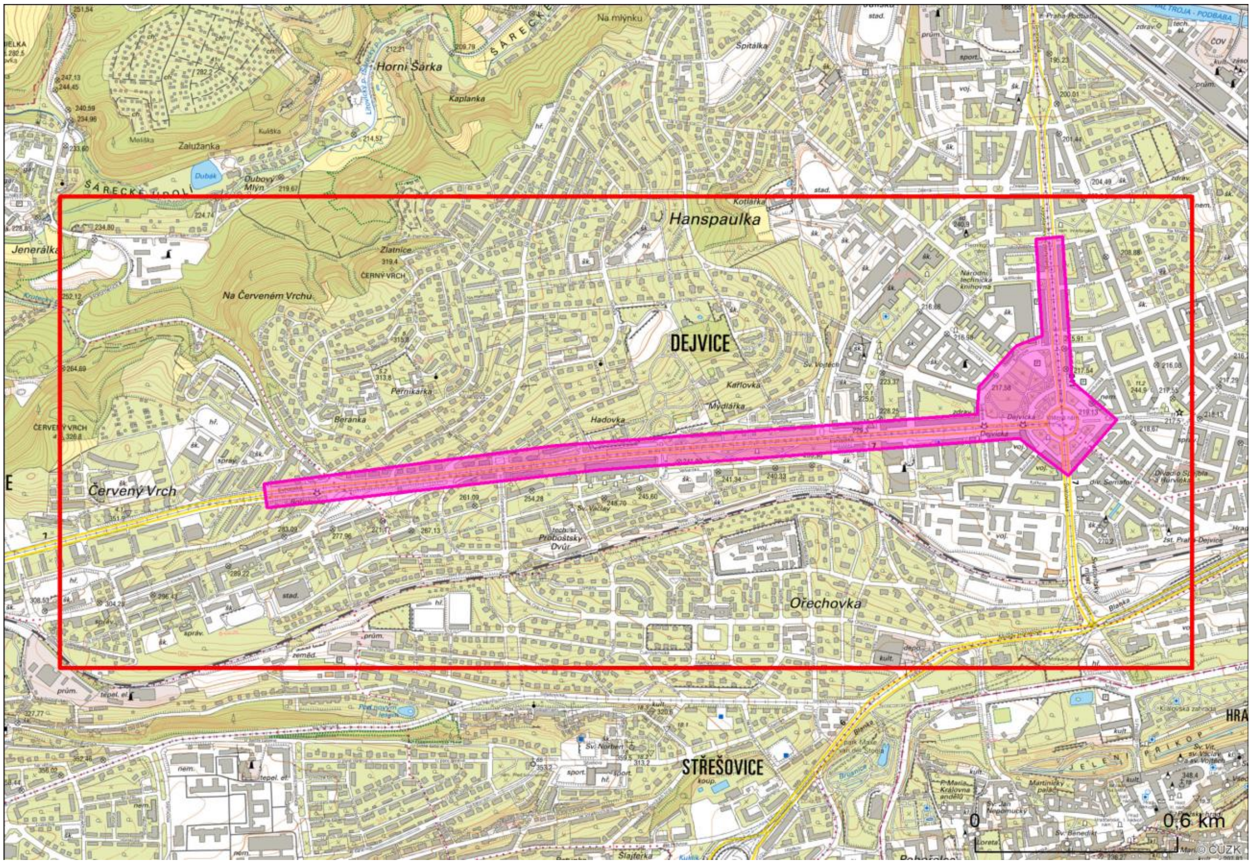


Figure 22 - Evropská domain environmental KPI area within child simulation domain

6.9. NCK PALM data API

The API resides at base URL “https://ftp5.cs.cas.cz/nck-api/”. Only HTTPS is supported, using unencrypted HTTP returns an error. Authentication is provided using basic HTTP authentication. For the purpose of the NCK project, the username is “nck” and the password will be provided separately for interested team members. The HTTPS server supports directory listings.

For each scenario, the metadata including KPIs is provided in a JSON file at URL “/scenario/metadata.json”, where scenario is the scenario name. The file contains a description of the scenario, list of available variables and KPI values. If the scenario is related to a specific base case, the name of the base case is also provided. There are two global KPIs: Thermal comfort and Air quality. Thermal comfort KPI values are provided as floating point numbers in range [0,4]. For display in percent, the value has to be multiplied by 25 %. Analogously Air quality values in range [0,5] has to be multiplied by 20 to obtain value in percent / in range [0,100] as it is in the case of other project WPs (work packages). An example of the metadata file follows:

```
{"scenario": {
                "name": "kulatak-scen01",
                "desc": "Vítězné náměstí (scen01)",
                "generated": "2020-07-19T21:22:22Z",
                "variables": [
                        {
                                "name": "bio_pet",
                                "abbr": "PET",
                                "unit": "°C",
                                "desc": "Physiologically equivalent temperature"
                        }
                ],
                "basecase": "kulatak-base"
        },
        "kpi_global": [
                {
                        "name": "Thermal comfort",
                        "value": 0.8
                },
                {
                        "name": "Air quality",
                        "value": 0.9
                }
        ]
}
```

6.10. Static map images

Static images of variable values are available at URL “/scenario/img/variable/t###.png”, where scenario is the scenario name, variable is the variable name and t### is the timestep (starting with t001). For scenarios which are related to a specific base case, the images with differences of variable values relative to the base case scenario are available at URL “/scenario/img_diff/variable/t###.png”.

6.11. Animated maps

The animated maps are available at URLs: “/scenario/anim/variable.png” and “/scenario/anim_diff/variable.png”, where scenario is the scenario name and variable is the variable name. The second form is available only for scenarios related to a specific base case.

7. Digital ecosystem of smart services.

The general idea of CSS for modeling, planning and strategic assessment of urban areas is to create the very first model of the SmartCity by the combination of different microsimulation models. The main purpose of CSS is to show the real situation in the city and model (f.e. in VR) the reaction of the city for different disturbing impacts and try to check the system stability. The second phase of the project is more concerned with creating the framework resilient by design. We want to answer the question of how to create the Smart City framework with resilient and sustainable properties.

To solve this task, we describe the Smart city system as a large scale networked application composed of the functionally similar elements:

- “Task” (demand, order, request for services) incoming from any entity within the system or external world;
- “Resource” as the particular entity or product of the smart city services (taxi, parking spot, a table in the restaurant, etc.);
- “Data source” as the basic telemetry data (sensor, GPS, cloud data, etc.);
- “Software” for supporting platform operation.

The basic approach to support the new Smart City framework is to achieve the interaction of all tasks and resources. This means that every problem solved by Smart City can be described as a combination of resource and demand interactions (RD service model). Practically, we can simulate different city sectors as it is shown in Fig.23 using different simulation software for transport, energy, land use, environment, or other segments.

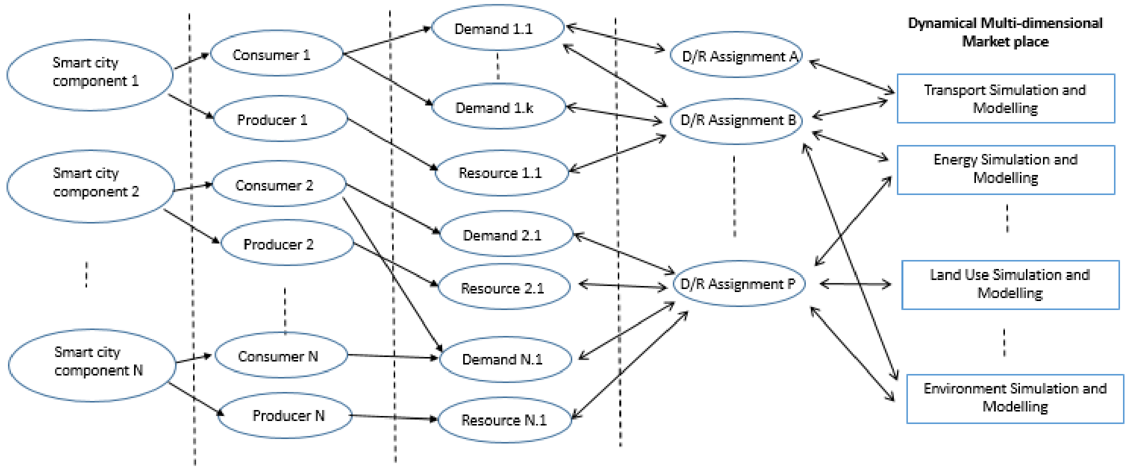


Figure 23 - RD model

Each technical component (building, street light, charging station, etc.) or different users (citizen, municipality, group of people) requires limited resources (energy, transport, parking slot, land, etc.) in a given time interval *t*. We can call them dynamical demand requirements. This means we need to make a plan for all entities.

To solve this task, we use multiagent technologies where all requirements and resources are represented by Demand Agents and Resource Agents which can negotiate among themselves.

In multiagent systems, we can organize negotiations among demand agents through different modeling and simulation tools [35]. Each model (transportation, energy, environment, etc.) plays the role of "dynamical digital RD market place" with limited time-varying resources. Different demand agents negotiate in each time interval to capture requested resources.

Our approach to a smart city is like puzzles of different pieces (urban areas) which could be assembled into higher urban units like districts or whole cities. Negotiation among Demand agents with the city simulation model will yield into dynamical resources assignments represented by Resources agents that offer the best possible service to each consumer. In case one consumer does not accept the assigned resources it must change their demands. The negotiation can be repeated once again under new conditions.

The resulting approach as a user interface between aggregated demand agents assigned into different smart city components and aggregated urban sustainability parameters (economic, environmental and social) is represented by a plan. The decision-makers, typically municipality, should specify the sustainability parameters (KPIs) for the whole urban area. The demand and resource agents mutually negotiate with a city simulation model to propose to each smart city component the reduced comfort to fulfill the requested KPI.

We use RD service architecture to combine requests and resources, as well as a multiagent technologies to create a work plan (to satisfy all the demands with limited resources), so every match of the resource and demand will have their time slot. From this perspective, the Smart City is becoming a resource and demand model which advanced by agents, satisfaction functions and bonus-penalties and compensations. This model and technology allow rebuilt a plan in real-time. In the case of unpredictable events, we can reschedule the emergency services, governmental services, and other services. This already gives a first but important profile for Smart City resilience. If the rescheduling process can be maintained automatically we can say that this architecture is resilient by design (Fig. 24).

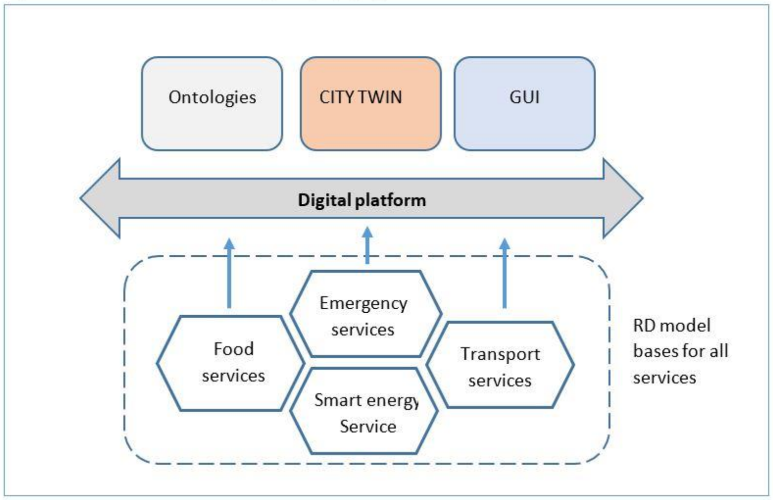


Figure 24 - New Smart City framework

The second profile of Smart City resilience can be a model of different “what if” scenarios of city development. The MAT can provide hundreds of different variants according to the set of different KPIs.

Different systems on the top of the proposed framework will provide additional services (AI, Knowledge Bases, Blockchain, and other instruments) [36]. It will help to achieve the third and the most complicated profile of Smart City resilience. The system based on stored knowledge and AI can provide new, not predefined in any mode and modeled beforehand solutions. Creating new links between entities in predefined knowledge base the system can offer to use hotels like hospitals, mobile field services teams can be used for emergencies and managing of volunteers, taxi to deliver injured people.

Acknowledgment

The project was supported by the Technology Agency of the Czech Republic (TACR), National Competence Center of Cybernetics and Artificial Intelligence, TN01000024.

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Appendix 1

List of website sources for emission calculation during Spring-time COVID-19 closure

- https://www.czso.cz/csu/czso/katalog-produktu?filtr=true&roky=2020&skupiny=03,35,15
- https://www.cnb.cz/cs/o_cnb/cnblog/Prvni-odhad-dopadu-pandemie-COVID-19-na-ekonomiku-CR/
- https://chmibrno.org/blog/2020/03/24/koncentrace-no2-behem-karanteny-v-ceske-republice-druzicove-snimky-a-stanicni-data/
- https://www.irozhlas.cz/zpravy-domov/praha-doprava-mhd-mene-aut-koronavirus_2003271752_cen
- https://zdopravy.cz/doprava-v-praze-klesla-kvuli-boji-s-koronavirem-o-pet-procent-nejvice-na-evropske-45204/
- https://pid.cz/pokles-prepravenych-cestujicich-temer-tri-ctvrtiny-rust-poctu-zamestnancu-karantene-mhmp-dpp-ropid-proto-prazske-mhd-zavadi-prazdninovy-jizdni-rad/
- https://faei.cz/covidova-karantena-zvedla-domacnostem-ucty-za-proud-o-tisice-korun/

Appendix 2

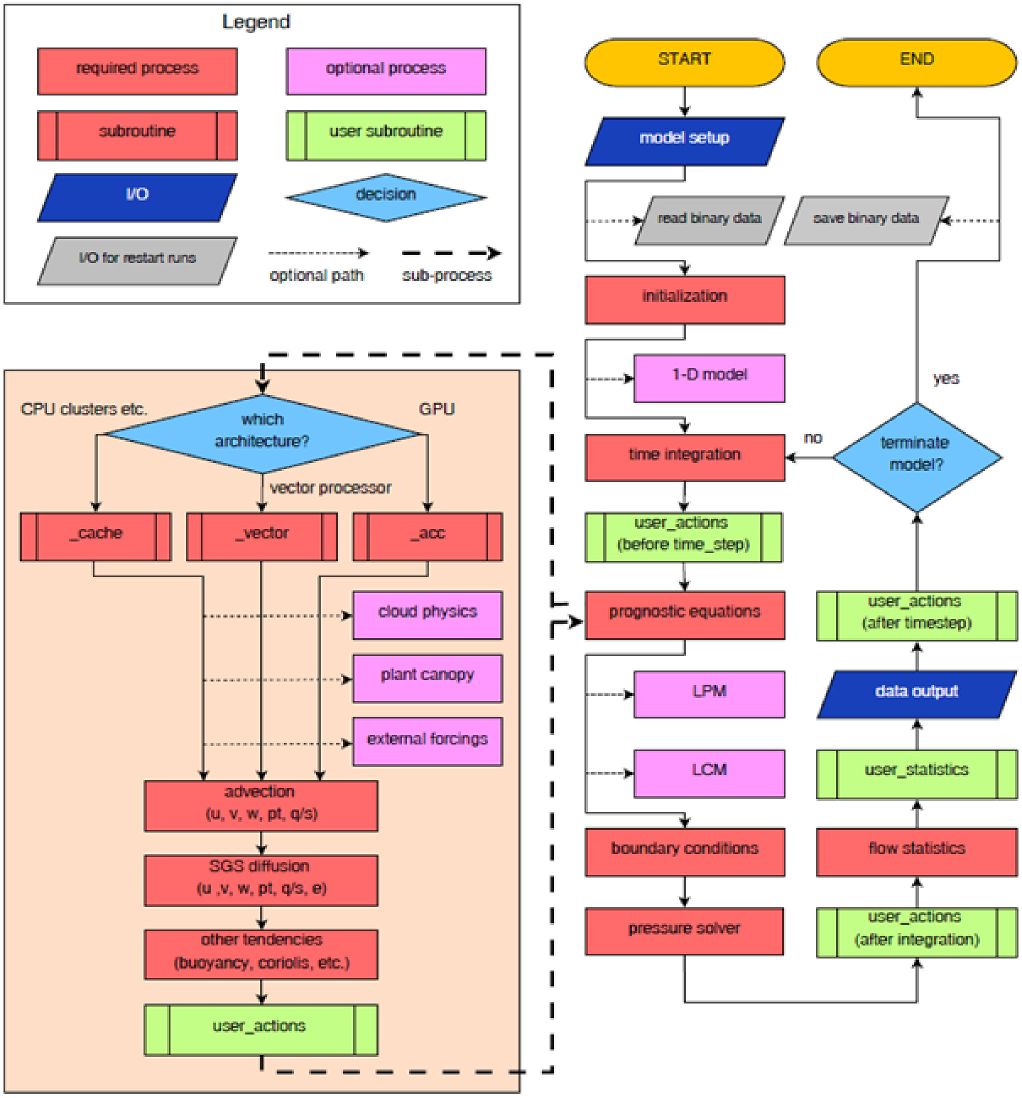


Figure 25 Simplified flowchart of PALM 4.0 without PALM-4U modules (Maronga, 2015)

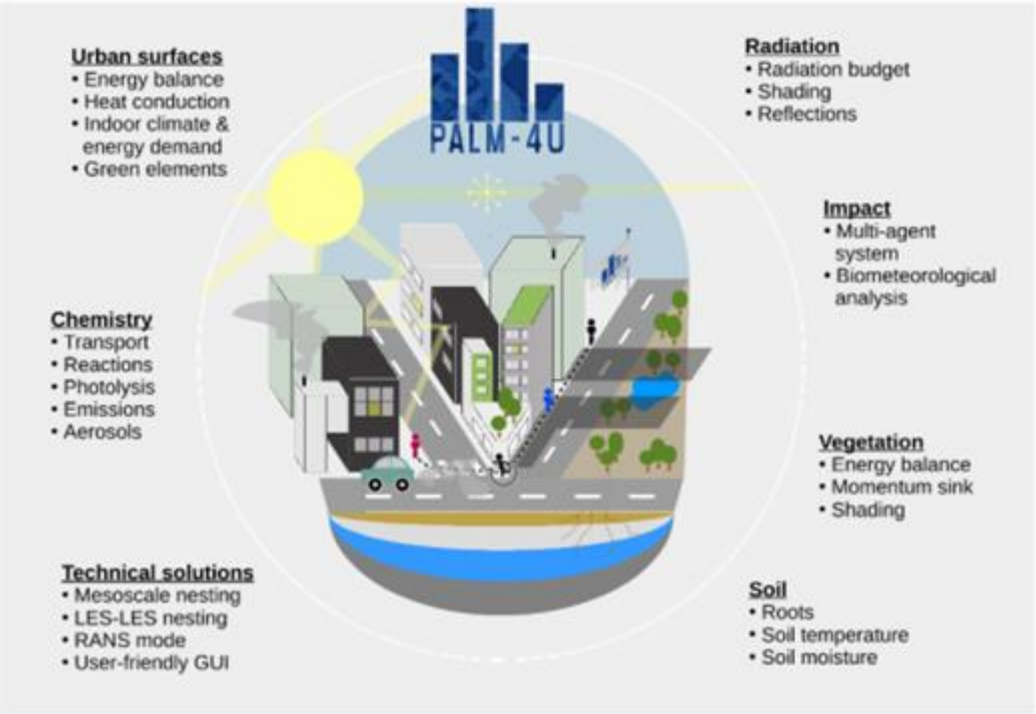
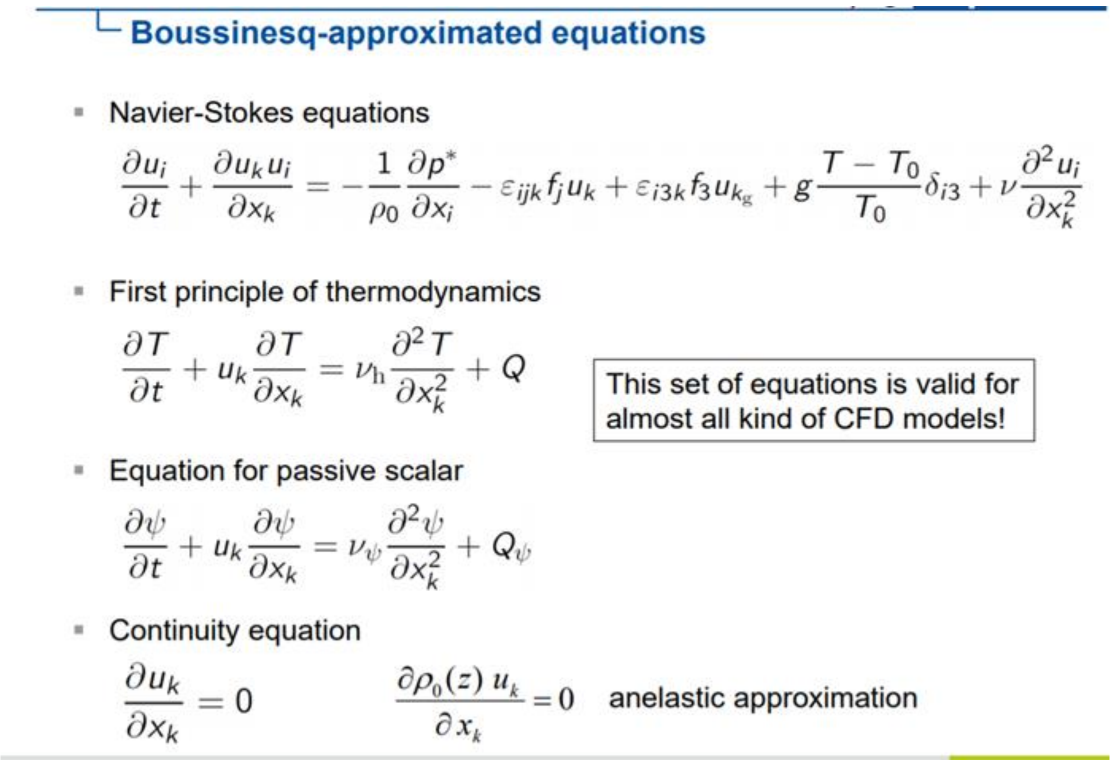


Figure 26 PALM-4U components (https://palm.muk.uni-hannover.de/trac/wiki/palm4u)



Boussinesq-approximated equations

- Navier-Stokes equations

$$\frac{\partial u_i}{\partial t} + \frac{\partial u_k u_i}{\partial x_k} = -\frac{1}{\rho_0}\frac{\partial p^*}{\partial x_i} - \varepsilon_{ijk} f_j u_k + \varepsilon_{i3k} f_3 u_{k_g} + g\frac{T - T_0}{T_0}\delta_{i3} + \nu\frac{\partial^2 u_i}{\partial x_k^2}$$

- First principle of thermodynamics

$$\frac{\partial T}{\partial t} + u_k\frac{\partial T}{\partial x_k} = \nu_{\mathrm{h}}\frac{\partial^2 T}{\partial x_k^2} + Q$$

This set of equations is valid for almost all kind of CFD models!

- Equation for passive scalar

$$\frac{\partial \psi}{\partial t} + u_k\frac{\partial \psi}{\partial x_k} = \nu_\psi\frac{\partial^2 \psi}{\partial x_k^2} + Q_\psi$$

- Continuity equation

$$\frac{\partial u_k}{\partial x_k} = 0 \qquad \frac{\partial \rho_0(z)\, u_k}{\partial x_k} = 0$$

anelastic approximation

Figure 27 - Large-Eddy Simulation fundamentals: Boussinesq-approximated equations (PALM tutorial, 2020)

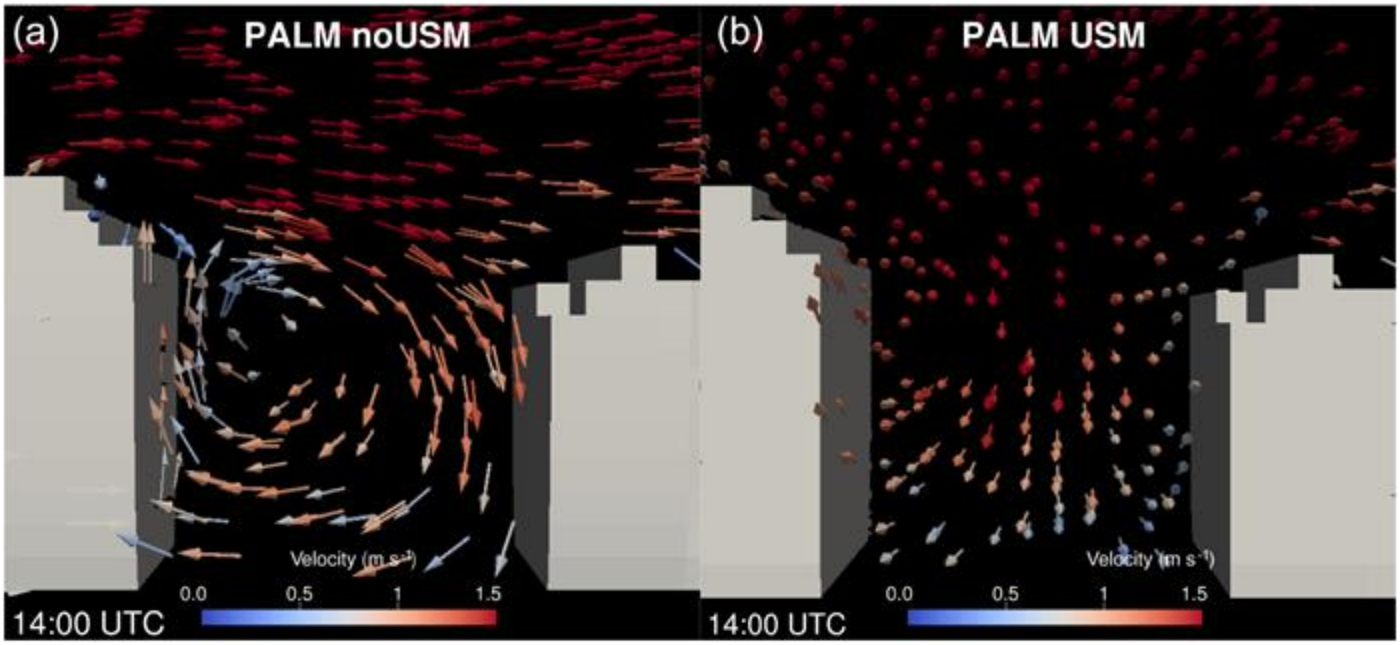


Figure 28 - Simulation of street canyon using/not using Building Surface Model (BSM), formerly USM) in Prague 7, our previous simulations based on data form July 2015 (Resler, 2017).

Appendix 3

City simulation software for modeling, planning, and strategic assessment of territorial city units

R-energy

Sumo

PALM

ArcGIS App

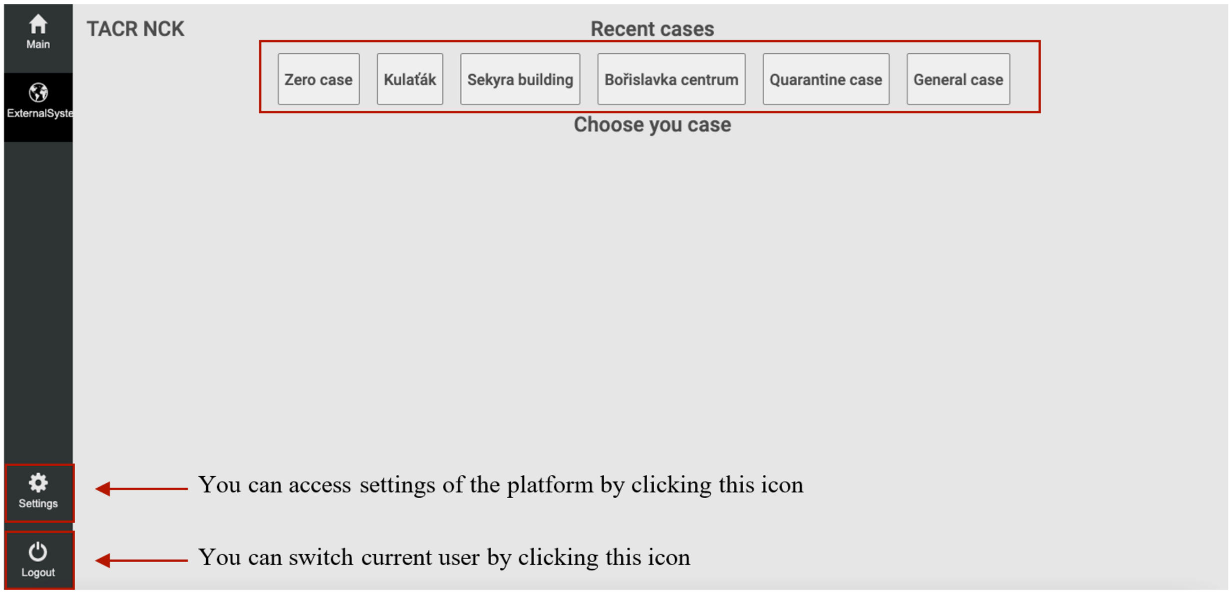
Software User’s Manual

1. Software description

City simulation software for modeling, planning, and strategic assessment of territorial city units (Smart city platform) enables the implementation of different smart city models created in different applications and products into one web-based platform that provides the complementary overview of the current situation of the section of the city or provide the results of what-if modeling of this area. The platform collects the heterogeneous data from different information sources to simulate possible city evolution strategies. Smart city platform enables to integrate the several existing simulation tools and models to very narrowly specialized issues to develop the holistic simulation of the whole territorial unit.

2. Navigating the platform

This section describes how to find your way around the Platform. Use the images and descriptions below to learn about the layout of the Platform and find the features you need.



You can access settings of the platform by clicking this icon

You can switch current user by clicking this icon

2.1 Pick up a case

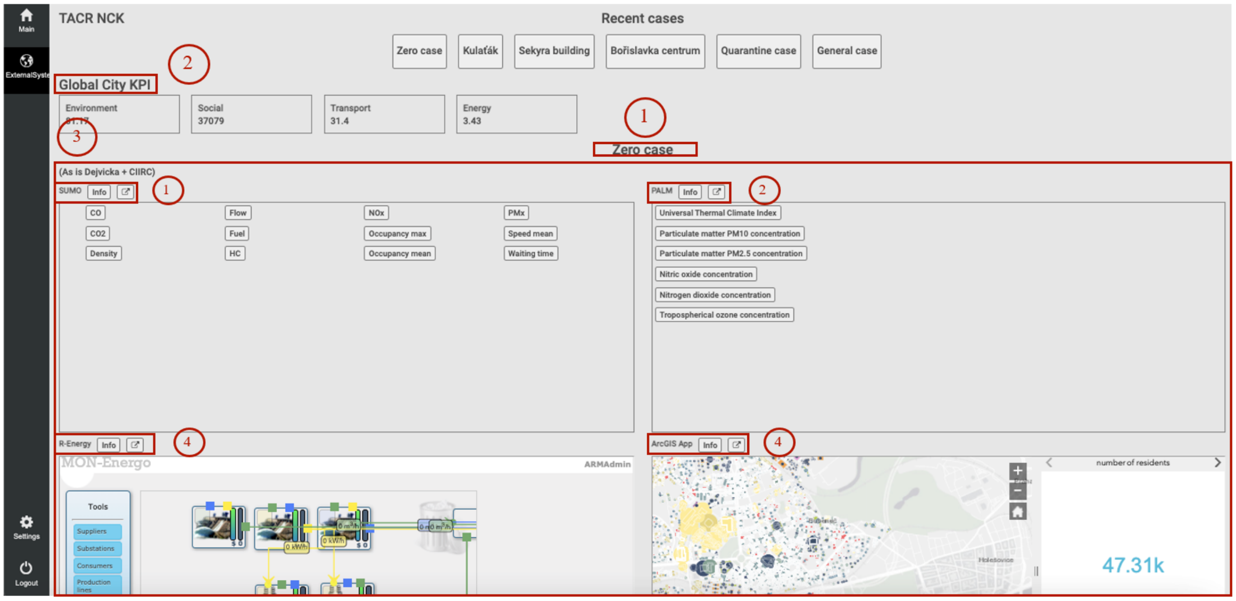
After you've logged in, you'll be taken to the page named ExternalSystems. This is the page with options to choose a case scenario to explore. Currently available cases are the following ones:

1) **Zero case (As is Dejvicka + CIIRC).**
2) **Kulat'ak** (New roundabout (Kulatyak)+ Evropska st.+KES (CIIRC yes Sekyra no)).
3) **Sekyra building** (As is Dejvicka+ New building Sekyra + CIIRC).
4) **Borislavka centrum** (As is Dejvicka + CIIRC + New building Borislavka + streets nearby).

5) **Quarantine case** (As is Dejvicka + CIIRC + no new buildings (no Borislavka+ no Sekyra)).
6) **General case** (New roundabout (Kulatyak)+CIIRC+Borislavka, Sekyra).

2.2 Home page

The following screenshot displays the Home Page and highlights the key features that can be used to navigate the platform.

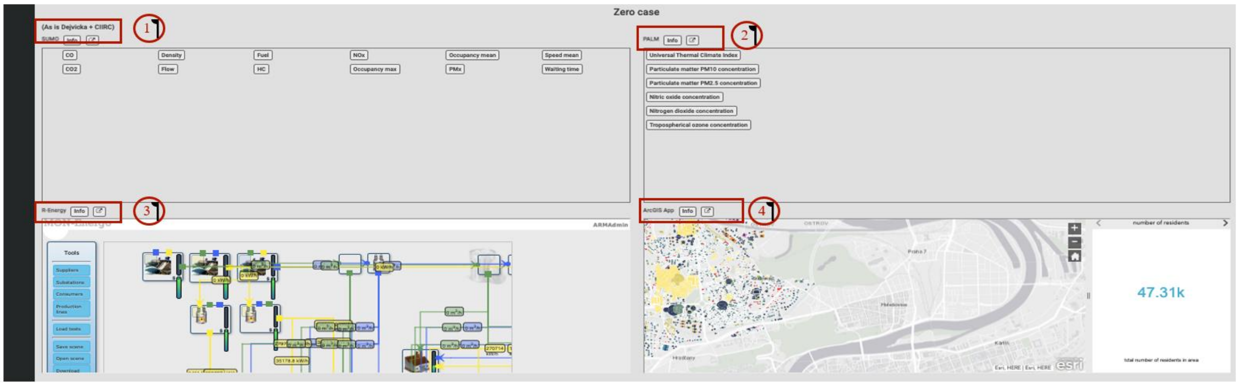


1) **Current case** The current case you are viewing is displayed in this field at the top middle of the page. To view a different one, click one of the buttons above and choose from the list of all available cases.
2) **Global City KPI** This panel indicates the state of global Key Performance Indicators. Those indicators are related to the chosen case scenario overall through all applications.
3) **Application panels** This is the main section of the platform website. You can access all four available systems for data analysis of the currently selected case. The section consists of the following systems:

- R –Energy smart energy grid model.
- Synthetic population model.
- Environment model.
- Mobility model.

3. Applications

Each application could be either opened in a new window or could be accessed directly from the main page



1) Mobility model

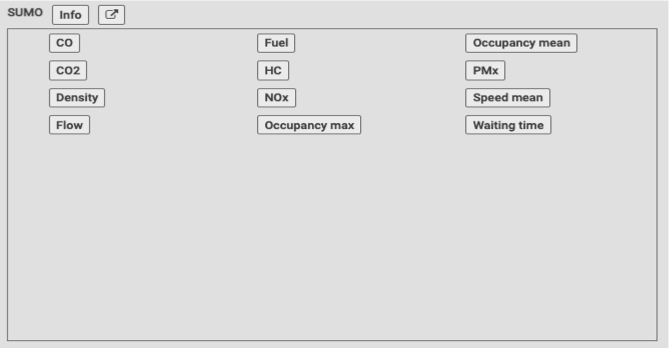
The model determines the benefits and impact of major highway improvements in metropolitan areas. It has the capability to accurately estimate changes in operational characteristics (such as speed, delay, and queuing) resulting from the implementation of ITS/operational strategies. It stimulates the movement of individual vehicles based on car-following and lane-changing theories.

Vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network over small time intervals (e.g., 1 second or a fraction of a second). Each vehicle is assigned a destination, a vehicle type, and a driver type.

Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulation runs that can be completed.

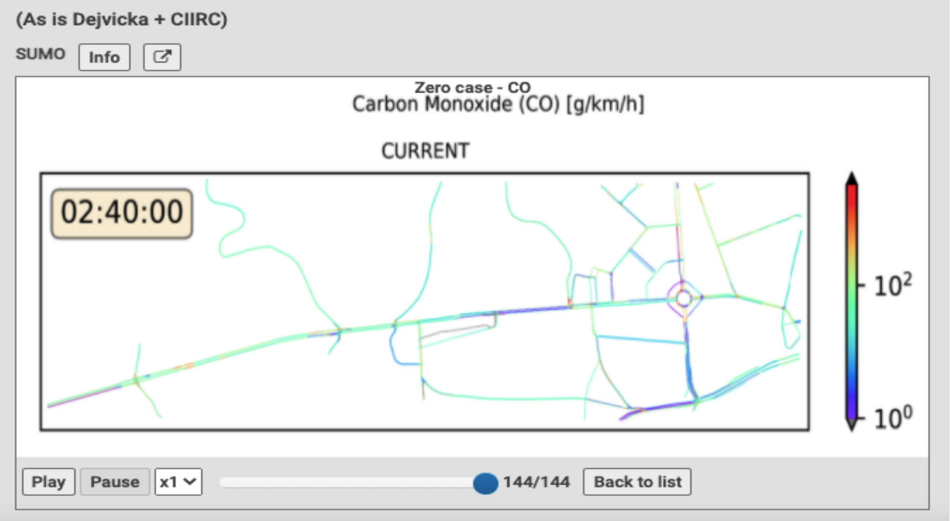
Functionality of the mobility model

On the application page user can pick which of the represented indicators he wants you explore.



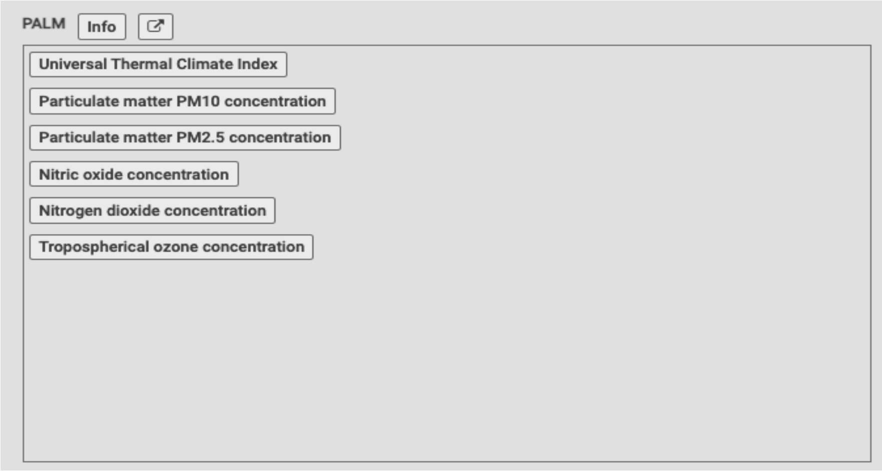
Every available indicator is represented by set of buttons, characterized by buttons name - as example indicators of CO2, CO, Waiting time and etc. could be shown for selected case.

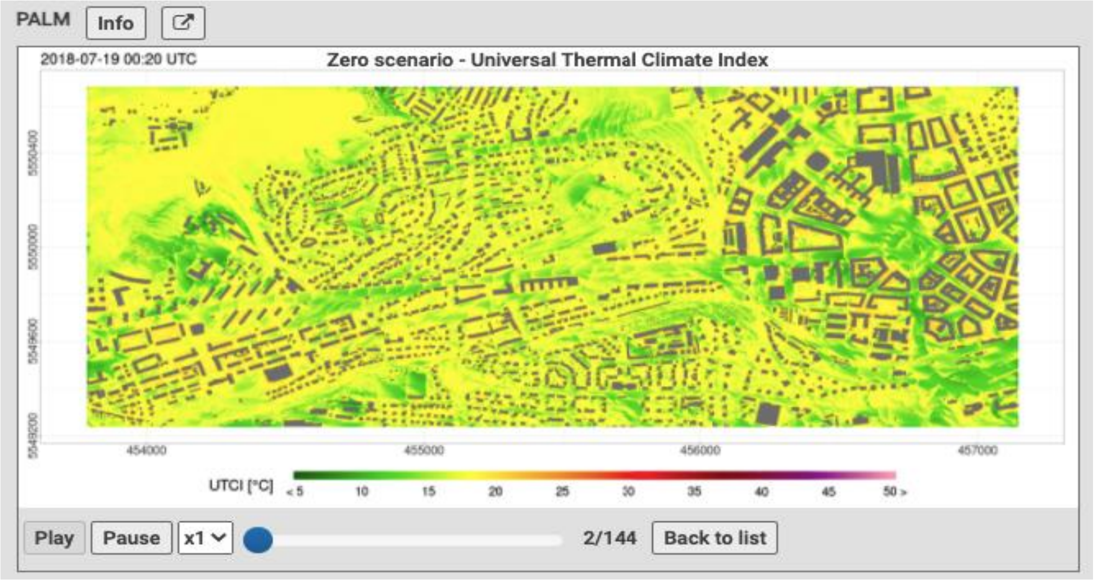
On the picture below you can see the contents of the application window with CO indicator selected.



2) Environment model

The model provides explicit simulation of the interactions of the atmosphere and solar radiation with buildings and other objects of the urban environment, particularly with the components of the green and blue infrastructure, in a micro-scale resolution (units of meters). Its main components are:





The model requires a detailed description of the simulated area, e.g. terrain and land surface model, detailed building models including building materials and surface properties, plant canopy structure etc. The model further uses initial and boundary conditions of weather and air quality from a larger area atmospheric model and/or measurements and emission profiles of the local sources of air pollution and anthropogenic heat. Among the outputs, the model provides meteorological variables like wind speed, air temperature, humidity, concentrations of air pollution components, biometeorology indices and further specialized outputs.

Functionality of the environment model

On the application page user can pick which of the represented indicators he wants you explore. Every available indicator is represented by set of buttons, characterized by buttons name - as example indicators of Universal Thermal Climate Index, Particulate matter PM10 concentration and etc. could be shown for selected case.

On the picture below you can see the contents of the application window with Universal Thermal Climate Index indicator selected.

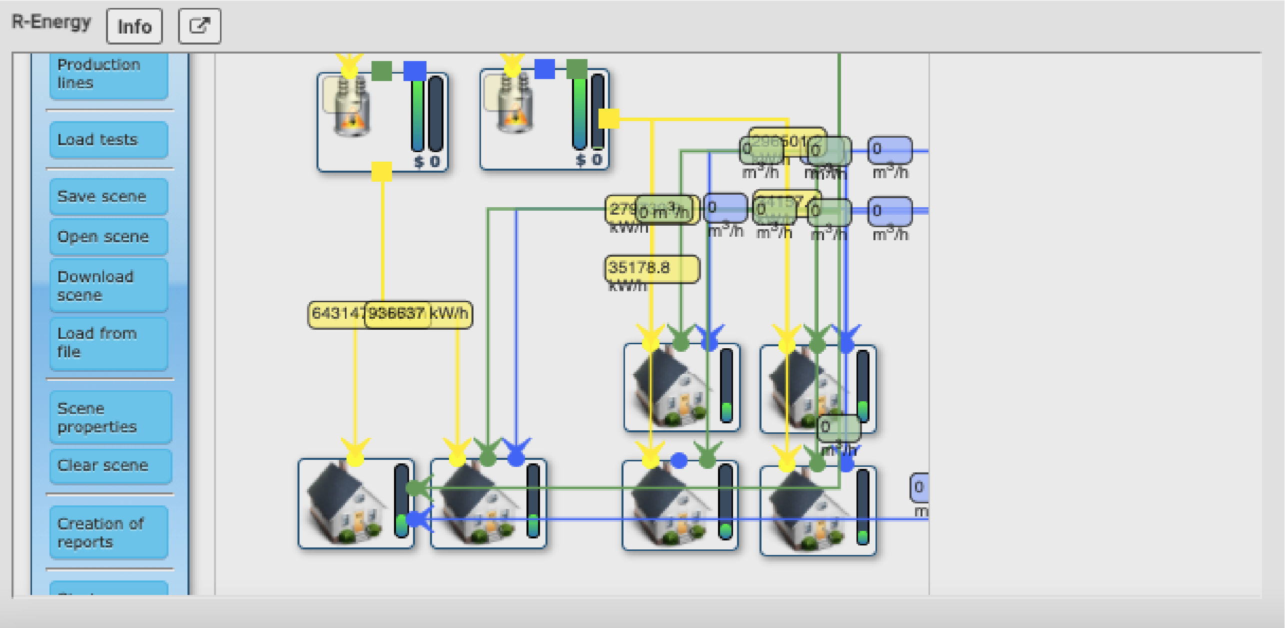
3) Energy model

Intelligent network-centric system. It allows to create models of integrated networks of gas, heat, and electricity consumption and helps dynamic schedule resources in real-time. Each node of such a network (consumer or resource provider) has its agents to resolve conflicts in the network through negotiations.

It uses data from sensors and devices to collect information about the level of resource consumption, environmental parameters, workload and condition of transport networks, and the power of suppliers. The result of the system is the better (optimal) production plan and distribution of resources.

In addition, consumer demands can be adjusted by monitoring the state of the environment in real-time, as well as making forecasts for the short term. In the system, different alternative energy sources can be considered.

Functionality of the energy model



On the application page user can see the scheme of preloaded use case, which was chosen on main page above.

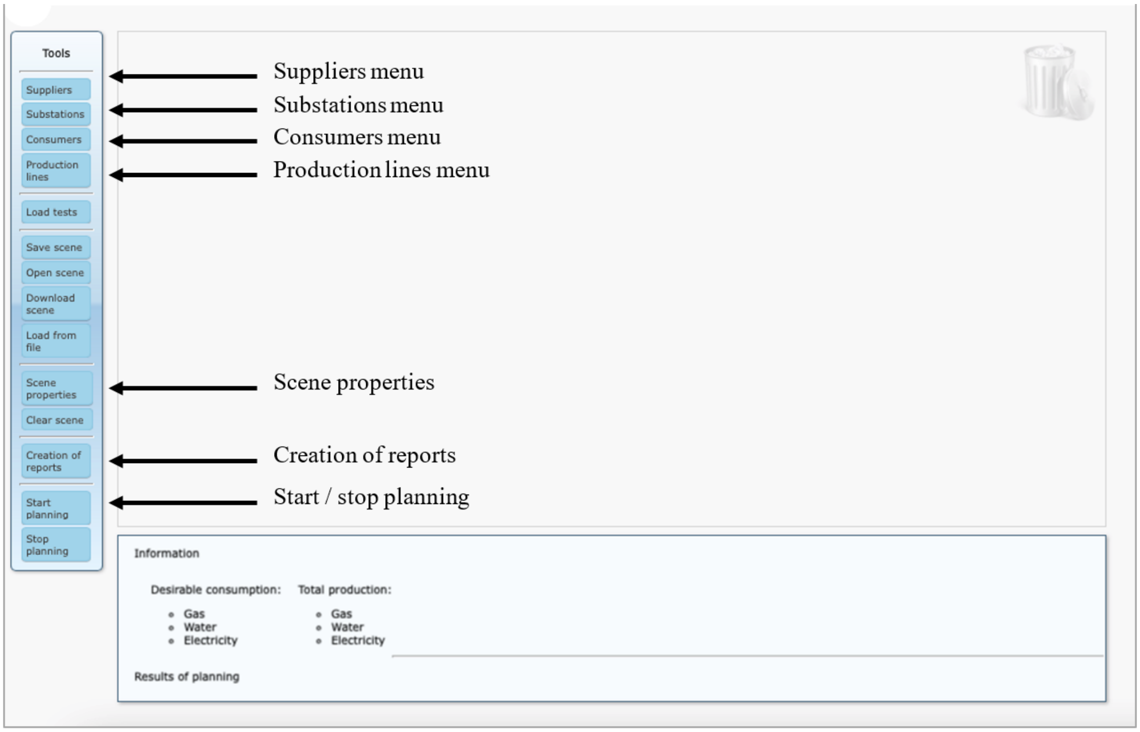
The Home page is the default page for the simulation design.

Main functions that can be accessed on the left side of the toolbar:

- Click the Suppliers button to set up level of daily resource production by provider, change cost and size characteristics, check inputs, and specify optimization variables. Production rate can be defined on an hourly bases in terms of a single day, also designed schedule can be copied for the entire planning period. You can select as many components as you want to consider as part of the power system. Drag the icon to the trash bin in upper right corner to remove the component from the schematic and model.
- Click the Substations button to review and plot optimal parameters of individual parts of the power system. A substation is a part of a generation, transmission, and distribution system. You can select a substation component for electrical, water and gas systems. You can add as many components as you want to consider as part of the power system. Drag the icon to the trash bin in upper right corner to remove the component from the schematic and model.
- Click the Consumers button to specify parameters of the system that consumes energy. You can add electric, water, or gas load data. Consumers can be specified in two categories —

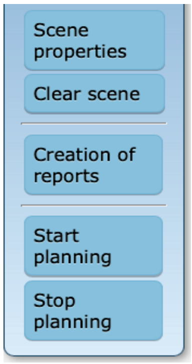
household and a factory. Settings allow user to define grid prices with a regular schedule according to time of day, month of the year, and weekdays or weekends.

- Click the Production line button to set the required performance indicators of the network (cost, equal load, etc.) Every provider of water, electricity and gas has its own tariff price, as well as each communication line has its own capacity and cost.



Lower side of the toolbar contains buttons which correspond to the following functions:

Scene properties — allows user to define rules of agent's negotiations, that leads to a dynamic improvement of the network parameters.



Creation of reports — allows to generate report based on results of the scene simulation and review the details of individual properties of the system.

When you click the Start planning button software starts performing calculation and evaluation process and then displays the results on the Results window.

4) Synthetic population model

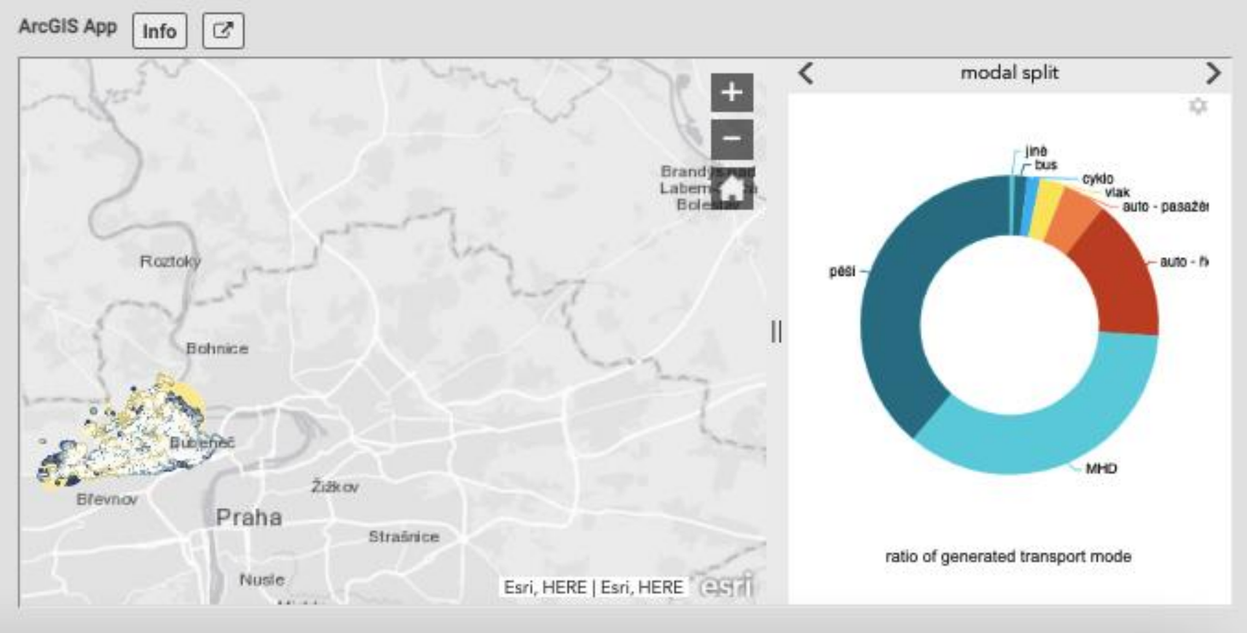
For the application of modern activity and agenda models, it is necessary to generate transport and non-transport activities of the population at the level of individuals. Generating activities at this level is based on a synthetic population. The purpose of the synthetic population is not to achieve complete agreement between the real and synthetic populations, but to achieve agreement at the level of aggregated population statistics.

The trip generator is based on a synthetic population of the following entities:

- Residents.
- Households.
- Employees.
- Visitors.
- Buildings.
- Streets (street segments).

The following data are used to create a synthetic population:

- SLDB (Census Data of Population, Houses and Dwellings).
- RSO (Register of Census Districts - Building Points).
- Land use - IPR Prague data.
- Traffic Generation Methodology (EDIP).

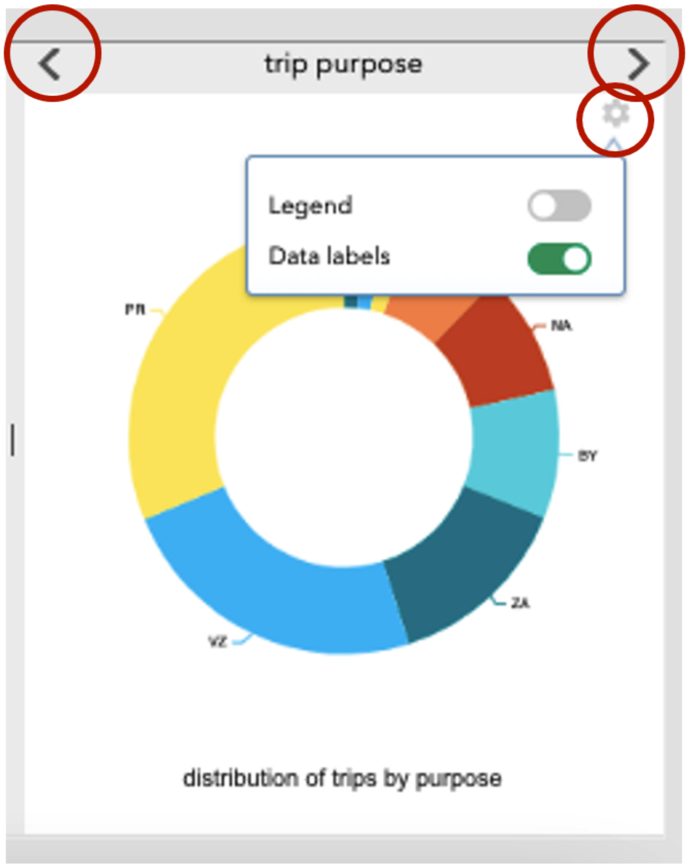


Functionality of the trip generation model

On the main application page, the following data can be available:

- number of trips from and to buildings classified based on trip purpose/transportation mode/time;
- number of work trips to workplace;
- number of visitors entering buildings.

Main functions that can be accessed are located on the right side of the window:



Legend ○

Data labels ●

Using arrows on the side of a menu window, user can switch data panels with following content:

- Modal split;
- Trip purpose;
- Age of the residents;
- Number of residents;
- Legend.

Clicking Option icon gives user an option to show or hide Legend and Data labels.