DEVELOPMENT OF A SIMULATION PLATFORM FOR THE EVALUATION OF DISTRICT ENERGY SYSTEM PERFORMANCES

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ABSTRACT

The phenomena and thus also the simulation of district energy systems is very complex. The district is a multi-energy system with the vectors heat and electricity and in many cases the interaction of these both vectors. The components of the system are distributed with phenomena of consumption, production, distribution and storage, on a central or local level.

The main difference to single building simulation is that local phenomena are not deterministic (occupancy profiles, equipment consumption profiles and internal gains related to these profiles) and that used models have to be appropriated to the study objectives.

In order to allow the numerical analysis and optimisation of the global district energy system, a simulation platform DIMOSIM (DIstrict MOdeller and SIMulator) has been developed in the frame of the European Resilient and Smart Med park projects.

The development of the numerical models and a method to automatically generate and parameter the global model from the district description is described in this paper. The models implemented concern buildings with their local energy system for heating, cooling and domestic hot water preparation, thermal networks as well as local and/or central energy production and storage.

Some examples are presented in the last part of the paper in order to illustrate the use of the tool.

INTRODUCTION

The analysis and optimisation of district energy systems in terms of energetic, environmental and economic performances is very complex due to the following reasons:

The applied heat transfer coefficients (constants) are:

- It is a multi-energy system (heat, electricity …);
- It includes distributed components of consumption, production and storage, on a central or local level
- Local phenomena that are not deterministic and superposed (occupancy and equipment)
- There is an interaction between components on a thermal and electrical level

The objective of the simulation platform presented in this paper is to consider and implement all key phenomena for the dynamic analysis of energy systems in districts, with or without networks (local versus central solutions).

Basically, the developed tool focuses on the development, test and analysis of the optimisation of concepts and operation of district energy systems.

In the European “Resilient” project (Resilient, 2015) the main application of the tool is to develop and test a multi-agent (MAS) control system by simulation which will later be applied to the Resilient pilots.

However, the tool can be used with “classic” control strategies for any other district analysis on:

- New districts (buildings and infrastructures do not exist)
- Existing districts (buildings exist, infrastructure does or does not exist)

STATE OF THE ART

The use of classic dynamic thermal simulation programs is not appropriated to simulate a large number of buildings, especially in dense urban areas.

Phenomena such as solar shading from relief and between buildings, thermal networks as well as electric grids have to be considered. At the same time, classic approaches for estimating specific electricity consumptions and internal heat gains as used for single building simulation has to be reviewed. Contrarily to single building simulations these profiles have to be generated using a stochastic approach. Besides criteria as computation time the detail of available data (or even missing data) that is necessary to parameter all component models naturally leads to the use of simpler models as in single building simulation.

This statement is true for all components of the energy system: buildings, generators (heating, cooling, domestic hot water and electricity), storages (electrical or thermal) as well as thermal networks and electric grids.

Several tools have been developed for urban energy simulation. A very brief list is given hereunder.

CitySim (Kämpf et Robinson, 2006) allows the calculation of heating and cooling loads and energy consumptions. The tool includes solar mask calculations and seems quite complete, but networks or grids are today not fully integrated. Larsen et al. (Larsen et al., 2004) compare aggregated models for the simulation of large districts for the operational optimisation of district heating networks. Berthou et al. (Berthou et al., 2014) suggest a method to simulate building parks up to a high number of buildings, but with no aspect of thermal networks or electric grids. Vesterlund et al. (Vesterlund et al., 2015) propose a model for the numerical optimisation of district heating systems, including meshed networks. Molitor et al. (Molitor et al., 2013) present a simulator for city district energy systems, MESCOS. This platform aims in the simulation of control strategies linked to the simulation of electric grids.

The simulation objectives in each of the cited references being different, each tool has its own specificities. Platforms are often tailored for some special purpose. As such a platform for the evaluation of energy demand generally misses details on systems and their consumptions. Platforms for the optimization of district heating systems are not necessarily very suitable for simulation districts without network. While those for the optimization of control (e.g. for the management of electrical grids) miss details on other aspects or are too detailed for energy studies.

FUNCTIONAL SPECIFICATIONS OF THE SIMULATOR

The key specifications and requirements

- An ease description of the district (networks, buildings, generators …)
- A completely modular structure (choice between different levels of detail of component models)
- Possibility of coupling/integration of electric load generators (for electric grid calculations as well as realistic estimation of internal gains)
- The ability to choose between central or local energy solutions in the district (with or without thermal network, with or without electrical grid calculation etc.)
- To cover at the same time heating, cooling, domestic hot water and electricity production, storage and consumption
- The automatic generation or import of thermal and electric grid models
- The automatic sizing of components (expert rules) where possible and where needed
- Hydronic balancing of thermal grids and correct calculation of pump(s) consumptions in districts
- The ability to dispose of any necessary output on building, distribution and central level, necessary for the analysis and optimization of district energy systems in terms of feasibility, conception and operation.
- Compatibility to standards of data modelling of urban areas (Citygml etc.)

Outputs of the simulation platform

Energy flows:

- Detailed consumptions (gas, fuel, electricity)
- Detailed productions (heat, electricity) on local or central level
- Detailed losses (production, distribution and building level) for heat and electricity
- Renewable energy production (heat and electricity).

Efficiencies:

- Thermal and electrical production(s)
- Thermal and electrical distribution (including auxiliaries).

Emissions and costs:

- CO2 emissions for electrical and thermal production
- Global costs calculation of energy solutions in districts

Simulation horizon, time, time steps and environment

Depending on the studied solution and its objectives, simulation horizon can be some weeks (control studies etc.), one year (energy consumptions etc.) but also several (20-30) years in the case of seasonal storage (e.g. geothermal). The objectives of the simulation projects being different from case to case, this leads to the necessity of different levels of detail in the used models as well as time steps. Typical time steps are between minutes and one hour.

The simulation engine is implemented in Matlab environment. A GUI has also been developed and implemented in Matlab.

MODEL DEVELOPMENT

Building model

Thermal building model

Different building models have been implemented in the simulator. The default choice is a lumped R7C4 model with 7 resistances and 4 capacitors (Perez et al., 2015). However, the choice of the appropriated building model will depend on the simulation objectives and no “perfect” model can thus be presented.

In the current version of the simulator, no interaction between buildings is considered except solar masks.

Equipment and occupancy model

On a district level it is crucial to generate electric consumption data with a combined statistic and stochastic approach. In order to have realistic profiles, electric consumptions are prepared by a pre-processor based on measurement data with a stochastic approach. The pre-processor developed from CSTB (Gay et al., 2013) is to date focussed on residential buildings (single or collective housing). It generates for each dwelling load profiles for all electrical equipment and occupant behaviour on a stochastic basis.

For larger districts these load profiles are more and more smoothed due to the stochastic behaviour of the district.

Internal gains

In the preprocessor, the electrical load profiles are used at the same time to calculate internal heat gains in the buildings. Therefore, equipment and occupants are characterised by a heat injection coefficient (e.g. 0.5 for cooking) and injected as global sum to the corresponding nodes of the building model (wall and/or air).

Solar masks

A solar mask calculation module has been implemented as a pre-processor. This module calculates for each building, at the centre of the building and at mid height, a 360° view of masks around that point with a resolution typically of 1°. The result is one array by building with the height of the masks for each of the 360 view angles (*Figure 1*).

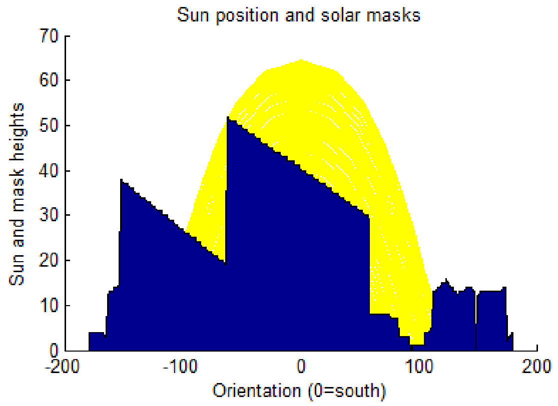


Figure 1: Solar mask calculation example

This array is then used for filtering solar data calculated by the radiation processor and calculating the view factor of the sky (long wave radiation). No reflexion between buildings is considered in the current version.

Adjacencies between buildings

A module has been implemented into the tool to detect and calculate adjacent envelope elements.

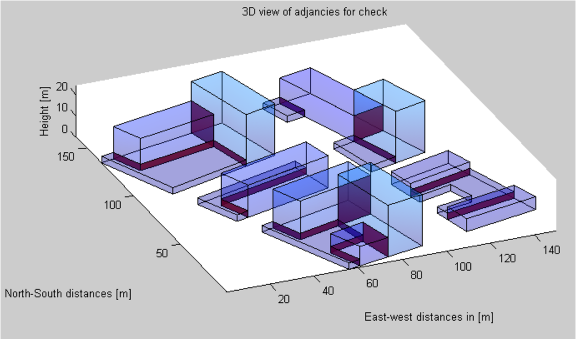


Figure 2: Calculation of adjacencies

Thermal adjacency between buildings is dealt with as adiabatic, the thermal mass of the adjacency is lumped to the internal mass of the building in order to correctly represent thermal inertia.

Building thermal control

Two types of control are implemented and the appropriate type chosen by the user:

- Ideal control: The building zone is heated or cooled to the set point (following set point scheduling or constant). The necessary heat flux is calculated and sent to the generator model calculating the corresponding consumption (fuel, gas, electricity). No emitter model is used in this case.
- Real control: On/Off, P or PI control is used in this mode. A control loop is simulated in this case with Zone / Emittor / sensor / controller. The sensor, measuring air and radiant temperature feeds back the temperature to the controller that controls the emitter which injects heat to the air and the envelope in the building. The emitter model is a transient model that considers either air as source (no time constant and blowing directly into the building) or water with the choice of low or high inertia systems (radiator or floor heating respectively). The real control mode with emitter model has the great advantage to allow calculation of free-cooling (e.g. from geothermal) with no fixed set points.

Scheduling and set points are based on a statistic / stochastic approach.

Local and central generator models

In districts, generators can be placed inside the building as a local system, but also in a centralised production for district heating and/or cooling. To date, the model types used are the same, for central or decentralised systems; they are only sized for the corresponding building (decentralised) or district (central). The modular structure of the platform allows the integration or more detailed models in future versions.

Boiler

The boiler model implemented in the frame of the Resilient tool is a simple transient model with constant combustion efficiency. The general equation of the boiler water output implemented is:

$$m * cp * \frac{dT_b}{dt} = \dot{m}\, cp\, (T_{in} - \dot{T}_b) + \Phi_{comb} \qquad (1)$$

As for all other transient models in the simulator, the implementation of the model is done using the state space approach:

$$\dot{X} = A \cdot X + B \cdot U \qquad (2)$$

Heat losses of the boiler from convection/radiation at the boiler envelope and ventilation are neglected in this model but can be added easily.

CHP

The model for CHP in the tool has been developed as a black box model in order to be able to calculate any type of cogeneration (Internal combustion engine, gas turbine, Stirling, fuel cell) without the necessity of modelling the internal components.

The equations used are generic for any type of cogeneration. They are modelled as follows:

- Fixed electrical efficiency:

- PEMFC:	0.5
- Stirling:	0.12
- Microturbine:	0.3
- Combustion engine:	0.25

- Delay for electrical output:

A delay in the output of electricity to the building or grid (the power output is only available if the CHP is switched on since a minimum operation time):

- PEMFC: no delay, immediate power output
- Stirling, combustion engine and micro-turbine: delay function of power (default 7 minutes for small scale)

The delay shown is a default delay; it can be adjusted individually if data is available.

- Thermal efficiency:

For reasons of simplicity, this model assumes a global efficiency of 90%. Thermal efficiency is thus calculated as 90% minus the electrical efficiency. The parameters can be adapted by the user.

- Thermal transient heat balance of the CHP:

Assuming a time constant of 2 * P_{nom} [kW] * cp_{fluid} the transient heat balance without thermal losses is solved. The time constant has been estimated from testing experiences. It can be, if available, derived from other data. The equation is identical to Eq.1.

- Electrical output:

The parts of active and reactive power outputs are fixed to 0.7 and sqrt(1-0.7^2) respectively. The total power calculated is multiplied with this vector of active and reactive output for electric grid calculations.

Heat pump

The heat pump model is based on basic polynomial laws on COP (or EER) and compressor power, identified from measurement or catalogue data:

$$COP = f(T_{evaporator}, T_{condenser}) \qquad (3)$$

$$P_{comp} = f(T_{evaporator}, T_{condenser}) \qquad (4)$$

Evaporator and condenser temperatures are averages on inlet and outlet states, a change in flow rate on the efficiency is thus correctly considered.

Both polynomials are then used to calculate outlet states of condenser and evaporator by a steady state balance on the heat pump.

Thermal storage

Storages are used in the simulation for building substations, central energy production and domestic hot water production. The latter can be charged by solar and/or electric or gas sources. In the case of solar thermal panels a steady state heat balance on the collector is used. Radiation data is calculated with a radiation processor for each building and collection orientation and inclination.

The storage model implemented is a well-mixed, transient model. The model considers losses to the environment with a constant heat loss coefficient. The general equation of the storage temperature is calculated as follows:

$$\mathrm{m} * \mathrm{cp} * \frac{\mathrm{dT_{st}}}{\mathrm{dt}} = \sum_{\mathrm{i=1}}^{\mathrm{nin}} \dot{\mathrm{m}}_{\mathrm{i}}\, \mathrm{cp_{fluid}}\,(\mathrm{T_{in,i}} - \mathrm{T_{st}}) + \mathrm{UA}\,(\mathrm{T_{amb}} - \mathrm{T_{st}}) \qquad (5)$$

Thermal network model

The thermal grid is at the same time characterised by its thermal and hydronic behaviour. There is a link between these two phenomena. If the fluid temperature changes pressure drop and flow rate will also change.

Both phenomena are implemented in two separate modules: one for the thermal calculation and another one for the hydronic calculation. In order to accelerate simulation time, the hydronic calculation uses the temperatures from the previous time step.

Figure 3 illustrates the structure of the thermal grid for pressure and thermal calculation.

Each interconnection between connection nodes is represented by a thermal and hydronic tube model.

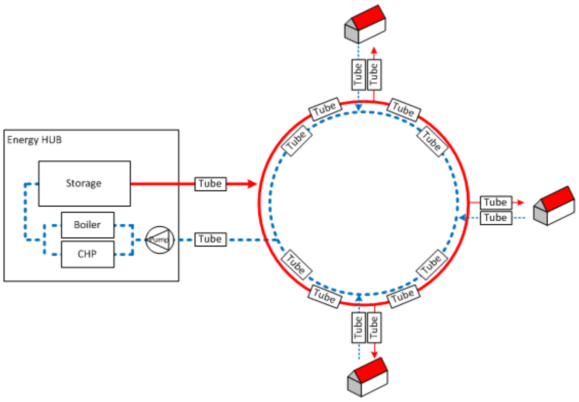


Figure 3: Layout of the thermal grid model structure

The structure of the Resilient simulator has been developed in order to allow a modular model that allows an easy implementation of different model types, i.e. simple or detailed models (the simulator allows to plug easily different models of the same component, e.g. transient or steady state models.

The objective of the thermal grid model is to be able to model and simulate meshed and non-meshed hydronic loops for at least 1000 buildings (200 have been tested at the current state). Since grid topology can be very different from case to case, the model has to be able to simulate any configuration with network and variable numbers of sub-networks.

Basic assumptions of tube pressure drop / flow relationships

From the Reynolds number, the hydraulic pressure drop coefficient λ can be calculated as follows:

- For laminar flow (Re < 2320):

$$\lambda = \frac{64}{Re} \qquad (6)$$

- For turbulent flow (Re > 2500) – Colebrook:

$$\frac{1}{\sqrt{\lambda}} = -2 \cdot \log\left[\frac{\mathrm{k}}{3.7\,\mathrm{D}} + \frac{2.51}{\mathrm{Re} \cdot \sqrt{\lambda}}\right] \qquad (7)$$

with λ the Darcy-Weisbach friction coefficient and k the roughness of the tube.

- For the transient region (2320 < Re < 2500):
  A linear interpolation is applied between the edge points of both laminar and turbulent region. It is crucial to have a continuous function over the whole range of Reynolds numbers in order to avoid stability problems.

Finally, hydronic head loss for a segment can be calculated as:

$$\Delta p_{tube} = \lambda \cdot \frac{L}{D_{tube}} \left(\frac{1}{2} \rho V \right) - \rho g \Delta H \qquad (8)$$

The height difference between inlet and outlet of the pipe (or pipe segment) can easily be considered in order to estimate flow generation or variations due to height and density differences.

Hydronic valves (balancing or other valves)

Each building is equipped with a substation (heat exchanger) delivering heat to the building system. In order to hydronically balance the thermal network delivering flow to each building, a balancing valve is implemented in each building substation. This allows to guarantee the correct flow that has been calculated in the conception phase.

The model of the balancing valve is based on the hydronic characteristics and position of the valve. Generally the valve is described in the following equation [PETITJEAN 1994]:

$$\dot{m} = K_v \sqrt{1000 \frac{\Delta p_{valve}}{\rho}} \qquad (9)$$

The valve is described in terms of the kvs which corresponds to the kv value for the fully open valve. This factor is given for any commercial available valve.

Circulation pumps

The thermal hydronic network is equipped with one central or several de-central pumps, allowing the circulation of fluid through the network.

In this model, the flow rate through the hydronic network is calculated (and then forwarded as input to the thermal network model). The flow generated by the pump is calculated by crossing the system flow/pressure curve and the characteristic curve of the pump with the following assumptions:

- Pressure drop through the network is equal to the pressure difference generated by the pump:

$$\Delta p_{pump} = \Delta p_{network} \qquad (10)$$

- Hydronic characteristics do not change significantly from one time step to the next one:

$$\Delta p_{network} = b_{equiv} \cdot \dot{m}^2 \qquad (11)$$

Therefore, the equivalent resistance coefficient b_{equiv} (function of tube, valve and singular resistances) is calculated based on the data of the previous time step. This assumes that valve positions do not change significantly from one time step to the other.

The calculation of the equivalent resistance coefficient allows the generation of the characteristic flow/dp curve of the network and the determination of the intersection with the pump curve.

The pump curve is determined by the following relationship:

$$\Delta p_{pump} = \Delta p_{max} \left(\frac{w}{w_{nom}} \right)^2 - (\Delta p_{max} - \Delta p_{nom}) \left(\frac{\dot{m}}{\dot{m}_{nom}} \right)^2 \qquad (12)$$

The pump power consumption is calculated as:

$$P_c = \frac{9.81 \times H \cdot \dot{m}}{3600 \times \eta_p \cdot \eta_m} \qquad (13)$$

Global hydronic equation system

The global system is solved with the following balances that MUST be satisfied:

- For each node, the sum of entering and leaving flows is 0
- For the global system (or subsystems), the sum of entering and leaving flows is 0

These mass conservation equations are used construct and solve a matrix system with the pressures at all nodes of the network.

Based on the general phenomena of tube hydronic relationships, the hydronic grid model is generated based on the following relationship:

$$\Delta p = C \cdot \dot{m}^2 \qquad (14)$$

The pressure loss coefficient C is composed of two parts, the tube pressure drops (derived and linearized from Eq. 8) and singular pressure drops due to valves, elbows, tees etc.

The implementation is based on two main assumptions allowing robust and fast calculation:

- A matrix system is build that solves pressure of all nodes by respecting the described balances;
- The non-linear expression linking flow and pressures Eq 14 is linearized as:

$$\dot{m} = \Delta p \; C_{lin} \qquad (15)$$

with $C_{lin} = 1/C_{segment} \cdot \dot{m}_{(t-1)}$

The approximation of taking the flow rate of the previous time step in C_{lin} is only valid if flow rate does not change significantly from one time step to the next. The simulation time step has thus to be chosen depending on pump and valve control laws. On/off control of these components cannot be calculated with this approach.

The balance on each node i is:

$$\sum \dot{m}_{i,j} = \Delta p_{i,j} \; C_{lin\_i,j} + \dot{m}_{inlet} = 0 \qquad (16)$$

with $\dot{m}_{inlet}$ the flow rate imposed from the central circulation pump (connected to the first node only).

The system assumes thus two external inputs that are pressure. The flow rate imposed to the first node (node where the central circulation pump is connected to) is calculated in the pump model using the characteristic curve coefficients of the hydronic network from the previous time step. Furthermore, this assumes that no valve can be opened or closed completely from one time step to the other, since this would falsify the calculation completely.

Since C_{lin} is the inverse of $C_{segment}$, C_{lin} is:

$$C_{lin} = \frac{1}{\frac{1}{C_{lin-pipe}} + \frac{1}{C_{lin-singular}}} \cdot \dot{m}_{(t-1)} \quad (17)$$

The term $\dot{m}_{(t-1)}$ is used to linearize Eq 14.

The complete system is built and solved as:

$$A \cdot P + B \cdot U = 0 \quad (18)$$

with P the node pressures and A a matrix composed of all C_{lin} relationships. U are the external inputs from the pump model i.e. flow rate and inlet pressure and B a matrix with the input relation coefficients.

The solution of all pressures is thus:

$$P = -inv(A) \times B \cdot U = 0 \quad (19)$$

Thermal network equation system

This model is an assembly of tube models calculating the temperature distribution throughout the thermal network. As for the hydronic model the system is solved on a matrix basis.

Different types of tube models have been implemented allowing the following options:

- Steady state or transient behaviour
- With or without sub-nodes for each segment.

In this paper the simplest model is presented, based on the analytical expression of heat losses in the tube. Since this model describes the steady state solution from integration over the segment length, transient effects have been represented by adding a storage volume at each building connection or in the central production system. This might be sufficient for basic energy demand and consumption calculations.

Based on the general equation of a heat exchanger, the outlet temperature of a tube segment can be calculated as follows:

$$T_{out} = (1 - \varphi) \cdot T_{in} + \varphi \cdot T_{amb} \quad (20)$$

with T_{in} the inlet temperature into the tube segment, T_{amb} the temperature around the tube (ground), UA the heat exchange coefficient from the fluid inside the tube to the ground temperature [W/m²/K] and:

$$\varphi = 1 - \exp(-\frac{UA}{\dot{m} \cdot cp_{fluid}}) \quad (21)$$

Supply and return networks are both solved on a matrix basis.

A transient, nodal model has also been implemented.

To improve calculation accuracy and simulation speed, a more detailed model is currently being implemented based on transient plug-flow approach; it will be presented in a future work.

DISTRICT DESCRIPTION, INITIALISATION AND CALCULATION PROCEDURE

A brief overview on the whole calculation procedure including model initialisation is detailed hereunder, with the following steps:

Definition of buildings:

- Two possibilities have been implemented, either to load a district in form of a citygml data model or adding buildings by clicking on a map
- Eventually input of additional parameters of building models (floor, window and wall area, orientation, thermal characteristics etc.)
- Building system parameters: consumer, prosumer, local storage or production, system types for heating, cooling and DHW etc.

Import of all district parameters and generation of district model

- Hydronic network parameters: connections and distances;
- Electric network parameters: connections and distances.

The network topology can also be loaded from citygml data or other file formats (shapefile etc.).

Import of Energy HUB parameters and generation of HUB model

- Central thermal and electrical production (configuration and sizing)
- Central thermal and electrical storage (configuration and sizing).

Generation of building electrical loads

- Each building is divided in sublevels (e.g. apartments) with occupants, for which a load profile is generated, mainly based on occupant activities;
- From the sublevels, a general load profile for each building is generated from the sum of all sub-levels. These load profiles are then connected to the electrical grid model.

Sizing of the thermal system and components

- Based on the nominal heat demand of each building, the tool sizes all grid connections automatically, based on expert rules, using a database of district heating pipes and isolations;
- The Energy HUB is also sized automatically based on the heat load of the network.

Hydronic balancing

- Based on the nominal flow demand of each building, the tool automatically balances the thermal network.

Calculation

The simulation is carried out in a loop over time. In each time step, models are either called in sequence or, for strongly coupled components, in a global matrix equation system (eg. building with complete control loop).

All relevant simulation outputs are saved for the current time step in a data output structure. They can be accessed at the end of the simulation for the evaluation of system performances in terms of energy efficiency, emissions and costs.

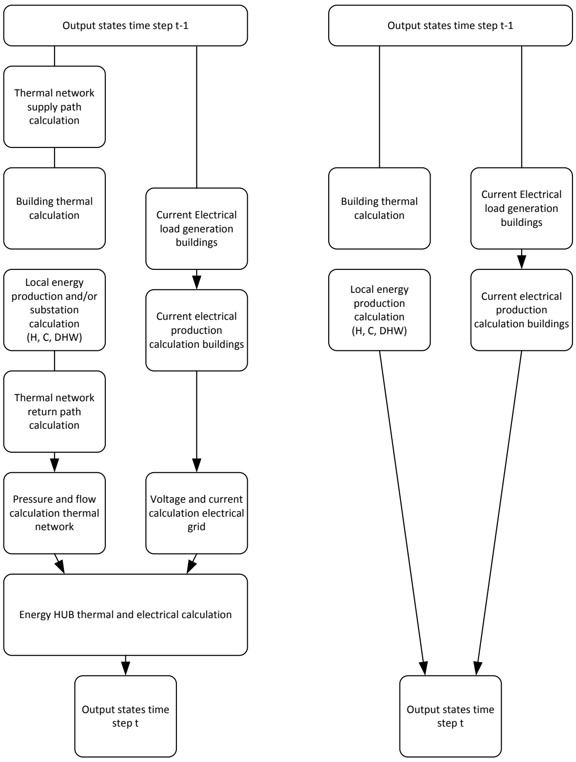


Figure 4: calculation procedure with networks (left) and without networks (right)

IMPLEMENTATION OF PERFORMANCE INDICATORS

The detailed methodology for performance calculation is not described in this paper. It will be the topic of a separate communication.

After the simulation, three types of indications are calculated, each of them on different levels:

- Building level (local production)
- District distribution level
- Central production level (energy HUB)

Furthermore, results are detailed in different groups:

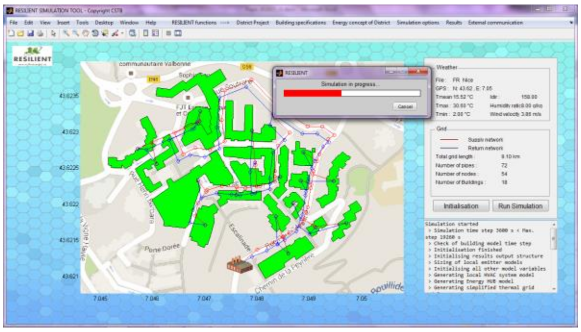
- Energy HUB
- Thermal network
- Local system for heating services (either individual generator or substation in grid)
- Local system for cooling services
- Local system for DHW services
- Building

For each of these groups and levels, the following data is produced:

- Energy performances and consumptions
- CO2 emissions (CO2 emissions are calculated form detailed consumptions using hourly emission data for France)
- Global costs: a global cost module has been implemented in the tool distinguishing costs for investment, maintenance and operation.

EXAMPLES FOR ILLUSTRATION

The import of district data is shown in *Figure 5*. In this example the district description is imported from CityGML data.



File: FR Nice
GPS: N 43.62, E 7.05
Tmean 15.52 °C
Tmax: 30.60 °C
Tmin: 2.00 °C
Idir: 150.00
Humidity ratio 8.00 g/kg
Wind velocity 3.85 m/s
Total grid length: 8.10 km
Number of pipes: 72
Number of nodes: 54
Number of Buildings: 18

```
Simulation started
 > Simulation time step 3600 s < Max.
step 19260 s
 > Check of building model time step
 > Initialisation finished
 > Initialising results output structure
 > Sizing of local emitter models
 > Initialising all other model variables
 > Generating local HVAC system model
 > Generating Energy HUB model
 > Generating simplified thermal grid
```

Figure 5: DIMOSIM GUI with for district heating

In the example, a district heating network has been generated. The topology of the network can either be imported from citygml data, by manual generation or by a hybrid generation. In the latter case, the user draws or imports only main or existing parts of the network and the tool generates all other connections automatically. An optimisation procedure from street topology is under development, allowing to calculate the optimal configuration of the network.

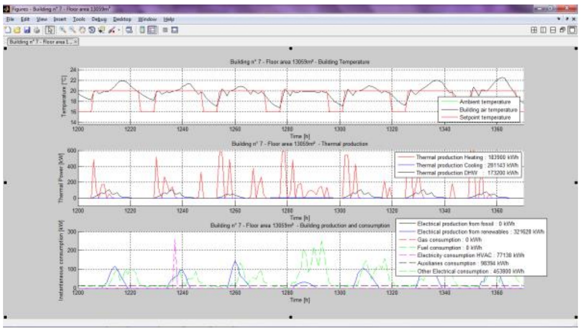


Figure 6: Layout of the thermal grid model structure

Figure 6 shows an example of result on the building level, for one week with hourly calculation. Temperatures, instantaneous powers and consumptions as well as electric, gas or fuel consumptions can be visualised.

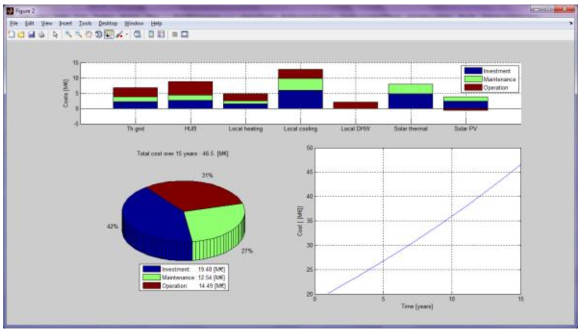


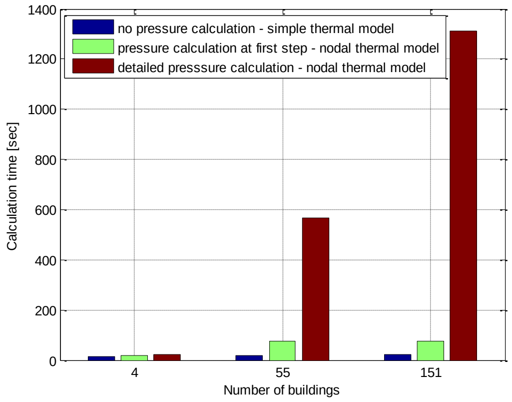
Figure 7: Layout of the thermal grid model structure

Cost data is also generated from sizing data, calculated consumptions and a cost data base. CO_2 emissions are calculated from hourly consumptions and hourly emissions data and displayed as a carpet plot with the days of the year and time of the day.

More detailed information on the use and possible outputs of the simulator can be found in (Partenay et al., 2015).

Simulation speed and district size

The simulation speed on a laptop Core I5 with 2.66GHz for an annual simulation and hourly time step depends strongly on the size of the district.



While the calculation time for a district with 4 buildings and simplified thermal grid with heating, cooling, DHW (solar) and PV calculation is about 15 seconds (5 seconds per building) it takes 23 seconds for 151 buildings (0.15 seconds per building). A test on 700 buildings with the same configuration took 45.6 seconds (i.e. 0.065 seconds per building).

The calculation of solar masks between buildings and ground is about 0.6 seconds per building (proportional with district size).

Thermal network calculation is the weak part in the simulation, especially is hydronic balancing is carried out. Simulation time increases significantly with the number of nodes in the network. Simulations with pressure calculation at the first time step took 74.5 for 55 buildings and 568 seconds for 151 buildings. In case of pressure calculation at each time step we obtained 76.3 (55 buildings) and 1312 seconds (151 buildings).

Concerning the question of the size of the district, the largest district that has been tested is about 3000 buildings, with local energy production and without thermal network.

CONCLUSION

The paper presents the modelling approach of the simulation tool DIMOSIM for the simulation of district energy systems.

The tool has been developed in the frame of the European Resilient and Smart Med park projects for the simulation of districts with and without thermal networks. This approach has been chosen in order to allow case studies on districts for the optimisation of district energy concepts (e.g. choices on building refurbishment, local energy system, district heating/cooling with centralised energy system).

The tool has been developed in a modular approach, allowing an ease implementation of models with higher and lower level of detail since the choice of modelling detail depends strongly on the objectives of the study.

NOMENCLATURE

A	area (m^2)
c_p	specific heat capacity ($J.(kg\ K)^{-1}$)
$\dot{m}$	flow rate (kg/s)
m	mass (kg)
P_{nom}	nominal power (W or kW)
T_{amb}	ambient temperature (°C)
T_b	boiler temperature (°C)
T_{in}	inlet temperature (°C)
T_{st}	storage temperature (°C)
U	U value of heat exchange ($W/m^2/K$)
ρ_i	mean density of node i ($kg.m^{-3}$)
Φ_{comb}	*boiler* combustion power (W)
Δp	pressure difference (Pa)

REFERENCES

Berthou T., Stabat P., Salvazet R., Marchio D., 2014. Development and validation of a gray box model to predict thermal behavior of occupied office buildings, Energy and Buildings 74, p. 91-100.

Gay C., Schetelat P., 2013. Low carbon district - Energy and behaviour modeling, Sustainable places, Nice.

Kämpf J.H., Robinson D., 2006. A simplified thermal model to support analysis of urban resource flows. Energy and Buildings 39, p.445-453.

Molitor C., Gross S., Zeitz J., Monti A., 2013. MESCOS – A multi-energy system co-simulator for city district energy systems. IEEE Transactions on Industrial Informatics (Volume 10, Issue 4).

Partenay V., Caccavelli D., Riederer P., Perez N., 2015. Potential Improvements for Retrofitting Applications in Scientific Technology Park: A Case Study of Sophia-Antipolis using a District Simulation Platform. 8th Mediterranean Congress CLIMAMED, Antibes/Juan les Pins, France

Perez N., Riederer P., Inard C., Partenay V., 2015. Thermal building modeling adapted to district energy simulation. To be published in Building simulation 2015, India.

Resilient project, 2015. coupling REnewable, Storage and ICTs, for Low carbon Intelligent Energy maNagemenT at district level (www.resilient-project.eu)

Vesterlund M., Dahl J., 2015. A method for the simulation and optimization of district heating systems with meshed networks, Energy Conversion and Management 89, p.555-567.