CITYOPT

Holistic simulation and optimisation of energy systems in smart cities

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***Abstract* — CITYOPT is a collaborative project supported by the European Commission through the Seventh Framework Programme (FP7). CITYOPT mission is to optimise energy systems in smart cities. The project will create a set of applications and related guidelines that support efficient planning, detailed design and operation of energy systems in urban districts.**

Keywords-energy efficiency; smart cities; urban planning; detailed design; demand-response; user awareness.

I. INTRODUCTION

68% of the European Union population lives in urban areas, this proportion is growing as the urbanization trend continues, raising the energy demand for private and public consumers and for economic activities with the subsequent increase in CO2 emissions [1].

Furthermore, urban areas have high levels of air pollution, primarily from the burning of fossil fuels in energy production and road transport, resulting in enormous economic and social costs [2][3]. Additionally, energy security is also becoming increasingly important with declining European natural gas and oil reserves together with the current geo-strategy situation [4][5]. This highlights the importance of the development of more sustainable urban areas which are more energy and resource efficient, the use of renewable energy sources, reduction of the carbon footprint, infrastructure development, engagement of the stakeholders and users, removing administrative and regulatory barriers and new business models [6].

The CITYOPT project addresses energy system optimization in different lifecycle phases, supported by a user-centred design approach. Stakeholders, including city decision makers, city planners, energy utilities, facility managers, and citizens, are involved in all project phases.

CITYOPT develops a set of applications and guidelines supporting efficient planning, detailed design and operation of energy systems in urban districts. Business models for the use cases have been developed and are shortly described in this paper. The project considers appropriate service business models, privacy and trust and involves users in all the project phases.

This paper presents the overall context in Section II and project objectives in Section III. It then introduces the 3 pilot case studies in Austria, Finland, and France in Section IV. Finally, preliminary results and expected results of the approach are presented in Section V.

II. URBAN ENERGY SYSTEMS

A holistic view considers integrating the design of the urban areas, the built environment, infrastructure and the energy system creating opportunities to explore the possibility to optimize the use of resources and synergies in an efficient way. However, existing cities are captive to their history which constrains the implementation of new measure without high economic investments. Nevertheless, relatively short turnover times for many technologies provide opportunities to improve the efficiency and develop integrated design [7]. The following aspect should be considered during the design and use of the urban energy systems:

- Energy efficiency of the built environment

The primary focus of energy-efficiency in most cities is on the built environment (i.e., dwellings and commercial properties) which should be designed to optimize their sustainability. This situation implies a strong argument for definition and regulation of building standards.

- Supply side

The supply side is having an important progress in innovation to design efficient energy networks which allows integration of energy resources, such as solar energy, heat pumps, fuel cells etc. or the use of energy storage systems, allowing shifting the production to match with the demand. This integrated thinking has been highlighted in the design of the new eco-cities, avoiding strong dependence to fix solution as big power plants and giving to the city an integrated growth based on a higher flexibility from the energy supply side.

- Holistic approach - Optimisation of the energy systems

Energy systems are traditionally designed separately looking at demand and production as separate issues. There has been some progress in linking demand and transmission with for example demanding low temperature heating systems in buildings to enable low temperature levels in district heating systems. To analyse the whole energy system from demand to production with one design tool is a new approach. Also to include both heating, cooling and electricity into one holistic approach is a new aspect in

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planning energy systems in districts. Systems and integration methods could have an important potential for reductions in direct primary-energy use, without other significant physical impacts, and significant advantages in terms of a reduction in externalities of energy use such as air pollution.

- Role of real-time monitoring and steering systems

For the new urban energy system design expertise should also focus on the operational phase. There are opportunities in the field of Information Control Technologies (ICT) applied to the urban energy sector which enables effective management of the real-time performances of the energy systems, allowing the interaction between them and citizens, which could be increased through real-time energy pricing, virtual energy markets, real-time displays for households, large building, neighbourhood, city resource-use profiles, and personalised decision-support services.

III. Objectives

CITYOPT addresses energy system optimisation in different lifecycle phases, considering potential and user & stakeholder involvement characteristics (Figure 1):

- **Planning tools** - support analysing, simulating, optimizing and communicating different alternatives in the city planning. A holistic approach integrates energy dynamics of local grids and buildings, consumption behaviours, energy storage, and local energy production units.
- **Design tools** - optimise design for energy efficiency of supplementary construction and renewable integration ensuring grid stability. Stakeholder and user research on design requirements specifies how new or retrofitted energy efficient buildings interact with nearby buildings through local energy networks, e.g., exchanging surplus renewable heating/cooling energy.
- **Operational tools** - increase optimization opportunities related to user behaviour, like residential demand response schemes for inhabitants to participate in online-optimization, and visualizations to engage users.

IV. Pilots

Three case studies in different climate zones will demonstrate the CITYOPT solutions:

A. *Helsinki, Finland*

The Helsinki case study evaluates electricity- and heat storage solutions and business models in the new residential districts of Kalasatama and Östersundom. In the planning phase of the new districts, CITYOPT applications will examine technologies, sizing, placement and steering of electric and heat storage solutions, to find the optimal storage solutions.

In both study cases of Helsinki, the optimisation task is divided into two connected parts:

- Design optimization (I)
- Operational optimization (II)

In part I, the optimisation will strive to choose the correct type and size of energy storage unit(s) and its connections to energy producers and consumers. This being done, the second part of the optimisation (II) will find the operational optimum. Thus the problem is a bi-level optimisation. The optimisation tasks are described below in terms of:

- Process description
- Performance metrics with constraints
- Degrees of freedom
- Scenarios

The bi-level optimisation means that the operational optimisation (II) runs inside the design optimisation (I). In other words, for each design candidate from part I, a new solution of the operational optimisation (II) will be solved. This enables a more holistic analysis of the situation and can provide some new insights in what is the best combination of solutions for both design and operation strategies.

B. *Vienna, Austria*

In Vienna, at the Austrian Institute of Technology (AIT) premises, CITYOPT investigates the optimal design and possible implementation (including cost assessment and business model development) of integrating the AIT buildings, their existing energy supply and storage systems, and the cooling system of RTA's climatic tunnel into a site-wide energy system that uses the waste heat to heat office buildings. The expected impact will be to maximize the utilisation of waste heat to increase the energy performance and reduce CO2 emissions of the overall urban area modelled in the study case.

The optimization process in the Vienna study case is based on the integration of a thermal energy network of the office buildings, current supply systems, energy storages together with the use of the waste heat from the RTA´s climatic wind tunnel.

The performance metrics which will be taken into account in the objective function are:

- Energy consumption (kWh)
- CO2 emissions (tons)
- Investment cost (€)
- Running cost (€)

Running cost makes reference to the operational and maintenance cost. The design optimisation should set the best option according to the objective function and constraints defined by the user. The objective function also will be able to combine all the listed metrics weighted properly by the user. There are two main goals; first, to optimize the design of this thermal energy network by a suitable design of the water tank which is used as thermal energy storage and the number of boreholes of the ground heat exchanger and second, the optimisation of the operation of system taking into account the temperature levels and the mass flows.

In this context, there are several type of constraints that should be considered to perform the optimization process: the maximum size of the water tank, the maximum area were

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the boreholes of the heat exchanger can be allocated, the maximum temperature of the ground which can produced by the rejected heat, the minimum and maximum temperature levels of the warm water needed to cover the heat demand of the office buildings, economical constraints based on the investment and operational cost of the system, oscillations on the production of the waste heat from RTA´s climatic tunnel due to its use and the influence of the weather conditions in the heat production from the solar thermal panels.

To produce usable information, the optimizations are performed in different scenarios which comprise different options in terms of the design of the water tank, ground heat exchanger, the district heating networks together with operation of the system according to the variation on the defined constraints. These scenarios could include the best design of the district heating network: to maximize the rejected heat to the ground to maximize the energy efficiency of the chillers of the RTA´s climatic tunnel, to minimize the CO_2 emissions of the overall system according to the technical and economic constraints, to minimize the importation of the energy (gas and electricity) to the system, to minimize the energy bill of the of the office buildings, etc.

C. Nice Côte d'Azur, France

Provence Alpes Côte d'Azur (PACA) is one of France's most fragile regions for electricity supply. In Nice Côte d'Azur, CITYOPT will develop and demonstrate innovative demand-response services, to reinforce the continuity of service of the electricity supply network. 200 families will be recruited to participate in the experiment. CITYOPT will analyse the conditions for which the customers will agree to modify their behaviours, within a CITYOPT energy community.

The CITYOPT NCA case study takes place amid restrictions of energy use at certain times of the day due to dated electricity infrastructure. Nice depends on a single high voltage transport line which supplies electricity to the south east of France (around 5 Million inhabitants), covering in particular the densely urbanized coast from Marseille to Menton. Due to the tourism attractiveness of the region, the population can be doubled in certain towns during summer holidays. As an answer to the recurrent problem of higher peaks in load demand, the French electric energy supplier EDF is forced to use thermal power plants which generate CO_2 emissions and have a high cost in terms of maintenance.

The Nice case study will develop and experiment an internet application called Community Network for Energy. Its objective is to encourage individual actions for promoting the reduction and/or shift of power consumption at homes during peaks of consumption in the PACA region. EDF consumers use electricity primarily for heating, cooking, dish and clothes washing, and consumables operation. As a reward, the dwellers earn bonuses that will be invested in useful projects in the community to which they belong to. Such projects are for example funding of new public buildings, such as schools, an academic project, cultural activities, or complimentary "Vélo Bleu" (electrical bicycles) memberships. Thus, instead of using additional and punctual energy production from thermal power plants, end-users of electricity will "learn" how to consume energy in a better, more optimized way and at the same time they will benefit from these economies of scale for their community. When joining the experiment, the 200 volunteers will have at their disposal a tablet pc to access the application.

The community Network for Energy developed and tested in CITYOPT is a new mean:

- to contribute to energy demand reduction of households through increased energy awareness;
- to contribute to time-shifted energy usage, through timely demand-response notifications;
- to enhance coherence between different energy projects/services and city planning alternatives.

The project will offer a new insight on how citizens react to the utility's request and how the community scale and crowd funding approach offered in the application act as incentives. A 12 months operational validation and test phase with the 200 volunteers will be conducted from October 2015 to September 2016.

V. RESULTS

The CITYOPT holistic solution is composed of two layers as represented in Figure 1: it includes both a planning application and an operational application.

A. CITYOPT planning application

The CITYOPT planning application is ready for demonstration use. The tool is designed to be used by city planners and energy systems planners in the early design phase of a district. The user first enters the basic information about the area. After this the user can create different scenarios regarding the energy solutions, the scenarios are then simulated by the CITYOPT Planning application using APROS simulation software. The next step is to choose the weighing factors for the optimisation. The user can choose for example that economic factors should be weighted with 80% emphasis and CO_2 emissions with 20%.The tool gives as result which of the scenarios is the most optimal according to the chosen weighing factors.

A genetic algorithm based optimization can be performed where the application seeks the best solution by creating a number of scenarios by itself and seeking the most optimal scenario within the constraints set by the user, meaning that the optimal scenario can be different from one of the scenarios chosen by the user. If the genetic algorithm ends up with Pareto optimal scenarios, the user can then execute the weight based optimization to acquire the most optimal scenario.

B. CITYOPT operational application

The CITYOPT operational application is currently being implemented and will be tested in Nice Côte d'Azur. A typical user journey in the application is presented below in the following 6-steps tutorial:

1. Welcome to CITYOPT: a community committed to protect the environment, avoiding overconsumption and resources waste.
2. CITYOPT engages citizens through the support to local projects. Projects will address issues at the neighbourhood scale, lowering the impact on the environment.
3. Like in crowdsourcing, people can support their favourite projects. Support is given “investing” CITYOPT points in one project or more. CITYOPT points are the “currency” used to back projects up. Points are earned by CITYOPT members for their successful commitment during peak load alerts.
4. CITYOPT calls its participants to rally to avoid severe peak loads. The entire community has a common mission: reduce energy waste and respect the environment.
5. Participants set ready for an alert laying out a strategy. Choosing what will be off, decreased of shifted during an alert will allow people to gain points to be later invested in community projects.
6. CITYOPT will succeed if people will engage with each-other. Participants will receive after each peak the result on their energy savings (at the individual scale and at the community scale) based on the load curve analysis (statistical models are implemented). Moreover participants can tap into social networks to show their commitment and get others to join for a healthier environment.

Users will receive regular notifications and updates before and after every alert on their mobile phones and email.

VI. CONCLUSION

CITYOPT seeks to assist the challenges posed by ever increasing urbanization and the pressure placed on grid infrastructure in cities. It looks at how grid optimisation can help to improve the utilization of renewable energy generation and the impact on local energy markets. In addition to this, considerable user analysis is performed in an attempt to shed further light on the reactions and behaviour of people using the networks and the buildings involved and ensure solutions developed will be well received.

A comprehensive technical and socio-economic evaluation of the 3 CITYOPT pilots will be conducted and publicly documented by the end of 2016. It will include an analysis of the replication potential of CITYOPT solutions from one country to another.

ACKNOWLEDGMENT

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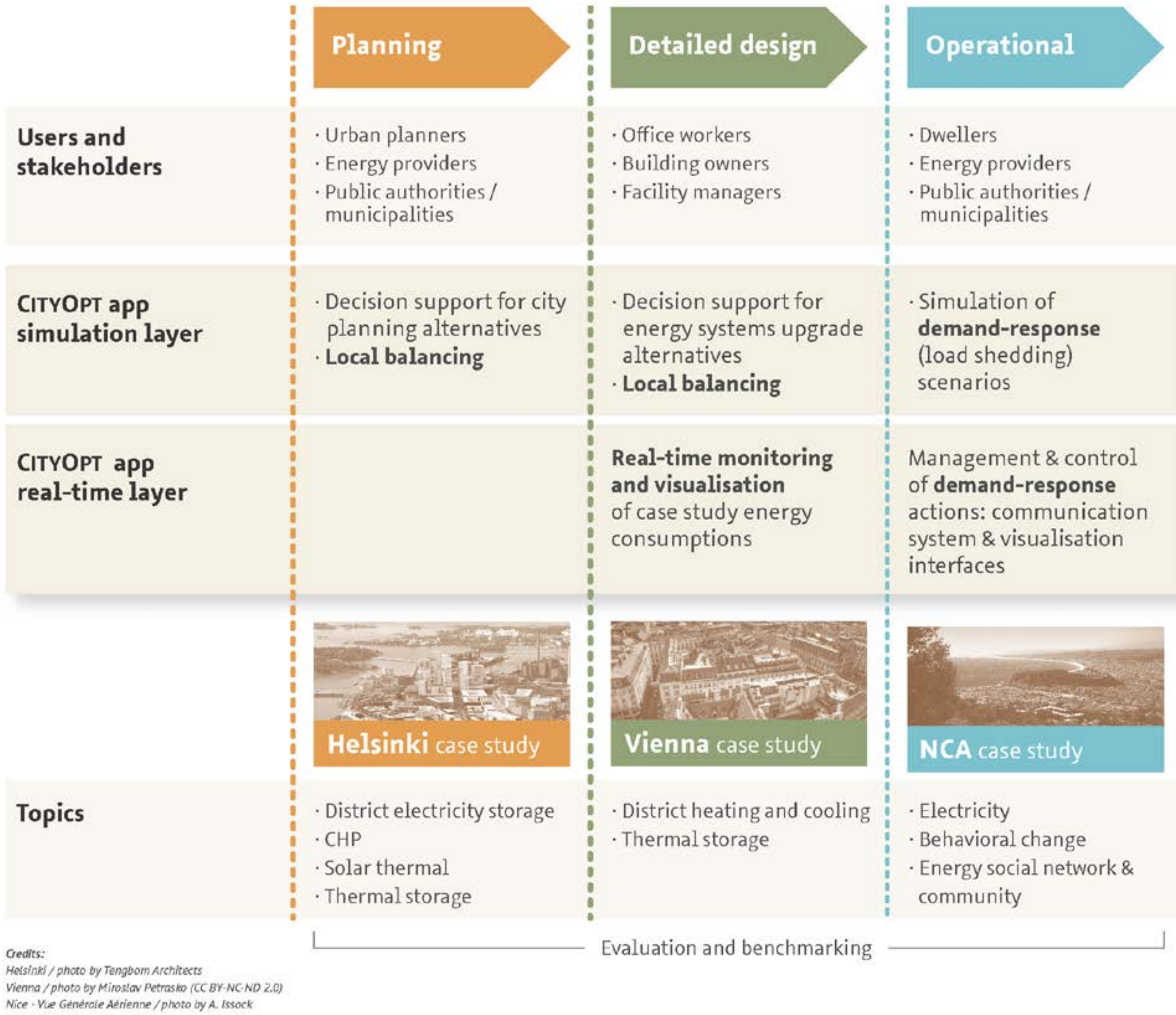

Figure 1. CITYOPT holistic approach of energy systems optimisation in smart cities