Sustainable Places 2015

Conference Proceedings

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Foreword

Sustainable Places 2015 is the third edition of a successful event that brings together the stakeholders of Energy Efficiency of Built Environment innovation in Europe. The conference is committed to support all players of the Energy Efficiency field, in their clustering and dissemination activities. The event features a strong and sustained relationship with the projects funded by the European Commission under the FP7 and H2020 frameworks, with a particular dedication to those that develop under the umbrella of the Energy Efficient Building Public-Private Partnership.

The need to enhance the sustainability of places – buildings, districts, cities – where we live, work and have leisure, is now acknowledged as one of the top contemporary societal concerns. Enabling sustainable places requires a major breakthrough that encompasses many dimensions: making regulatory and policy frameworks evolve, increasing business incentivization, fostering technology innovation and assessing societal impact. The recognition of the multiple dimensions of the issue is at the very heart of the Sustainable Places initiative. The aim at the beginning, back in 2012, was to foster inter-disciplinary dialogue between the stakeholders, and in particular to support cross-fertilization between downstream business-oriented innovation and upstream technology-oriented research.

Indeed, in the area of technology innovation, the gap between research and market is often referred to as "Death Valley". It maps roughly to the Technology Readiness Levels (TRL) 4 to 6, i.e. the level at which a prototype has been developed, but has only been experimented in limited scales - wider field deployment and business-oriented technology sharpening is still needed to address the market needs. The need to devote great effort to this gap and bridge it is widely shared, in particular in the H2020 programme that puts an emphasis on so-called "Innovation Actions".

Sustainable Places simply aims at being one (among many others) component of this innovation gap-bridging strategy at European level. Bringing together researchers from multiple areas, business stakeholders, local authorities, enabling for projects clustering and sharing market insights, performing wider dissemination of the European knowledge - in a few words, to enable an open, fruitful and constructive dialogue – is the main objective of the conference.

This year's edition is particularly attractive, with a large audience (more than 150 registrations) from key on-going European projects, high-profile keynote speakers from diverse backgrounds (industry, research, SME), a wide thematic spectrum (from building energy modelling to district-level energy management), and - last but not least - an outstanding venue (Savona, on the Mediterranean coast)!

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Off-design analysis of a micro gas turbine under stochastic conditions

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Abstract

The concept of energy support is heading more and more towards the idea of a distributed production, which points to a gradual replacement of the standard production concept centered on single large units. In this respect, for example, uncertainty associated to the energy demand of each unit of a district becomes a fundamental point to take in account: thus, a probabilistic approach to the analysis of distributed generation systems is highly recommended. In this sense, an off-design steady-state model of a micro-gas turbine (mGT) has been employed: it is built on the configuration of a Turbec T100 actually installed at the research laboratory of the Thermochemical Power Group. In particular, elements of uncertainty linked both to operating parameters of the machine and to the load demands during the year were present. Uncertainty analysis has been treated with two different methods. The first and most famous is Monte Carlo method, which, however, requires a large time consuming in order to achieve the necessary number of samples. It is clear that its application for analyze such complex systems would be computationally inefficient and expensive so, this paper proposes as alternative an approximated method called Response Sensitivity Analysis (RSA). It is based on Taylor series expansions and promises good accuracy still retaining acceptable computational time. This work has led to the following results:

1. Estimations of probabilistic distributions for electrical power production at the outlet of generator, fuel consumption and net efficiency of the system during the entire working period; and in addition
2. An evaluation of the most probable return on investment time and the range within it could fall, depending on the requested interval of confidence based on the standard deviation of the output distribution probability.
3. Moreover, RSA has shown a wide compatibility with different types of problems, promising an easy applicability and scalability in different fields of study.

Keywords

Micro gas-turbine, design under uncertainty, monte-carlo simulation, response sensitivity analysis

Nomenclature

Abbreviation

CHP	combined heat and power generator
MCS	Monte Carlo Simulation
mGT	micro Gas Turbine
RSA	Response Sensitivity Analysis

Variables

$g_{Mj}(Z)$	functional relationship between j-th output parameter and the inputs Z
$\dot{m}_0$	nominal mass flow [kg/s]
M_j	j-th parameter of output for the system
M_{ji}^+	value of j-th output calculate at one step size forward of i-th input
M_{ji}^-	value of j-th output calculate at one step size backward of the i-th input
p_0	nominal pressure [Pa]
R_0	gas constant [J/kgK]
T_0	nominal temperature [K]
Z_i	i-th parameter of input for the system

Greek Symbol

β_0	nominal compression ratio
ε_0	nominal expansion ratio
η_0	nominal efficiency
μ_{Mj}	mean value of the distribution of j-th output variable
μ_{Zi}	mean value of the distribution of i-th input variable ν_{Mj} variance of the distribution of j-th output variable
ν_{Zi}	variance of the distribution of i-th input variable
σ_{Mj}	standard deviation of the distribution of j-th output variable
σ_{Zi}	standard deviation of the distribution of i-th input variable

Introduction

Energy is and will continue to be the backbone of the global economy in the foreseeable future. However, due to fast rising energy prices, climate change and technology advances, reshaping the energy industry has become an international priority (International Energy Agency, 2012). The overall energy efficiency and cost-effectiveness of fossil-fueled power generation can be improved based on the availability of new technologies in terms of combined heat and power (CHP) plants (Yazdi, B. A., et al, 2015). The CHP plants can be used to supply both electrical and heat loads by utilizing the waste heat produced during electric power generation, which, in turn, reduces the thermal pollution in the environment. Therefore, optimization of such systems is of the great importance in the area of power generation. However, there are still myriads of uncertainties that ultimately besiege the design and operation of CHPs (Gamou S, Ito K., Yokoyama R, 2002 - Mücke R., Vogeler K., Voigt M., Oevermann M., 2004). In a deterministic framework, the accuracy of the output solutions depends on the accuracy of the input variables when the possibility of some prediction error is just common (Aien M, Ehsan, 2011 - Caire R, Ehsan M, Hadjsaid N., Soroudi A, 2011). The uncertainties associated with model input parameters can affect both the short- and long-term performance and the cost. In order to reduce the error associated with the uncertainty of the input variables, methods for system design under uncertainty become essential (Kim K., Nelson D.J., von Spakovsky M.R., Wang M., 2011).

The objective of this paper aims at proposing and assessing a comprehensive framework for uncertainty analysis (Ajah Austin N. a,b, Bouwmans Ivo a , Heijnen Petra W. a, Herder Paulien M., Houwing Michiel a, 2008) in the distributed generation field. In particular, this paper presents the study of a micro-turbine, the Turbec T100, actually installed at the research laboratory of University of Genoa, in Savona (Ferrari M., Pascenti M., Magistri L., Massardo A.F., 2010) under stochastic conditions. This work focuses on a stochastic analysis of the performances of mGT, no optimization for cogenerator working condition are considered and its operating conditions are simply assumed in order to evaluate the uncertainties on outlet parameters. The MCS and RSA methods were applied on this system model to estimate its main performance and economic parameters under the influence of the uncertainties related to various operating parameters.

Methods

Simulation of a deterministic model provides a set of outputs, which may give an incomplete and frequently misleading representation of the system. To complete this information, the sensitivity (variability) and uncertainties in the results are needed. A deterministic single-point simulation gives no value of the range of sensitivity, which may be expected in the system, and it also does not provide information about the uncertainties in the results. Uncertainty analysis methods can be classified into sampling methods (e.g., Monte Carlo simulation (MCS), Latin hypercube simulation, etc.) and approximate methods (e.g., response sensitivity analysis (RSA) method, fast probability integration methods, etc.) (Kim K., Nelson D.J., von Spakovsky M.R., Wang M., 2008).

MCS

Among the sampling methods, MCS is the most common traditional probabilistic simulation technique for performing a probabilistic analysis on a model via a very large number of repeated simulations. Once the probabilistic information of a variable such as the mean value, the variance, and/or the probability distribution is known, the randomness of the variable can be simulated close to its true or real randomness using a random number generator (Kim K., 2008). By repeating the same process based on a set of randomly generated input variable values and storing the system output values, a set of probabilistic values and probability distribution functions (PDFs) of the output variables is obtained. This type of approach explicitly results in exact uncertainty (relatively speaking) propagation from the input variables to the system response provided, of course, given that the sampling number is high enough.

RSA

However, even though MCS produces exact solutions it is not very practical because of the very large computational effort or burden required. This computational difficulty can be overcome by approximate approaches as the sensitivity-based approximation approach, the RSA method, in which system outputs can be found by a Taylor series expansion (Kim K., 2008). If only the mean and variance of each system input $\boldsymbol{Z_i}$ are known and an implicit nonlinear functional relationship $\boldsymbol{g}_{\boldsymbol{M}_j}(\vec{\boldsymbol{Z}})$ between each system output $\boldsymbol{M}_j$ and the inputs $\vec{\boldsymbol{Z}}$ is available, the approximate mean and variance of each system output $\boldsymbol{M}_j$ can be estimated by using a Taylor expansion as reported in equation 2.1 and 2.2.

$$\mu_{M_j} = \mu(M_j) \cong g_{M_j}(\mu_{Z_1}, \mu_{Z_2}, \dots, \mu_{Z_n}) + \frac{1}{2}\sum_{i=1}^{n}\left(\frac{\partial^2 g_{M_j}}{\partial Z_i^{\,2}}\right)\nu(Z_i) \tag{2.1}$$

$$\nu_{M_j} = \nu(M_j) \cong \sum_{i=1}^{n}\left(\frac{\partial g_{M_j}}{\partial Z_i}\right)^2 \nu(Z_i) \tag{2.2}$$

System description and modeling

The model of the mGT, implemented in Matlab-Simulink environment, is based on the Turbec T100, actually installed at the research laboratory of the TPG in Savona (Ferrari M., Pascenti M., Magistri L., Massardo A.F., 2010).

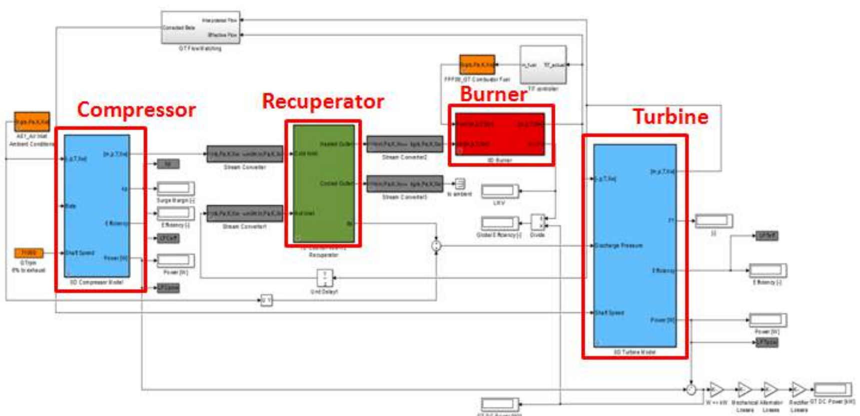

Figure 1: Simulink model layout of the mGT system

In particular, both compressor and turbine maps, based on experimental test, were implemented in the code. Compressor and turbine data (Caresana F., Comodia G., Pelagallia L., Renzi M., 2014) extract at 100% of load condition are reported in Table 1.

Variable	$\dot{m}_0$ [kg/s]	T_0 [K]	R_0 [J/kgK]	p_0 [Pa]	β_0 or ε_0	η_0
Compressor	0.858	288	288.1836	101300	4.3435	0.78
Turbine	0.8253	1170	294.41	400000	3.4057	0.83

Table 1: Compressor and turbine nominal data.

Since the nominal design is a critical issue in the performance analysis of mGT, in this paper the uncertainties on compressor nominal efficiency of compressor and turbine were taken into account:

Rotational speed		*Compressor nominal efficiency*		*Turbine nominal efficiency*	
μ	σ	μ	σ	μ	σ
71000	355	0.78	0.039	0.83	0.0415

Table 2: Mean and standard deviation values of input variables

In addition, an uncertainty in the load demand was implemented in the analysis considering, that the mGT works at the load conditions reported in Table 3.

% of the load	*Operating hours*
100%±5%	1/3* annual operating period
80%±5%	1/3* annual operating period
50%±5%	1/3* annual operating period

Table 3: Load condition and corresponding working period

Such uncertainty was implemented in the model in order to understand the impact in the performance (fuel consumption and efficiency) and payback period of the mGT. The assumptions for the calculation of the payback period are:

- An initial investment of € 130.000 for the purchase of mGT
- Revenue of € 0.18/kWh for electricity sold
- Revenue of € 0.08/kWh for heat sold
- A cost of € 0.6/kg of fuel consumed
- An annual cost of 1% of the total investment to take into account the maintenance cost
- An operating period of 8000 hours per year

In particular, the effect that each input has on the considered outputs was analysed through the MCS and RSA method.

Results

The micro-turbine model gives the possibility to monitor various operating parameters, such as: electrical power, fuel mass flow and the net efficiency of the system. The probabilistic distribution of outputs was obtained using both the MCS method and RSA analysis by introducing the effect of stochastic inputs described before. The first method was performed using a sampling number equal to 300 and the achieved distributions were taken as references for the Response Sensitivity Analysis. Looking at the following figures, where all the parameters obtained at the 100%±5% of electrical load condition are reported, the formulation of RSA using the second order mean is able to obtain results very close to the MCS, which is considered as a reference. All the pdfs of output values show a good level of approximation both for their mean values, RSA distributions are centered on the MCS ones, and for their standard deviations, the shapes of distribution obtained from the two methods are very similar.

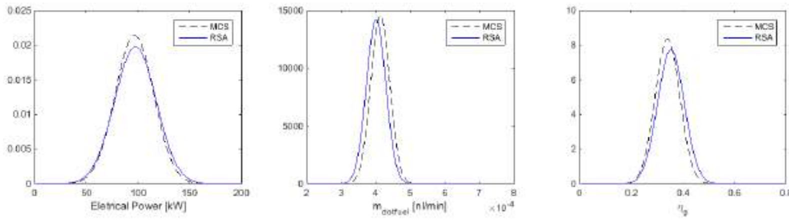

Figure 2: Comparison between MCS and RSA results: electrical power, fuel mass flow, net efficiency

Then, for each fixed operating condition, a simple economical study on the payback period was performed: there are not relevant differences between the estimation of output using MCS or RSA underlining the robustness of the latter.

The calculation of PBP under stochastic conditions allows to estimate two different important aspects: on one hand, it lets to obtain the most probable period for the return of investment as the mean value of a normal distribution; and on the other hand it useful to evaluate the range, in which it is possible that this value can vary. The semi-amplitude of this last interval is set here equal to the standard deviation.

All this procedure was repeated also at 50%±5 and 20%±5 of electrical load, showing similar level of approximation in the comparison between MCS and RSA. In the end, the same economic analysis was developed, but this time taking in account all the three possible working conditions during the whole year. This is a complex situation to study with a strong non-linearity, and it causes the larger approximation error found until now using RSA. On right hand side of Figure 3 the corresponding cash flow diagram is reported, in order to explain graphically what was obtained from this analysis. As shown in this figure, the prediction on the mean value of the PBP distribution is still accurate but the range of variability linked to the standard deviation results underestimated respect the one used as reference. A plausible explanation of this has to be found in how the RSA works. In fact, the Response Sensitivity Analysis estimates the single output reaction to each stochastic input and uses the superposition of effects in order to evaluate the final results. When, as in this case, the input values are not independent, there could be a higher approximation error. In particular, for this mGT model, the correlation between inputs seems to be more influent as the load condition becomes lower, and could explain the difference in estimation of standard deviation.

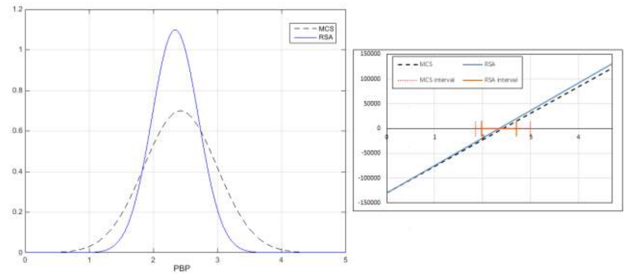

Figure 3: Final Pay Back Period distribution (left side) and cash flow diagram (right side)

Overall, this application shows that Response Sensitivity Analysis provides results quicker than MCS, but maintaining a good level of approximation even in those cases that presents relative high level of non-linearity.

Sensitivity analysis

An important aspect of Response Sensitivity Analysis method is its capacity to estimate the impact of each single input on the monitored outputs. This is done through the parameter called sensitivity, defined as the first derivative of outputs with respect to the input variable, which can be non-dimensionalized as it follows:

$$\boldsymbol{Sensitivity} = \frac{\partial g_{M_j}}{\partial Z_i}\frac{Z_{i,nom}}{g_{M_{j,nom}}} \tag{5.1}$$

In this way, it is possible to know how much influence each input can have on the monitored parameters. The following series of pictures show, on one hand what is the different effect of inputs at a fixed operating condition, and, on the other hand, how this effect evolves if the working condition is changed. It is clear for this system that reducing the load condition, the influence of every input increases: this behavior is observable with different magnitudes but it appears as a common aspect for every parameter.

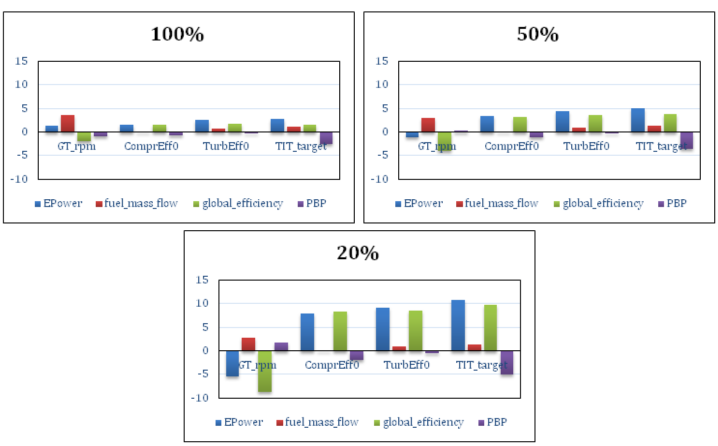

Figure 2: Sensitivity of the outputs to each input variable at 100%, 50% and 20% of electrical load condition

Conclusion

A stochastic analysis of a mGT turbine was performed in order to understand how the uncertainty of the input parameters influence the outputs. In particular, the variability in the load demand and in the performance was taken into consideration to evaluate the impact on fuel consumption, net efficiency and cost (payback period). The analysis was performed with MCS and RSA methods and the results were compared. In general the RSA approximate method is able to return the most probable value of each monitored variable and the range, described in terms of standard deviation of the outlet probabilistic distribution, where it could fall, with a small error in respect to the MCS method. For the economic point of view, considering the scenario reported at the end of chapter 3, the value of 2.34 years was found for the most probable Pay Back Period with a range of ±0.36 years of variation where it could fall with 68% of probability. Both methods provides the possibility of threating problems with high level of uncertainty linked to their internal variables, but the RSA has remarkable advantages:

- It shows an important saving in computational time if compared to traditional stochastic analysis like Monte Carlo simulation, conserving a good accuracy. For example, using a 3,30GHz, 8 GB computer, looking at the necessity of more than one hour to conduct a MC simulation with 700 samples, the RSA takes only about 10 minutes to get results.
- It can be used to easily investigate the direct effect of single uncertainty on final results, in order to know what are the most influent inputs and what are the negligible ones.

In conclusion, the suggested route to employ MCS and RSA is: perform a limited number of Monte Carlo simulations during the initial phase, to define the references values of the output distributions and then utilize the Response Sensitivity Analysis to quickly verify all the changes made during the development of the project.

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Thermo-economic analysis of the energy storage role in a real polygenerative district

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Abstract

This paper presents simulation analysis based on data from a real Smart Polygeneration Microgrid (SPM), designed to satisfy energy demands of the University Campus of Savona (Italy). The plant is made up of different generators (conventional, cogenerative, renewable), which are “distributed” around the campus and coupled to electrical and thermal storages. Since the grid is constituted by co-generative units, the integration of storage is really important in order to follow both the thermal and electrical requests, pursuing the best management strategy.
WECoMP software, developed by the Author's research group, was used to find the best operational strategy showing the importance of an appropriate storage system to manage the grid taking into account its polygenerative features. The integration and the combination of three different kind of storage were analyzed: hot water tank, cold water tank and electrical battery. Different scenarios are presented combining the storages and showing the impact of them in terms of money savings and reduction of electricity purchasing from the National grid, both considering an interconnection with the National grid and to operate the SPM in-island mode.

Keywords

Polygeneration, energy storage, thermoeconomics, distributed generation.

Introduction

As District Energy (DE) is an energy concept that offers many advantages in terms of energy savings and reduction of emissions, consequently research has been ongoing in order to improve its efficiency. Energy technologies that can be integrated with DE include CHP (Combined Heat and Power), TES (Thermal Energy Storage), renewable energy sources (RES) generators. multi-fuel heating, electric and non-electric chilling. In particular, TES can enhance the performance of DE significantly as shown in many recent investigations about the impact of TES in polygenerative districts (Rezaie et al., 2014) (Rezaie & Rosen, 2012). Furthermore, Distributed Generation (DG), aims to concentrate energy production close to the users reducing or avoiding thermal and electric losses through the grid (Menon et al., 2013)**Erreur ! Source du renvoi introuvable.**. Nevertheless, according to the unpredictability of many RES and the different peak moments for thermal and electrical energy demands in district, storage and efficient control strategies are needed.

Thermoeconomic analysis is a well-known method to approach energy systems, in order to develop efficient and profitable real time controllers and to identify the most suitable enhancements in terms of installed equipment (Ferrari et al., 2014). The purpose of this paper is to optimize the management of a real polygenerative energy district installed at the University of Genoa campus located in Savona (Ferrari et al., 2014) (Cuneoet al., 2014) managing local generators to satisfy thermal (warming and cooling) and electrical load demands of the district and managing in the optimal ways the energy storage installed in the demonstrator. A one-year analysis is carried out with one hour time horizon, taking into proper account the time-dependent nature of energy demands, RES generation and investigating the best operational strategy for the devices. The optimization is performed employing the software W-ECoMP (Web-based Economic Cogeneration Modular Program), developed by the Authors' research group (Cuneoet al., 2014) (Rivarolo et al., 2013).

Polygenerative district layout

The plant investigated is the Smart Polygenerative Microgrid (SPM) shown in Figure 1, installed in the University of Genova campus, located in Savona (Italy) and it is one of the demonstrator sites in the FP7 European Project RESILIENT (www.resilient-project.eu).

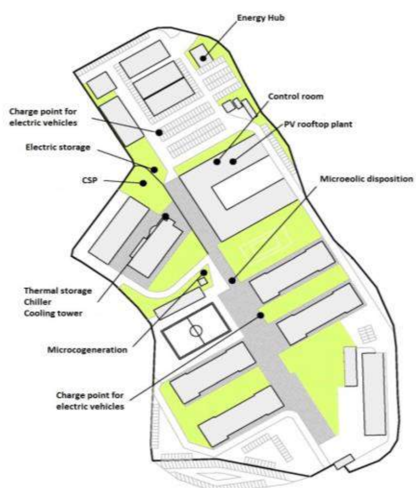

Figure 1: University of Genoa campus located in Savona (left) - SPM overview (right)

The SPM installed in Savona is presented in Figure 1: it includes several commercial CHP units, traditional prime movers and renewable generators, as it follows:

- A co-generative micro gas turbine (mGT) Turbec T100, 100 kWe, 165 kWth and a co-generative internal combustion engine (ICE) TANDEM T20, 20 kWe, 44 kWth: these two generators are included in the Innovative Energy Systems laboratory.
- 2 storage tanks for hot water, with a total volume of 10000 l (Energy-Hub lab.) and 1 storage tank for cold water with a volume of 3000 l.
- 1 co-generative micro gas turbine (mGT) Capstone C30, 30 kWe, 49 kWth and 2 co-generative micro gas turbines (mGT) Capstone C65, each rated 65 kWe, 112 kWth;
- A photovoltaic roof, about 400 m2 (about 77 kWe of peak power);
- 3 CSP dish Stirling units, each rated 1 kWe, 3 kWth;
- 2 conventional natural gas boilers, each rated 500 kWth, $\eta = 0{,}90$;
- 2 absorption chillers, LWM-W003, each rated 100 kWth;
- A FIAMM SoNick electrical energy storage, with a capacity of 470 Ah and a Nominal voltage of 300 V.

The SPM is connected to the National electrical grid in a single point and it is able to sell and purchase electricity. The CSP dish Stirling units (Figure 1 previous page) energy contribution to the grid is not considered in the analysis, as it is too low.

W-ECoMP tool for energy district optimization

W-ECoMP (Web-based Economic Cogeneration Modular Program) is an original modular tool developed by the Thermochemical Power Group (TPG) (www.tpg.unige.it)(Rivarolo et al., 2013), at the University of Genoa. It aims to the thermo-economic, time-dependent analysis and optimization of energy systems. Each component in the library is described by three subroutines, defining mass and energy flows, off-design performance curves, variable and capital costs (Ferrari et al., 2014) (Cuneoet al., 2014) (Rivarolo et al., 2013). The analysis of a plant can be performed considering different economic scenarios, and looking at two different levels:

- The operating strategy for existing energy systems (low level)
- The size of components or whole plant design (high level)

Capital and variable costs are considered for the system size optimization, while only variable costs are considered to optimize the operating strategy.

In the software, only energy and power flows between units are considered: fuel mass flows and consumptions are evaluated from the energy flows and the features of the generators, which are input data from the user. The thermal storage is modeled starting from a volume capacity and evaluating the storable thermal energy by hot water with that volume and a fixed temperature. The electrical storage is modelled starting from a capacity and evaluating the storable electrical energy taking into account the different type of battery (Li-On, Sodium

Nickel, Lead Acid), the depth of discharge and the power of the inverter coupled to the battery.

In order to study storage management, as they have not any effective variable costs, a fictitious costs system was designed. Storage energy cost is based on primary energy cost. The filling/emptying strategy is then decided according to a predictive vision, based on a three-hour energy demand interval, for each simulation instant.

Constraints to the problem are the balance equation between supply and demand of the components. For example, the energy produced by each generator (E_{prod}) in the system, the energy sold to the user (E_{req}) and the energy consumed (E_{cons}) by system components is included in the energy balance.

$$E_{req} = \sum E_{req} = \sum_{i=1}^{N} E_{i,prod} + E_{acq} + E_{virt} - \sum_{i=1}^{N} E_{i,cons} \quad (1)$$

At low level, size of the components is considered fixed (therefore capital costs are fixed) and a genetic algorithm is used in order to determine the best operational strategy [5]. In this case, the software aims to minimize the objective function (Eq. 2) that represents the variable costs per unit of time, as it follows:

$$C_{\mathrm{var}} = C_{\mathrm{var}} = F_i \cdot \sum_{i=1}^{N} c_{fuel,i} + c_{el} \cdot E_{acq} + c_{virt} \cdot \left(F_{virt} + E_{virt} + Q^{*}_{virt}\right) \quad (2)$$

Variable costs (C_{var}) are made up of the following terms: (i) a term related to fuel consumption (c_{fuel}), (ii) a term related to electrical energy costs (c_{el}) and (iii) a term that represents "virtual costs"(c_{virt}). "Virtual flows" (F_{virt}, E_{virt}, Q_{virt}) represent energy exchanges between the plant and the external environment, necessary to satisfy the optimization constraints (i.e. load demands). Since these amounts of energy cannot be produced by the plant, penalty costs are associated to virtual flows. Since the term "Cvirt" is high (usually, two orders of magnitude higher than the other specific cost terms), the optimization process is forced to find an operational strategy, which minimizes virtual flows (Cuneoet al., 2014) (Rivarolo et al., 2013). The determination of cost functions (and of off-design curves when experimental data were not available (Cuneoet al., 2014) for the modules has been performed thanks to specific curves that fit market data, courtesy of TPG's industrial partners over the last few years and by reference to open literature data, like technical sheet.

The SPM was modelled employing the modules of W-ECoMP libraries (Figure 2).

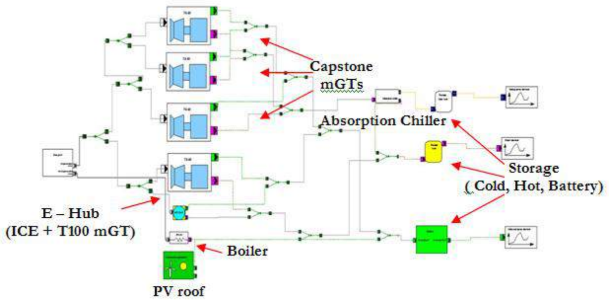

Figure 2: SPM plant layout in W-ECoMP

Economic Scenario and plant assumptions

The calculation is performed by dividing the year in 12 representative days (one for each month), for a total of 288 representative periods (hours). As the campus is closed during the weekend a representative working day for each month was considered. The main assumptions considered for the analysis are discussed hereby.

- **Energy load demands:** WECoMP receives the electrical / thermal demands as input: a typical day profile of electric and heating demand is generated for each month from real monitored consumption data (examples of demand profiles are shown below (summer and winter days).

- **Solar curves**: the irradiation curves considered are related to the city of Savona [16]. In each month, an hourly average irradiation value was calculated and compared to real irradiation data to find the most representative days.

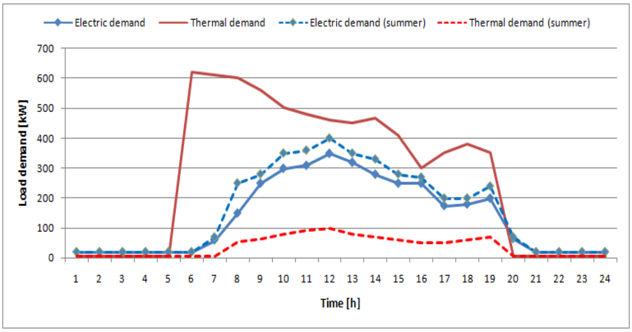

Figure 3: Electrical / thermal demand profiles in summer

- **Economic scenario data** (Table 1) are referred to electricity and natural gas Italian market price cost for energy producers at this power size, referred to the present statistics data. Price of electrical and thermal energy sold to users are referred to the local contract while cooling energy production was considered as an electric saving from the present cooling system (compressor chillers, COP=2), supposing to sell cooling power at 0.085 €/kWht.

Price of natural gas	0,50 €/kg
Purchasing price of electricity from the National grid	0,20 €/kWh
Selling price of electricity to the National grid	0,08 €/kWh
Selling price of electricity to the users	0,17 €/kWh
Selling price of thermal energy to the users	0,08 €/kWh
Selling price of cooling to the users	0,085 €/kWh

Table 1: Economic Scenario – values VAT not included

W-ECoMP Simulation Results

The reference case for all the following simulations is represented by the analysis of the plant managed without any storage. As reported in Figure 4, the grid is operated in "thermal following" mode and the boilers are used to cover the morning peak heat demand, as the electric demand is still low.

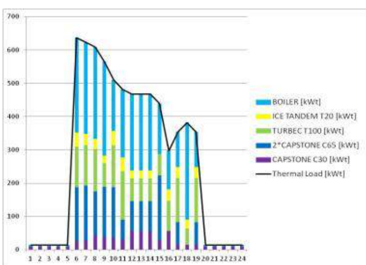

Figure 4: No storage Scenario – January Thermal Demand

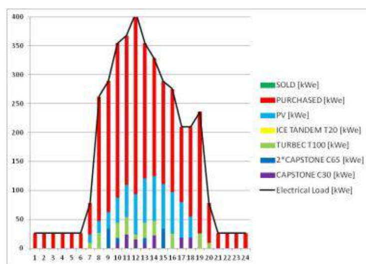

Figure 5: No storage Scenario – July Electrical Demand

Electrical and thermal load trends are a little bit disjoint and electricity is largely purchased from the National grid, particularly in summer (Figure 5) when, according to the decrease of thermal demand, CHP units aren't used at all.

Storage introduction

The three different storage systems (hot, cold, electrical) were introduced in the plant simulation, studying different possible layouts and the impact of each of them.

The electrical storage was studied in two different ways: the grid mode and the in-island mode. In the first case the SPM was able to exchange electricity with the external grid and the battery was used to manage the electrical demand exploiting higher selling prices to the users, but no penalties were addressed for external exchanges. In the second case the virtual costs of the penalties forced the plant to exchange as low as possible electricity with the National grid, forcing the battery to act as a buffer for the SPM and the users. In this case

CHP units were forced to work in summer too, increasing the overall variable costs of the grid during the whole year and a waste in terms of thermal production (Figure 6).

Different considerations can be made analyzing the installation of a thermal storage in managing the heat demand: boiler production is significantly reduced while CHP production strongly increases and electrical requests are more or less satisfied by local generators (Figure 7). Thanks to the possibility to store excess of heat, CHP units always work in nominal conditions, reducing their variable costs.

The introduction of a cold thermal storage is not so significant in terms of economic and energy savings as the installed absorption chiller was sized really close to the typical cooling request of the campus.

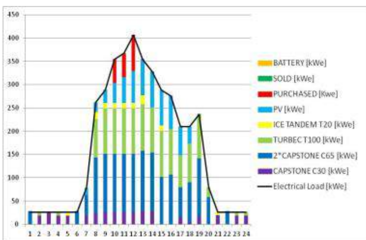

Figure 6: Battery Scenario – July Electrical Demand (In-Island Mode)

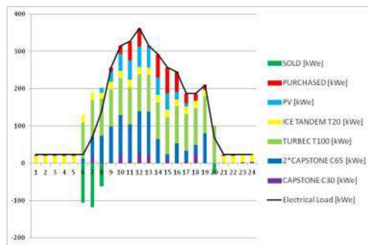

Figure 7: No storage Scenario – July Electrical Demand

Conclusions

In Table 2 a summary of the economic impact of the different kinds of energy storage is presented. As previously stated, the role of hot thermal storage has the highest impact in terms of economic revenues for the manager of the polygeneration district, reducing the gas consumption and guaranteeing a considerable income from high efficiency cogeneration Italian feed-in tariff framework. Nevertheless its combination with a battery in grid mode, allowing energy exchanges with the National grid, guarantees a strong reduction of electricity purchasing, particularly in trigeneration mode with cooling power produced by an absorption chiller.

	Gas Consumption	Electricity Purchasing (% on the demand)	Selling Electricity	Yearly Revenues	Feed In Tarifs
No Storage	303.9 t	58381 kWh (18.69%)	30095 kWh	31284 €	5289 €
Hot Storage	264.2 t	49241 kWh (15.76%)	28715 kWh	71394 €	6639 €
Cold Storage	309.1 t	55830 kWh (17.87%)	34878 kWh	29573 €	5603 €
Battery (Grid Mode)	300.9 t	46935 kWh (15.02%)	14777 kWh	39126 €	5305 €
Battery (In-Island Mode)	367.6 t	1559 kWh (0.50%)	16382 kWh	38161 €	7179 €
Hot & Cold Storage + Battery (Grid Mode)	294.1 t	14393 kWh (4.60%)	5911 kWh	65144 €	6400 €
Hot & Cold Storage + Battery (In-Island Mode)	330.7 t	592 kWh (0.19%)	8274 kWh	58187 €	6841 €

Table 2: Summary of different kind of storage economic impact

It is also important to underline that thermal storage has significant lower capital costs than electrical storage and less maintenance issues, so it can be considered the most profitable storage technology to be installed in a polygenerative grid with comparable electric and thermal demands, particularly in presence of CHP units.

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Ontology-controlled Energy Simulation Workflow

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Abstract

This paper addresses an energy simulation workflow for generating green building design variants regarding insulations of constructions and space type usages based on user requirements. The process is ontology-driven and the simulation steps are executed automatically until user-defined target values are fulfilled. The workflow is supported through parallel thermal simulations and the verifications are based on ontology constraints and rules. The concept facilitates the selection of energy parameters and saves configuration and validation time of energy experts.

Keywords

BIM, eeBIM, Energy, Ontology, OWL, RDF, IFC, Workflow

Introduction

The Building Information Modelling (BIM) approach brings many users from different architecture, engineering and construction domains together and different data formats which are supported by domain software have to be inter-operable. There occur many problems regarding the interoperability while engineering domain experts with their energy, cost or computational fluid dynamic tools often have to remodel the building in the software and inter-link it with other external data like material resources, occupancy information or weather data to calculate cost figures or thermal energy results. A green building design consists of strategies that conserve resources, reduce waste, minimize life cycle costs, and create healthy environment for people to live and work. Especially in the conceptual stage, decisions have considerable impacts on the building performance. While many potential design alternatives are generated and roughly evaluated in order to obtain the most promising solution within that phase, the right shape and the correct building orientation can reduce energy consumption by 30-40% with no extra cost (Wang, Zmeureanu, & Rivard, 2005). Unfortunately, the iterative trial-and-error process of searching for a better design solution is time-consuming and ineffective because of the inherent difficulty in exploring a large design space.

To meet the formulated requirements an Energy-Enhanced BIM (eeBIM) ontology-based approach is proposed in section 2 which is extended from (Katranuschkov, Guruz, Liebich, & Bort, 2011) for applying inference rules to check the used input data like climate data, HVAC data or materials and to analyse the energy performance. The eeBIM enables the integration and validation of input data and is part of a platform, which is called SemeeLab (Semantic Laboratory for Energy Efficiency) (Baumgärtel, Kadolsky, & Scherer, 2015). Users can work with their building information models while assigning energy-relevant data like materials or occupancy information to the Industry Foundation Classes (IFC) entities and can analyse its building energy performance, e.g. by semantic checks or thermal simulations (more in section 3). Thereby, the focus in this paper lays on the simulation workflow based on semantic technologies. At the end of this paper (section 4), we show an example how to optimize a green building design of a small residential building.

eeBIM Methodology based on Ontologies

The integration of all relevant sub models like the IFC is a big problem regarding consistent data processing and performance. The data should not only be compoundable but also be filterable, combinable, serializable and analysable with each other. Ontologies implemented in Web Ontology Language (OWL) can help to solve such problems. Beetz et al. developed a converter to transform any format using EXPRESS schema like the IFC in a corresponding OWL schema and a Resource Description Framework (RDF) generator to create the individuals by reading an IFC file (Beetz, van Leeuwen, & de Vries, IfcOWL: A case of transforming EXPRESS schemas into ontologies., 2009). Pauwels et al. developed a similar tool but focused more on the semantic web approach by providing it as a web service where the building information can be stored (Pauwels, Meyer, & Campenhout, Extending the design process into the knowledge of the world, 2011). They used it also to apply rules so that building models can be checked against a variety of constraints or to infer semantics (Pauwels, et al., 2011) . Motawa et al. proposes an ontology approach for representing the National Calculation Method (NCM) from UK semantically (Motawa & Carter, 2013) . Weather data, building specifications, energy assessments and site details are modelled as OWL classes including properties like temperatures, floor areas and dimensions. This approach leads to a machine-interpretable regulation framework but also often needs a remodelling of regulation details. Pauwels et al. developed a design ontology to describe construction types, topology, people, location and more semantics (Pauwels, De MEyer, & Van Campenhout, Interoperability for the design and construction industry through semantic web technology, 2011) . With that ontology it is possible to define design decisions and requirements. Design entities represent variants with certain design requirements and are referenced to the original entity. SPARQL Protocol And RDF Query Language (SPARQL) is used to search for specific information in the RDF graphs. The design ontology approach is also very interesting for defining parameter and requirements of energy simulations. Curry et al. developed a similar Linked Open Data approach where all the building information is mapped from IFC to RDF graphs (Curry, O'Donnell, Corry, Hasan, Keane, & O'Riain, 2012). They argued that the main advantage is the possibility to combine the data with other Linked Data. Also the scalability by adding new information is improved even if terms and definitions are changed in the meanwhile. The approach is used to calculate the energy need of buildings by retrieving all relevant energy parameters from the RDF graphs. Pauwels et al. developed a simulation model based on semantic web technology where the relevant data is structured to support energy calculations (Pauwels, Corry, & O'Donnell, Making SimModel information available as RDF graphs, 2015).

Hence, to allow a step-wise conversion of plain data to human-readable and machine-understandable information we are using an ontology approach and a multi-layer approach for integrating several heterogeneous data models into RDF graphs based on ontologies (Baumgärtel, Kadolsky, & Scherer, 2015).

Ontology-controlled Workflow

Thermal Energy Simulation Workflow

The overall simulation process for optimizing green building design can be expressed via Business Process Model Notation (BPMN) and is shown in Figure 1. The workflow is separated in external tools (*BIM-CAD*, top swimlane) that provide data, a cloud environment (bottom swimlane) where parallel simulations can be executed and data resources are stored and SemeeLab as middleware, which controls the processes. The workflow starts in a CAD tool where the architect creates the building information model (*Create Building Model*) and exports it via IFC. When uploading the exported file to SemeeLab the content is converted to a RDF graph enabling the advantages through Linked Open Data (Beetz, Coebergh van den Braak, Botter, Zlatanova, & de Laat, 2015). After the mapping process, some enrichments are done based on the information out of existing building entities (*Semantical BIM Extension*). This data interpretation uses selection, translation, simplification and calculation methods to prepare simulations (Bazjanac & Kiviniemi, 2007) and is based on the ontologies. The ontologies and the related ontology platform pursue three goals: 1) the integration of different heterogeneous domain models for forming an overall eeBIM, 2) the quality control of the resulting eeBIM model as fast and rule-based pre-check for the envisaged energy simulation and 3) the check of key performance indicators against user-defined *green building design requirements* and simulation-based *target values*. The starting point for the instantiation of the eeBIM RDF graphs is based on the IfcOWL ontology (Beetz, van Leeuwen, & de Vries, IfcOWL: A case of transforming EXPRESS schemas into ontologies., 2009) while we are using Apache Jena (http://jena.apache.org/) for generating the corresponding RDF graph of an IFC file. After that, the data interpretation is executed so that information of external or internal building elements, their inclination and orientation is present which are relevant for thermal simulations (Bazjanac & Kiviniemi, 2007) (Bazjanac V. , 2010).

To provide connection points to external data and to offer the possibility for integrating easily filtering methods the eeBIM ontology provides energy-related architecture concepts. Hence, the resulting extended building information model comprises concepts like façade elements, thermal envelope, heated and unheated rooms. The user can specify more relevant energy parameters that are needed for a concise thermal energy simulation like defining constructions with material layers or occupancy information of rooms by a Graphical User Interface (GUI) with Drag&Drop capability in a 3D building viewer (*Resource Assignment*) before the information linkage is started based on all previous input. The parameters and resources like provided climate test reference years, occupancy data and material data, are prepared and included in additional ontologies (Kadolsky, Baumgärtel, & Scherer, 2014). Such ontologies provide concepts for important parameter like thermal conductivity or person loads. In the next step, the resources are connected to IfcOWL individuals by using mapping files, for example of room book information which contains occupancy information, or material mapping files where material can be assigned to walls, slabs, windows etc. This can also be done by ontology rules in an automatic way without user interaction by using statements like "assign gypsum material to all internal walls". All the assignments are stored as RDF triples by creating their correspondent individuals and finally checked against existing constraints by using predefined rule sets (*Resource Assignment Validation*) (Baumgärtel, Kadolsky, & Scherer, 2015). If the checks fail, the user has to reassign other valid resources. If it succeeds the Sensitivity Analysis will start (*Sensitivity Analysis*). In the Sensitivity Analysis the user specifies simulation-based target values which are validated against KPIs out of simulation results, e.g. a maximum of total energy need, and green building design requirements, e.g. the highest usable thermal transmittance value of constructions, and value ranges (for example material layer thicknesses, number of occupants in a room) for assigned resources which will vary. Furthermore, building targets (for example walls, windows, rooms, storeys) are addressed with which it is possible to simulate only some parts of a building each independent from each other or all together with its inter-dependency relationships (for example thermal energy transfer). Those combinations are stored in a file format, which is called *Simulation Matrix*. The matrix file is used to transfer the varied building parameters to the cloud environment so that a pre-processor evaluates and decides the created simulation jobs, which are performed in parallel based on the amount of combinations (*Zone Calculations*). Each combination defines a simulation variant so that, for example, one room is simulated ten times with different material and/or occupancy assignments. We are using two different energy solvers. One for single-zone calculations, called Therakles, and one for multi-zone calculations, called Nandrad (Nicolai & Paepcke, 2012) (Feng, Grunewald, Nicolai, Zhang, & Zhang, 2012) . After the simulations and collection of all simulation results the Key Performance Indicators (KPIs) are generated (*Evaluate Results*). KPIs are, for example, total energy need, heating and cooling energy need and will be compared with the predefined user requirements in the step *Sensitivity Analysis*. All simulation variants are processed in parallel in the cloud environment to improve the overall performance. There exist two scenarios: 1) all possibilities were simulated but the KPIs are not compliant to the target values or 2) some variants were found successfully with KPIs, which are compliant to the target values. In case 1) no green building design was found for the defined user requirements and the user have to change the green building requirements and/or simulation-based target values. In case 2), the user can take a look in the GUI on bar charts, scatter diagrams, parallel coordinate plot diagrams, radar charts and filtering capabilities (*Decision Making*). Finally, the user have to decide if the building geometry must be changed, to split or to merge rooms, to change walls, or an optimal variant was found through the Sensitivity Analysis in the workflow.

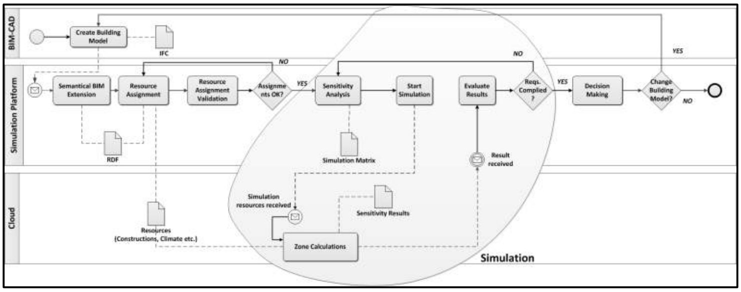

Figure 1: Simulation Workflow in BPMN, the location of the simulation cycles is highlighted

Rule-based Evaluation of User Requirements compared with Key Performance Indicators

In the *Sensitivity Analysis* task (highlighted in Figure 1 in the middle), there exists a setup phase where the emphasis is put on specific user-defined parameters at runtime (Figure 2). The simulation-based target values and green building design requirements are inserted in a GUI. Dependent on the user input the ontology rules and SPARQL queries are generated automatically on-the-fly at runtime and stored as files so that they can be used to configure and validate different simulations later on. In the example of Figure 2, the user defines that thermal transmittance values from *0.24 W/m²K* to *0.35 W/m²K* for external walls are necessary. The resource selection is done in the following way: if there are assignments which are of cardinality 1:1 they will be static in the whole Sensitivity Analysis and used for every simulation run. For example, the user defined that all windows are triple-glazed and have a specific glass and frame fraction.

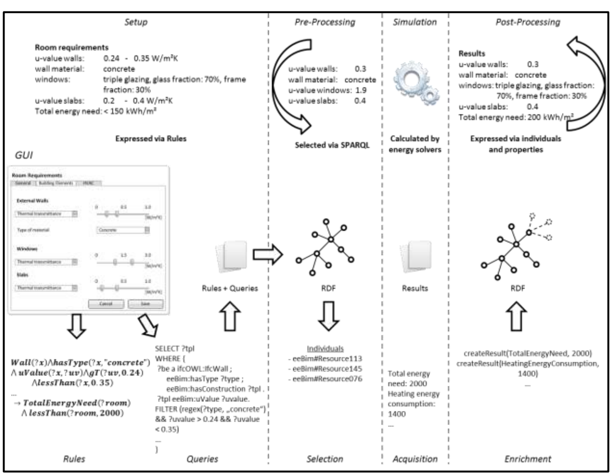

Figure 2: Ontology controlled simulation cycles

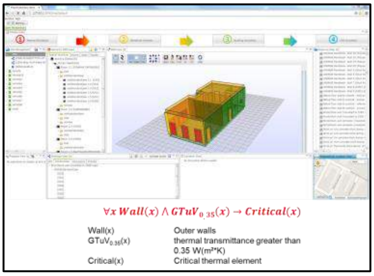

Figure 3: Example prototype

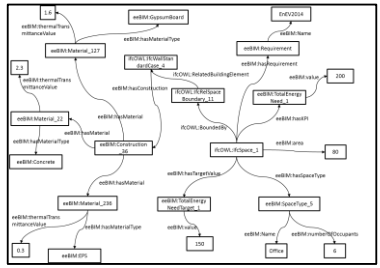

Figure 4: Part of an example RDF graph illustrating the relations of a space

If the user specified value ranges then this are dynamic resources and there will be a cardinality of 1:n so that in each simulation, e.g. the thermal transmittance value, will be replaced by a value within the defined range. In each simulation one resource will change regarding the required parameters until the first solution was found which fulfil all required key performance indicators or, if the user wants to have the best solution, until all acceptable resources were taken. The energy simulation solver consumes the selected static and dynamic resources and computes the results in multiple files like estimated room temperatures for the whole year based on the used weather data, heating energy, cooling energy etc. In the post-processing phase these results were used to determine the key performance indicators, which are used for validation against the key design requirements. The computed KPIs are instantiated as individuals in the RDF graph so that the generated rules and constraints of the setup phase can be applied. If the simulation results show that there is a variant with defined thermal transmittance values and a total energy not higher than *150 kWh/m²* then this is added to the design candidate list. In the example in Figure 2, it shows that the used thermal transmittance value of *0.3 W/m²K* for concrete walls, thermal transmittance of *0.4 W/m²K* for slabs and with triple-glazed windows doesn't fulfil the total energy need. Hence, this variant is not considered and will be not added to the candidate list.

Case Study: Design Optimization using the German EnEV

Our prototype which includes the ontologies and is based on the simulation workflow is shown in Figure 3 and consists of the upload of static resources like the building information model as IFC file, dynamic resource selection through resource catalogs for material, weather and occupancy data. Furthermore, we added searching, filtering and reasoning capabilities of the RDF graphs, a 3D viewer which visualizes the building geometry using IFC and additional information if validation fails (for parts of model elements), a geographical location view and several charts for visualizing simulation results.

We implemented the functionality to express national requirements as rule sets and let the user select rule sets that should be applied (Baumgärtel, Kadolsky, & Scherer, 2015) . In our specific use case of thermal energy simulations we are considering a rule-based requirements definition through the simplified method of the German Ordinance on Energy Saving (Energieeinsparverordnung, EnEV). The EnEV formulates technical standard construction requirements for the building owners, architects and energy experts to achieve an efficient energy demand of the building. Thereby, the Act on Energy Saving (Energieeinsparungsgesetz, EnEG) forms the legal framework for the EnEV. While the EnEV is a German regulation, it implements the European guidelines of the Directives 2010/31/EU and 2012/27/EU. The thermal insulation of building envelopes as well as the energy efficiency of the integrated building systems (HVAC, lightning, etc.) are considered and different calculation methods are introduced to determine their influence on the primary energy demand. A rule set excerpt based on the EnEV is given in Figure 2 (in SWRL syntax). The rules are all implemented as Jena rules with some custom rule functions. The design requirements are therefor deduced from these rule sets and will be applied in the preprocessing phase for selecting appropriate dynamic resources. The advantage is that any national regulation can be expressed via this conception. An example RDF graph is presented in Figure 4 which shows one room in the building and its relations to building elements, target values, occupancy assignments and the simulated total energy need. The 3D viewer highlights user selections and shows energy results by coloring building elements or rooms. Building elements, which can lead to potential problems, will be colored red while green color expresses that this element fulfils the requirements.

In our example, the user created and uploaded the IFC file of a small residential building with seven rooms and assigned dynamic resources by material types (glass, concrete with insulation, gypsum etc.) for space type usages, windows, slabs, internal and external walls and selects the EnEV 2014 as requirement for the green building design. Furthermore, the user specifies the target value of *150 kWh/m²* total energy need which must be fulfilled and that all possibilities are simulated at once without iteration. After the simulations, the results are validated against the target total energy need. If a key performance indicator is higher than the related simulation-based target value this green building design variant is disregarded. The prototype visualizes the simulation results for all found green building design variants in several charts like bar charts, hyper radial visualizations, parallel coordinate plots and radar charts. Finally, the user decides which variant will be used as final green building design.

Conclusions

The optimization of green building design through semantic web technology allows the immediate check if constraints are complied or if an automatic variation of design parameter is needed. This reduces the efforts of designers to change energy parameters after each simulation run. While such configurations and runs can take much time this allows automatic simulations until the target values are reached. The ontology framework helps to extend building models with higher level of details dependent on the user needs. This enables the change of algorithms without modifying the source code of the application. Hence, country-specific requirements or regulations can be easily adopted immediately.

In the future, we will focus on self-learning ontology methods so that previous simulation runs are considered which lead to an enhanced parameter selection with minimized user input before each new simulation run in the pre-processing phase. The weighting of target values will be also considered in future developments so that it is possible to make a fine-tuning of the desired green building design.

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Sustainable refurbishment in urban districts through a web-based tool based on 3D city model

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Abstract

The objective of this article is to present the work done within three projects which aim on the management and conservation of urban districts. The three projects are based on a 3D city model and a decision support system. The decision support system is fed by the 3D city model and provides assistance to select the most suitable interventions for urban districts focusing on the sustainability of a district. The 3D city model is based on CityGML and enables the storage and presentation of data at city and building scales. It contains both geometric and semantic data as part of a single data model. The described projects are European and National research projects: EFFESUS, FASUDIR and REACT. The EFFESUS project develops a Decision Support System (DSS), which aims to select suitable energy efficiency interventions for historic districts. The FASUDIR tool is an integrated decision support tool which assists decision makers to select the best energy retrofitting strategy at building scale, taking into account the surrounding area (the whole district). The REACT project develops an integrated management platform for the identification of interventions facing the conservation and improvement of habitability, energy efficiency and accessibility of historic districts.

Keywords

3D City Model, CityGML, Decision Making System, Sustainable refurbishment

Introduction

Buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the European Union. This situation is closely related to the emissions caused by existing buildings, as 50 million buildings across Europe are fifty years old or more, with the majority of these buildings found in European cities (Desa, U. N., 2010).

The construction industry is continuously searching for new retrofitting solutions and technologies in order to increase the energy efficiency of existing buildings. However the selection of the most suitable solutions and strategies for a specific retrofitting project can become a complex task. Even for the prioritization in the selection of buildings or districts in which the intervention should be carried out a large amount of factors must be taken into account.

Urban districts are ecosystems, which create a great deal of diverse information: different scales, different uses, different applications and formats. In the near future, this information will increase exponentially[1], making its modelling, storing handling a crucial and strategic aspect in management and decision-making.

The creation of innovative methods and management tools that make up a systemic, holistic and participatory approach with regard to the urban scale can become a key element in management and refurbishment processes. Analysis and processing of the information through the use of new technologies is potentially of great help in prioritizing and decision-making within these processes.

Nevertheless, the majority of current development regarding energy efficiency focuses on new building work, ignoring the specific issues of existing buildings in general and historic buildings in particular (i.e. preservation and compatibility with existing materials). New solutions also trend to focus on individual buildings without taking into account the urban dimension, where the connections between buildings and other urban infrastructures create an altogether different context.

3D City model for sustainable refurbishment of urban districts

The management and conservation of urban districts requires an approach that considers each of the buildings and other city elements as forming part of an environment that should be conserved, brought up-to-date and showcased. This approach requires the integration of Geographic Information Systems (GIS) and Building Information Models (BIM), while at the same time bearing in mind the particular nature of urban districts (Döllner, J., & Hagedorn, B., 2007).

The solution, based on 3D digital models, has grown in importance over recent years as it offers complete support which is easily brought up-to-date, allowing information storage and visualization on an urban scale (Mao, B., & Ban, Y., 2011). The visualization of 3D and semantic information of urban districts in a more understandable and user-friendly way to represent the spatial properties of urban elements, is of great use to those taking part in the management, conservation, use and enjoyment of towns and cities. The general aim is to combine geometric information and the characteristics relating to buildings, urban environments and archaeological sites into a single integrated data model. Egusquiza identifies the CityGML (Gröger, G., Kolbe, T. H., Nagel, C., & Häfele, K., 2012) as the data model that allows 3D geo-referenced and semantic information associated with geometry to be stored in a single data model (Egusquiza, A., Prieto, I., & Romero, A., 2014).

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[1] By 2020 there will be more than 200 billion sensors generating an estimated 10% of data in what will be a 44 Zettabyte (1021) digital universe. Hormann, Peter. "2020: Smart Cities, Zettabyte Data and 200 billion things. What's next?." (2014).

One way to tap into the real potential of the model (its use with international standards, its interoperability with other data model and other analysis, management and decision-making tools etc.) is through the development of a service ecosystem to make urban planning and management easier, by creating new cloud-based applications (Chen, R., 2011). This ecosystem takes into account and employs various standards to help define and to take full advantage of a common data model. These services include sustainable refurbishment, which assists in administration and maintenance of urban intervention, aimed at improving sustainability and energy saving in towns and cities. Services can also be designed to ensure the efficient management of energy resources, for the administration and optimization of urban mobility, tourist, cultural and service information which facilitate e-government and the participation of the general public, improving interaction and communication between government bodies and local people, among others (Gröger, G., & Plümer, L., 2012).

There are different alternatives of the usage of 3D city models in end user applications. In urban planning it enables the city administrators to present urban plans to the public to engage with stakeholders and facilitates also the public participation (Dambruch, J., & Krämer, M., 2014). Dambruch and Kramer has used innovative web technologies to present a public participation in urban planning with 3D web tool. Another alternative is the usage of 3D city models for analyze the information within the data model, for later visualization by mean of different web services (Soave, M., Devigili, F., Prandi, F., & de Amicis, R., 2013). An approach of configurable instances of 3D city models allowing the simplification of 3D models in different application has been presented by Klein (Klein, F., Spieldenner, T., Sons, K., & Slusallek, P., 2014).

Tecnalia is leading several projects aligned with the sustainable refurbishment of urban districts based on a CityGML 3D city model. FASUDIR[2] and EFFESUS[3] are under development and REACT[4] is a finished project.

EFFESUS project

The main output of the EFFESUS project will be a Decision Support System (DSS), a software tool, which includes all the parameters needed to select suitable energy efficiency interventions for historic districts (Eriksson, P., Hermann, C., Hrabovszky-Horváth, S., & Rodwell, D., 2014).

The overall objective of EFFESUS is to develop and demonstrate a methodology and criteria for selecting and prioritizing energy efficiency interventions, based on cost-effective technologies and systems compatible with heritage values, to achieve significant lifecycle energy efficiency improvements in the retrofitting of historic districts.

The main modules identified in EFFESUS and the connections between them within the DSS are shown in Figure 1. The main software modules

[2] http://fasudir.eu/
[3] http://www.effesus.eu/
[4] http://www-cpsv.upc.es/REACT/

developed in EFFESUS are: a multiscale data model, a categorization tool, a repository on technologies and the DSS.

The *multiscale data model* is a virtual 3D city model based on the CityGML data model. The multiscale data model provides a representation of the urban information at different levels (from the city level to the building component level). It represents graphical appearance of the city as well as semantic or thematic properties. The multiscale data model of the historic district of the city of Santiago de Compostela in Spain has been implemented within the EFFESUS project.

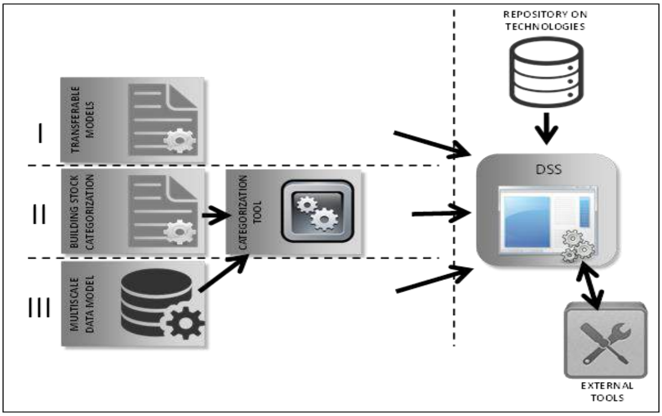

Figure 1: EFFESUS main modules

The *categorization tool* (see Figure 2) provides the user with an easy and intuitive way for the identification of building typologies in an urban district. The categorization tool is based on data included in the multiscale data model. Algorithms for building categorization have been implemented based on the building stock categorization methodology defined within the project. Geometry of the multiscale data model has been used for the visualization of the building typologies as well as the most representative building of each typology (City viewer on the right). The user interacts with the tool editing properties of representative buildings ('Features' section in left column) as well as editing parameters and thresholds for categorization ('Categorization' section in left column). EFFESUS DSS is emphasises on the identification of different typologies of building stock.

Figure 2: EFFESUS Categorization Tool

The *repository on technologies* is a relational database accessible through a web site, which structures the information about the energy saving technologies, systems and architectural solutions suitable for historic buildings and districts.

The *DSS* software tool is based on a holistic methodological framework for the assessment of energy-related interventions in built cultural heritage. This methodological framework for decision-making aims to identify and classify actions according to: compatibility with the cultural significance, energy saving, habitability and economical, technical and legislative feasibility. The methodology has been developed at two scales: The urban scale and the building level. It defines the specifications for its implementation in the expert system of the DSS.

FASUDIR project

The FASUDIR project was born to develop new business models and financial support tools, aiming to assist the necessary building-retrofitting market mobilization in Europe to fulfill EU-targets in 2020 and 2050. The key instrument will be the Integrated Decision Support Tool (IDST), developed to help decision makers to select the best energy retrofitting strategy to increase the sustainability of the whole district. With stakeholder feedback loops, training, and validation in three different urban areas, the IDST will ensure robustness and applicability in the entire value chain.

The software tool is based on seamless integration of both scales (district and building) through a unique data model based on CityGML standard, which represents a 3D City model at different levels of detail. It will combine the high potential of GIS tools for urban sustainability analysis with energy performance evaluation at building level. All the information will be accessible through a unique and coherent data model, which includes both geometric and semantic information. The tool is built upon a base of existing softwares and will be enhanced by more informed algorithms and most importantly of all, integrated to provide synergistic solutions at the district level which provide the user with more insight and powerful decision making.

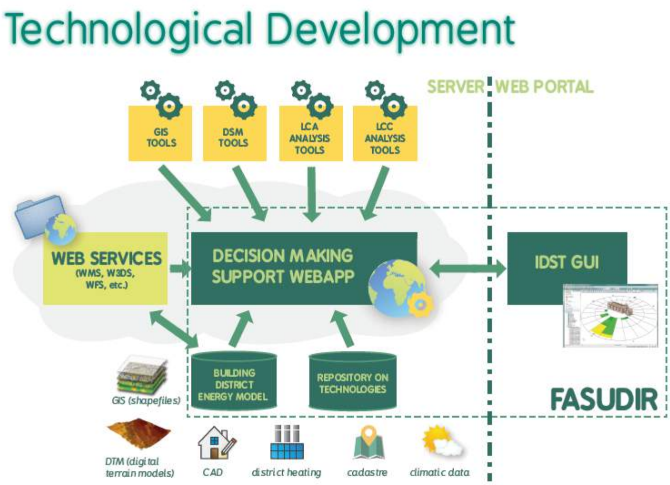

Figure 3: FASUDIR architecture

The software tool will comprise a set of four inter-related modules based on client-server architecture:

- Building District Energy Model. This CityGML based module will enable modelling the district and building with an adequate level of definition.
- Repository on Technologies. This module will contain a collection of sustainable retrofitting strategies and technical solutions at building and district level.
- Decision Making Support WebApp. This module will be the core of the IDST and will provide the following functionalities:
  - Evaluating the sustainability of each building.
  - Evaluating the sustainability of the district.
  - Suggesting the most promising sustainable retrofitting strategies and technical solutions at building and district level.
  - Managing different retrofitting scenarios.
  - Mapping the IDST sustainability assessment to similar already existing sustainability certification labels.
- IDST GUI. To make the definition of the retrofitting scenarios and understanding the evaluation results more straightforward and intuitive, a graphical user interface will be adopted. It will allow the interaction at building level and at district level.

REACT project

The REACT project represents a commitment to the identification and development of technologically innovative solutions for the management, implementation and maintenance of interventions in historic centers of cities from a holistic approach to sustainable rehabilitation.

One of the objectives is to develop an integrated management platform for the identification of interventions facing the conservation and improvement of habitability, energy efficiency and accessibility, which enables its subsequent management and effective maintenance, involving the inhabitants in the sustainability of the city through their participation.

REACT has designed the methodology for the integral management of sustainable rehabilitation of historic districts. This methodology defines a common strategy and framework on which the rest of the activities carried out is based. The first step is the collection of data, and information allowing for the development of comprehensive assessment of the historic center. The diagnostic methodology is supported by the integration of existing and new tools for documentation and analysis. The information collected should be stored in a way that on the one hand it is represented in a single model; and on the other hand, it connects the executive level (building) with the strategic level (historic center), representing this shared information as the main source for tools to be used in the management phase. The data model for the management of sustainable rehabilitation relies on the basis of the holistic diagnosis methodology. The last step is the management platform incorporating tools for the identification, prioritization and maintenance activities. These tools offer help to both, technicians and citizens in a bidirectional way to optimize the management of maintenance operations. The REACT platform consists of 3 management applications integrated into a single platform, which are:

- **Visual Information Management of Urban Model**:

It facilitates maintenance and tracking information with different levels of detail at different scales (building-urban) through a collaborative web environment. All information of urban elements is georeferenced. At the same time, this tool represents a unified access to the REACT platform shared by different types of users (citizen / administration) with different access protocols. The information is displayed in layers of information both geometric (associated with different types of urban elements) and semantics (energy, heritage, etc.). The information source is unique and remains consistently updated through a single multiscale data model. Information is displayed in a web environment with native HTML5-based representation for different multimedia formats (2D and 3D). Consultations and advanced searches are among other functional capabilities included in this application.

- **Identification of interventions at urban scale**

The main purpose of this application is to develop a management tool in which functionality such as identification, prioritization and maintenance activities at urban scale will be incorporated. It is intended to provide support and easy understanding of a complex heritage environment for technicians and managers of historic districts in the decision making process. The awareness will facilitate the implementation of shared solutions and consensus within collaborative environments. Some of the main functionalities implemented in the application are: display 3D urban maps by different criteria, generation and visualization of vulnerability maps and visualization at both building and district scale.

- **Citizen participation for urban improvement**

Digital citizenship module for urban improvement is a forum for advanced management of incidents at both district and city block levels. The forum for digital citizenship allows the citizenship to provide their opinion and suggestions in a structured way. The objective of this task is to provide the citizens with a tool to access the information provided by administration and enabling citizen participation in decisions related to urban management.

Conclusion

Integrated approaches with intuitive user-friendly software represent an innovative alternative for decision-making to prioritize the action to be taken and to improve the sustainability of urban districts and their subsequent management. The strategic management of the information generated by a city should be a key part of this process.

The development of data models based on the international CityGML standard allows GIS and BIM concepts to be integrated within the same model. The information contained in the model is unique and can be used to develop various applications that the different agents (city managers, technicians and members of the public) employ.

Web based applications have been developed that aim the sustainable refurbishment in urban districts by means of the usage of a decision making system. The decision-making system will be fed by a 3D city model of a urban district, enabling the storage and presentation at data at city and building scales.

Acknowledgements

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Smart management of historical heritage

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Abstract

Contemporary needs in terms of sustainability, energy production/consumption and smart management of our cities have to face and give concrete answers – as adequate methodologies and technologies - to the problem of the interventions on listed historical architectures and Cultural Districts. These, infact, are under protection of local, national or international Institutions that are often far from really understanding and controlling the issues of management and energy efficiency improvement. This is the main objective of the research here presented, focused on a huge historical complex in the heart of the city of Genoa, now largely abandoned and party already reused as humanistic university pole. The feasibility study for its complete reuse and restoration contains a part focused on its smart management: enhancement of its thermal behaviour compatibly with its architectural and historical values, energy production recurring to renewable sources, enhancement of its 'energy' management within a Cultural District framework.

Keywords

Cultural District, smart management, energy efficiency, renewable sources.

Introduction

Within the contemporary pervasive logic of sustainable development, memory and culture play a vital role in building the future. 'Sustainability' and 'Heritage', tangible and intangible, indeed, seem to belong to increasingly interacting spheres. Cultural heritage thus enters into those that have been long been codified as the 'four pillars of sustainability', actually regarded as a genuine driving force for economic and cultural activities, even though numerous conflicts emerge (Barthler-Bouchier, 2013). Conflicts that inevitably arise by comparing the active protection of heritage with some of the objectives of sustainable development, because architectural and historic districts are, at the same time, non-renewable and non-replaceable resources, thus reinforcing the importance of a 'sustainable management' of the whole process of conservation and revitalization, even recurring to ICT tools (Dvornik-Perhavec, Rebolj and Suman, 2014).

In this complex picture, varied and interdisciplinary, Energy Efficiency of historical heritage is only one aspect of sustainability, which is now strongly present also in response to the Community objectives and the roadmap EeB PPP (Energy efficiency of Buildings - Public Private Partnership). Many barriers, technological and not, however, hinder the implementation of the Directive on the energy performance of buildings of historical, especially in public buildings. A significant portion of these assets, in fact, is still conditioned by inefficient, fossil fuel, with high-energy costs and relevant air pollutant emissions. Associated with this is, very often, scarce management, which generates high-energy consumption.

Within this complex frame, an interdisciplinary research group of the Department of Architectural Sciences (Polytechnic School, University of Genoa), since few years is focusing its interest on the sustainable development and energy efficiency of historical architectural heritage, monumental and not, starting from the consideration that, within the huge programme of Genoa Smart City, Cultural Heritage has never been included. The research briefly presented has been funded by Liguria Region and is specifically focused on the monumental complex of the Albergo dei Poveri in Genoa, together with the industrial partner Ansaldo Energia (2013-2015).

Aim of the research was the exploration, from a methodological and technical point of view and through a feasibility study, of the possibility to submit the historical monumental heritage in a process of energy efficiency, taking into account a series of operations that are compatible with the conservation of historical values and enhancement of the constructive and architectural characters. Another investigated objective was the possibility to use the monumental complex and its site as an energy-producer, not only an energy-consumer, even linked to a smart grid system.

Intervening on a Historical and Cultural District in the heart of Genoa

This is the methodological approach at the base of the research here presented focused on the Albergo dei Poveri of Genoa, a large charitable complex built in the 17th century outside of the city walls, which radically modified a natural valley. The architectural complex was later incorporated in the expansion of the modern city and lost only around 1999 its original role, which lasted over three centuries. At the end of the Nineties of the past century, the complex has been almost completely abandoned and assigned by the legitimate owner to the University of Genoa through a specific Loan for Use for 50 years. The original prevision of the Athenaeum was to transfer in the complex the School of the Humanities that is still hosted in some monumental palaces of the Seventeenth century Strada Balbi.

Given its massive size and location in the city centre, the complex represents a unique opportunity for a large project to develop urban and, at the same time, a sort of symbolic occasion for the testing of new best practices.

For several general reasons, the original plan has been developed really slowly and with numerous stops, due to different problems of economic and technical nature that at least in part derive just from a lack of knowledge of the architectural complex, of its real consistency and state of conservation.

To fill this gap in knowledge the Building Development Sector of Athenaeum has made a general agreement with the School of Specialization in Architectural Heritage and Landscape, finalized to undertake a campaign of studies and to develop a preliminary feasibility study for its complete re-use as a university campus, even concerning its energy efficiency. All the work on going is reversed in a meta-model BIM (Building Information Modeling) which is actually a tool used in eastern and western countries, especially for the design and construction of new public works (Backes, Thompson, Malki-Ephstein and Bohem, 2014). The development of a multidisciplinary model of Knowledge (and a digital and computation representation of physical and functional characteristics) is a necessary step to make more reasonable and sustainable the further investment of public economic resources that, in any case, must be searched because the needs exceed the normal economic balance sheet of the University.

The work is organized into the following main phases, deeply and continuously interlaced:

- Reconstruction of the history of the complex based on archival and documentary (indirect) sources and on the building itself as direct source of its material history;
- Identification of all the juridical and administrative constrains or limitations;
- Building description (morphologies, extensions, spaces layout, constructive features, building physical parameters describing its behaviour…);
- Survey campaign (topographic, rigorous analytical and digital simplified photogrammetry, 3D laser and Z-scans);
- Analysis and diagnosis of materials, of constructive techniques and components, of structural elements and parts;
- Analysis and monitoring of the environmental conditions;
- Identification of old network of technical plants, even with recent investigations on the archive of building maintenance;
- Preparation of a feasibility study, in agreement with the Rector and the technical departments, to achieve a complete re-use of the complex;
- First identification of conservative measures for the restoration of the monumental facades and assessment of their impact on energy production and pollution (LCA analysis in collaboration with the research group of Polytechnic of Milan);
- Quantification of the energy behaviour of the complex in its current state, the needs of thermal energy, electricity and hot water for new uses, comparison of the results with the monitoring of real consumption (for the part of the complex already reused) and evaluation of the energy gains induced by technical solutions

to improve the efficiency of architectural structures (especially on windows and roof structures);

- Research on archives of the property (Azienda Servizi alla Persona Emanuele Brignole) especially for data pertaining to the old plant systems;
- Construction, for a part of the complex, of a 3D model and application of parametric software BIM (Building Information Modeling) for the management of numerous data resulting from the analysis and the project of restoration and re-use (Babbetto, 2014);
- Feasibility study for a new plant systems, paying particular attention to energy efficiency (co-generation and tri-generation plants produced by Ansaldo Energia) and its possible integration with systems powered by renewable energy (solar PV cells integrated in the greenhouses in the valley Carbonar and exploration of the possibility to insert PV films on the large amount of glass windows in the complex, together with IIT Foundation of Milan);
- Overall assessment of the micro- generation system for the complex of the Albergo dei Poveri: any electricity produced in the complex and not needed for new uses may be injected into the network at the service of other university buildings in the immediate surroundings.

All these data have been organized in a relational GIS system able to collect information of different nature (images, raster and vector, texts, numerical) and provenience, ensuring their storage and continuous updating. This database (easily transferable into other software packages like ACCESS or REVIT) is the basis for the construction of a BIM, starting from the three-dimensional parametric model of the complex to which are anchored the different alphanumeric data and graphics, to be experimented on a part of the complex in which some interventions are really foreseen in the near future.

Thermal behaviour, improvement and energy demand for new uses

The issues relating to the determination of the energy aspects in existing buildings, especially historical, have become a matter of great importance within the national community and global energy policies. Great importance in the process of determining the fuel consumption is based on the level of definition in data collection and in the type of the computing system.

The steady state method has been the method chosen in our case study. If, on the one hand, it provides more approximate results in respect of the dynamic one, on the other hand it requires a smaller amount of data for the determination of the calculation parameters. Facing a historical complex, this method has been considered the most suitable one, regarding the timetable of the research and the large amount of data needed. This difficulty can lead to deficiencies in the acquisition of data, or errors in the process itself that may jeopardize the reliability of the final results.

Once defined the calculation method, it was necessary to build a simulation model for the complex, taking into account a number of approximations, to transfer and translate real data into the calculation program. The approximations are geometric and constructive. From the geometric point of view the monumental spaces are characterized by constructive and decorative elements of complicated geometries and very difficult to be correctly transferred into the three-dimensional model. To overcome these problems the structures were reduced to simpler forms. The types of roofs have not been reported in their complex shapes, but all rooms with vaulted ceiling have been reduced to plane ceiling, considering, as the main height to calculate the volume, and average height. This approximation is allowed within the method of calculation, but it should be considered with higher accuracy in a dynamic calculation (Franco, Magrini, Pernetti, Guerrini, 2015; Franco, Guerrini, Cartesegna, 2014).

Once obtained the geometric and constructive data, the determination of thermo-physical properties of external walls, windows, roofs and ground floor has been carried out with reference to the Italian technical standard UNI 10351 Building materials - thermal conductivities and vapor permeabilities. The building envelope has been divided into several portions each of which having the same properties and characteristics in terms of thickness, thermal conductivity, surface mass and thermal capacity. From the constructive point of view, the features of the walls are approximately calculated considering always uniform the thickness of the plaster, which covers the wall externally and internally. The characteristics of the floors were assumed, whereas it was not possible to perform sampling or direct inquiries, in agreement with the period of construction and subsequent modifications investigated through to historical and archive documentation. Overhangs and sunscreens that affect solar gains, in accordance with the method of calculation, were not taken into account, also for conservative reasons. As the research is going on, we are now evaluating the effects of thermal accumulation on the walls trough dymanic thermal analisys.

Total surface of the complex	56.340 m²
Surface to be reused	38.255 m²
Surface already reused	18.085 m²
Volume to be reused	135.063 m³
Wall thermal transmittance, thickness 60 cm	1,9 W/(m²K)
Wall thermal transmittance, thickness 90 cm	1,44 W/(m²K)
Wall thermal transmittance, thickness 150 cm	0,98 W/(m²K)
Wooden vaults in the upper floor transmittance	3,1 W/(m²K)
Concrete floor in the upper part transmittance	1,49 W/(m²K)
Wooden frame and simple glass window	5 W/(m²K)

New proposed uses for the university pole in humanities are classrooms and laboratories, departmental offices, library of law and archives, museum of the Albergo dei Poveri, bar and restaurant, university residence.

Calculation of thermal energy demand and validation of the model

Once defined the energy modelling, obtained results have been validated through the comparison with current consumption. As a part of the complex (approximately 30%) has already been restored, the total annual energy consumption/surface has been used as validation criteria. Considering some uncertain input data, the previous mentioned aproximations, and the necessary difference between calculation and real behaviour, the model is considered acceptable only if the following condition is verified:

$$-0.2 < (E_{tot} - E^*_{tot})/E^*_{tot} < 0.2$$

$E^*_{tot} = E^*_{fuel} + f_{p,el} \cdot E^*_{el} = E^*_{fuel} + E^*_{p,el}$

$E_{tot} = E_{fuel} + f_{p,el} \cdot E_{el} = E_{fuel} + E_{p,el}$

E_{tot} : total specific energy demand [kWh_{th} /(m^2year)]

E_{fuel} : total specific energy demand related to fuel consumption [kWh_{th} /(m^2year)]

E_{el} : total specific electric demand [kWh_{el} /(m^2year)]

$f_{p,el} = 2.6\ kWh_{th} / kWh_{el}$ is the factor of conversion of electric energy in primary energy

$E_{p,el} = f_{p,el} \cdot E_{el}$ is the total primary energy demand corresponding to electric energy consumption [kWh_{th} /(m^2year)]

For the part of the complex that still need to be restored (almost 70%) there have been evaluated those terms that contribute to define the energy demand. In particular, it has been considered energy consumption to produce heating and hot water and electric consumption for lighting, technical equipment, technical plants as pumps or ventilators or cooling (considered electric), as:

Fuel	285,54 TEP
Electric	1078101 kWh_{el}

As the difference between specific demands is less than 20%, the model is considered acceptable, and the final results, in the current state (without any enhancement of thermal behaviour of the envelope) are the following:

Net surface to be reused	22.260 m^2
Volume to be reused	135.063 m^3
Heat load	1.494,62 kW
Thermal energy need for heating	1.892.480, 95 kWh

Possible intervention to improve energy efficiency

The improvement of energy efficiency of the historical complex depends in part on the installation of specific technical disposals and in part on the improvement of thermal behavior of those buildings elements that are characterised by thermal losses. For this reason, there have been individuated four possible interventions, all related to the parts connected with exterior environment (external walls, roof structure, floors and windows). These interventions could be done all together or partially (especially for those concerning external windows), so it is really important to determine in advance what gain in terms of energy consumption they could allow. The calculation program was set to produce results for five different scenarios: the first of the status quo, and the other four, labeled with letters A, B, C, D, which take account of the improvement of thermal behaviour.

	Improvement of thermal behaviour of the envelope	**Heat load (kW)**	**Consumption (kWh)**
A	Insulation of the roof	-3,04%	-4,55%
B	Insulation of the ground floor and ceiling under the roof	-12,22%	-20,85%
C	Insulation of the external walls under the windows	-2,88%	-3,76%
D	Addition of certificated new windows	-22,81%	-30,60%
	Interventions B+C+D	-38%	-55%

Table 1. Energy reduction (in percentage) referred to different interventions

The value of natural ventilation is considered as 0,3 volumes/hour. This value has been increased up to 0,5 volumes/hour, in the calculation of the energy for heat loads, for all the scenarios considered, except the intervention D that, of course, implies a reduction of natural ventilation. Specifically, the scenario of intervention A takes into account the insulation of the roof in the inner surface in order to respect the traditional connection between external wall and roof. The scenario B refers to the insulation of the floors suggesting the addition of an insulating layer thickness of 8 cm semi-rigid or flexible in mattresses, leaning to the existing structure, or with self-supporting structure fixed to the perimeter walls. The scenario C considers a layer of 10 cm of insulation. The scenario intervention D specifically responds to the need on conservation and safeguard of historical values, because it is coupled with the restoration of the existing old windows.

Energy demand for hot water

The demand for hot water has been calculated on the basis of different references, in relation to the proposed new uses and maximum value of crowding (especially concerning university dwellings and classrooms). The demand was calculated both in terms of water consumption and in terms of energy need for the production of domestic hot water.

Domestic hot water requirement	25,59 m^3/day
	7713 m^3/year
Daily energy requirement for hot water	833,19 kWh
Total energy requirement for hot water (yearly)	251123,19 kWh

Electric energy demand

The necessary data for the development of the calculation were obtained according to UNI EN 12464-1 'Lighting of workplaces. Part 1: Indoors work places', and the table developed by ENEA (National Agency for Energy and

Environment) - Information related to energy saving lighting. The hypothesis for the re-use of the 'Albergo dei Poveri' foresees the use of LED lamps.

Illuminated area	27.095 m^2
Lighting electrical power	93,29 kW
Daily energy requirement	659,73 kWh
Total electric energy consumption (yearly)	233,34 MWh

Conclusion

The feasibility study has been completed with the prevision of different technical combined systems to produce energy, according to the energy demand. Specifically, beyond the possible production of energy though PV cells in the greenhouses, it has been explored the implementation of a traditional heating system with micro-turbines fueled by natural gas (useful to define a system of co-generation or tri-generation). In order to cover a significant percentage of the energy demand, currently it is assumed, the use of 2 microturbines (900x1810x2527/3652 mm; weight 2650 kg; fuel consumption 34.5 m^3/h; electrical output 100 kW; thermal output 167 kW; thermal efficiency 48%), to be also connected to the electrical grid.

Total electric energy E_{EL}	956.000 kWh_{el}
Total thermal energy E_{TH}	2.496.000 kWh_{therm}
<u>Cogenerator 1</u>	
Thermal energy production	725.448 kWh_{th}/year
Electric energy production	434.400 kWh_{el}/year
Number of hours	4.344 h/year
Period ou use	24 hours/day (winter) 181 days
<u>Cogenerator 2</u>	
Thermal energy production	731.460 kWh_{th}/year
Electric energy production	438.000 kWh_{el}/year
Number of hours	4.380 h/year
Period ou use	12 hours/day (winter) 181 days
	12 hours/day (summer) 181 days
<u>Cogenerator 1+2</u>	
Thermal energy production	1.456.908 kWh_{th}/year
Electric energy production	872.400 kWh_{el}/year
Number of hours	8.724 h/year

Acknowledgements

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Sustainable Microgrids Interacting with Sustainable Buildings: the Case of the Savona Campus

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Abstract

Nowadays, many research and development projects are focused on the widespread over the territory of innovative technologies, environmentally sustainable and economically appealing, adopted to satisfy electrical and thermal needs of public and private consumers. The challenge is to seek to carry out the integration of different generation units by means of smart Energy Management Systems (EMSs) and two-way communication between producers and consumers; new and exciting opportunities are becoming available for balancing generation and demand, increasing energy efficiency and lowering electricity costs. In this paper, such issues are presented referring to the innovative research test-bed facilities owned by the University of Genova at the Savona Campus: the Smart Polygeneration Migrogrid (SPM) and the Sustainable Energy Building (SEB). Specifically, the overall control architecture and the technologies of SPM and SEB are described and some Key Performance Indicators (KPIs) are proposed to assess the sustainability of the aforementioned infrastructures.

Keywords

Smart polygeneration microgrids, renewable energy, sustainable buildings, energy efficiency, energy management system.

Introduction

As assessed by Clastres (2011) and Bracco *et al.* (2015), the development of smart grids has raised the possibility of reaching targets for climate-change (by the reduction of CO_2 emissions), energy efficiency policies, safety of systems and technologies. One of the main advantages of DER (Distributed Energy Resource) systems in a smart grid, as assessed by Mehleri *et al.* (2012), is their installation close to or even inside the end-users facilities, determining low electricity transmission losses and producing energy to satisfy local electricity and heating demands. On the other hand, the growing number of decentralized generation units has an impact on the traditional regulation and control strategies adopted by DSOs (Distributed System Operators) to manage distribution grids. In the aforementioned context, one of the aims of the smart grid concept is to develop technologies and advanced management software in order to face the continuous spread of DER and CCHP (Combined Cooling, Heating and Power) plants in low and medium voltage networks. In this regard, as described by Bracco *et al.* (2013), many national and international local projects are focused on the distributed generation and microgrid concepts but it is necessary to determine solutions that can be deployed also at full scale. To achieve this goal, it is essential to make the overall electricity system smarter, focusing in particular on ICT (Information and Communication Technologies). As reported by Higgins *et al.* (2011), smart grid technologies support a wide range of applications in power systems, such as protection and automation of the distribution system and security. A great deal of new functionalities should be considered: dynamic load management strategies, active response mechanisms, real-time control of the distribution network, energy storage systems, and automatic measurements of energy consumption. As a consequence, the success of such a system is possible only if ICT solutions for real-time data acquisition, transportation and processing are adopted. In this regard, Wang *et al.* (2011) propose a survey on the current state of research on the communication networks for smart grids.

In the aforementioned scenario, smart microgrids are acquiring more and more importance, providing an opportunity and a desirable infrastructure for improving the efficiency of energy production and consumption in buildings and groups of buildings. Microgrids, as well as large size smart grids, may include Renewable Energy Resource (RER) power plants, that are characterized by intermittency and volatility in the generation of energy, thus creating the need for a new electricity grid architecture. This problem can be compensated by the adoption of storage systems, both thermal and electrical, and CCHP units. In this paper, the attention is focused on microgrids and sustainable buildings with specific reference to the innovative research test-bed facilities owned by the University of Genova at the Savona Campus: the Smart Polygeneration Migrogrid (SPM) and the Sustainable Energy Building (SEB). Key Performance Indicators (KPIs) are here proposed to assess the sustainability of the infrastructures; specifically, the proposed KPIs mainly refer to operating costs, primary energy consumption and emissions, in order to provide valuable and reliable tools to assess sustainable energy systems from a technical, economic and environmental point of view.

The Savona Campus test-bed facilities SPM&SEB and the EMS architecture

One of the main aspects that characterize the Savona Campus are the research activities in the sustainable energy sector. In this context, it is worth mentioning the "Energy 2020 Project" of the University of Genova that is an important R&D project related to the concepts of Sustainable Energy (renewable energy, energy saving and reduction of CO_2 emissions) and Smart City. The project, which has been developed thanks to a full public financing, is designed to install within the Savona Campus innovative energy systems aimed at reducing operating costs, CO_2 emissions and, at the same time, at creating a comfort working environment for the Campus users.

The University of Genoa "Smart Polygeneration Microgrid" (SPM) has been developed within the "2020 Energy Project" as a joint "special project in the energy sector" between the University of Genova and the Italian Ministry for Education, University and Research (MIUR). The project started in 2010 and in February 2014 the SPM has become fully operational. The SPM is a three-fase low voltage (400 V line-to-line) microgrid characterized by distributed generation units, electrical storage devices, and a variety of thermal and electrical loads. The SPM can be seen as a system of systems; as a consequence, it can be divided in the following three main sub-systems:

- The electrical sub-system, which includes: two cogeneration Capstone C65 microturbines (65 kW_e each at rated conditions), a cogeneration Capstone C30 microturbine (28 kW_e at rated conditions), three Concentrating Solar Power (CSP) systems coupled with Stirling engines (1 kW_e each), a photovoltaic field (80 kW_e), two electric vehicle charging stations, elictrical storage systems (SoNick batteries - 141 kWh_e rated capacity, 36 kW_e rated power, and Li-Ion batteries - 25 kWh_e rated capacity and 25 kW_e rated power), smart meters and inverters, a dedicated grid connected to the existing Campus grid and to the public distribution network;
- The thermal sub-system characterized by: the C65 microturbines (112 kW_{th}), the C30 microturbine (64 kW_{th}), two preexisting traditional boilers (about 450 kW_{th} each), the three CSPs (3 kW_{th} each), a water - lithium bromite absorption chiller (70 kW of cooling capacity) and a dedicated district heating network connected to the Campus existing one;
- The control sub-system: local controllers, a communication network, a central controller, a data storage system, software tools for the SPM supervisory control, regulation, monitoring and optimization.

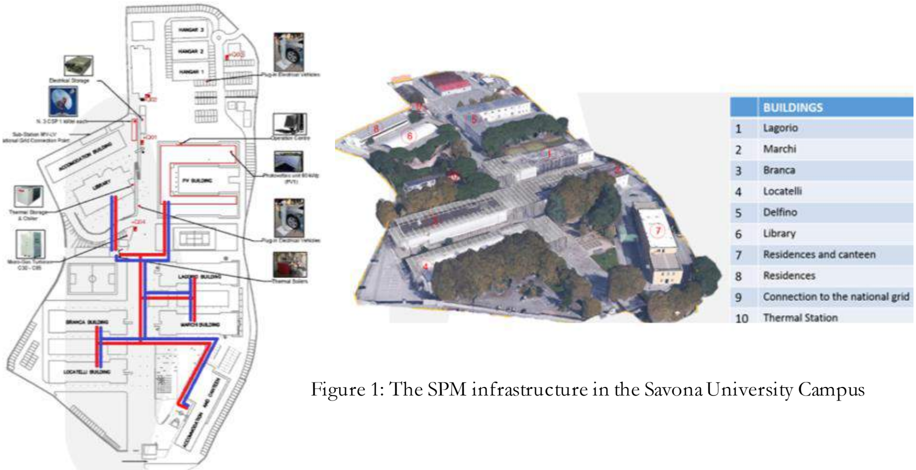

Figure 1: The SPM infrastructure in the Savona University Campus

In Figure 1, the 3D-view of the Savona Campus is reported, as well as the map of the SPM infrastructure. The list of the main buildings and the location of the electrical and thermal subsystems are shown. The red and blue lines in the map indicate the supply and return pipelines of the district-heating network. The thermal network, which is fed by hot water produced by the three cogeneration gas turbines and the two gas boilers, can be divided into two sub-networks: the circuit that distributes heat to the library and the circuit that serves through a network of pipes the two-flat buildings that host offices, classrooms and laboratories. The pipes are installed underground and are properly insulated in order to minimize heat losses. The domestic hot water is produced by electric boilers located in the buildings, except for the accommodation building next to the library where it is produced by CSPs and solar panels.

All the SPM is real-time monitored and operated by the software installed in the control room. In particular, the main input data of the SPM Energy Management System (EMS) are: the electrical and thermal loads of the Campus, the forecasting of generation from renewable power plants and the weather forecast; moreover, in the optimization model the EMS is based on, the cost and revenue functions, as well as the operating constraints of power plants are coded. The EMS output is the scheduling of dispatchable sources (microturbines, boilers, storage systems), which minimizes the SPM daily operating costs. The optimization process, based on linear programming, has a time-horizon of 1 day (typically the one of a day-ahead energy market session), subdivided in 15 (or 30 or 60) minutes time-intervals. The EMS performs also a real-time management: basing on the optimal dispatch plan, any deviation that occurs during operation concerning with the energy exchange with the external network is shared at minimum cost among generation units, storage systems, and loads, which can be controlled, so that the planned value can be met; for instance, if the electricity produced by the photovoltaic field is less than the expected one, the lack of energy is compensated by increasing the power delivered by the energy storage system.

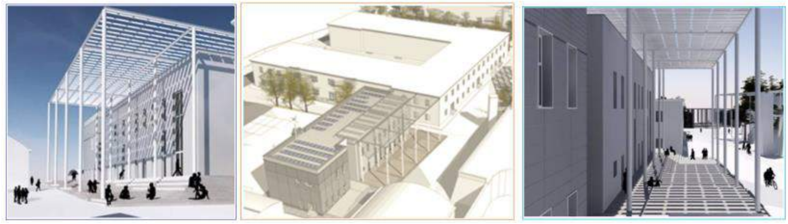

Figure 2: The SEB infrastructure in the Savona University Campus

The "Sustainable Energy Building" (SEB) is an on-going project (estimated completion date around the end of 2016), funded by the Ministry of the Environment and Protection of Land and Sea (MATTM), consisting in the construction, inside the Savona Campus, of an environmentally sustainable building connected to the SPM as a prosumer. The building will be characterized by energy efficiency measures from the thermal insulation point of view (high performance insulation materials for building applications and ventilated facades) and equipped by renewable power plants (a 20 kW_e roof mounted photovoltaic field, solar thermal panels, a 45 kW_{th} geothermal heat pump, a 3 kW_e vertical axis micro wind mill).

Integration of the SEB into the SPM

The most important peculiarity of the SPM&SEB system will be the possibility to control and manage the SEB equipment (the photovoltaic and wind generators, the geothermal heat pump, the air handling unit, the dimmerable lightings, the fan coils in each room, etc…) directly by the SPM management system. This will allow supervising the building operating conditions to the single room level, thus acquiring fine-grained data for tasks such as load characterization and correlation with exogenous variables (e.g. external temperature), as well as for forecasting purposes (load forecast based on historical data). Furthermore, it will enable demand response strategies by exploiting, e.g., the dimmerable lightings, the fan coil control, etc.; all these strategies will be integrated in the SPM energy management system. To this end, the data acquired by the sensors installed in the SEB, as well as the controls of the actuators (switches, valves, shutters, etc…) and the states and commands of the equipment, have to be made available to the SPM management system. The main difficulty to face, in order to make it possible, is the heterogeneity of the communication capabilities of the devices in both systems (SPM and SEB) and, in particular, the variety of protocols used by them. This is mainly due to the fact that the SPM architecture is very similar to that of an electrical substation, thus employing controllers (remote terminal units, RTUs), protocols (IEC 61850) and a communication infrastructure (high speed fibre optic ring) typical of an Electrical Automation System. On the other hand, for the SEB, busses and protocols meant for home and building automation are used (BAC/IP and KNX on twisted pairs). Furthermore, devices such as the inverters of the PV system and the wind turbine control unit employ the Modbus protocol.

To deal with the aforementioned heterogeneity, a hierarchical structure has been designed, employing the most suitable protocol/bus at each level, and exploiting the possibility of the controllers to act as gateways between different protocols. First of all, the SEB will be integrated in the SPM communication infrastructure by means of a new RTU, of the same type of those already used in the SPM (Figure 3), which will be installed in the building. This new RTU will be connected with the main fiber optic ring of the SPM (the communication backbone of the SPM, on which the IEC 61850 protocol is used). The RTU will be connected to the inverter of the photovoltaic field on the SEB roof, the controller of the SEB wind turbine and to the main controller of the SEB building automation system via a Modbus RTU interface on RS485. The main controller will communicate with the geothermal heat pump and the air handling unit via BACnet/IP. Furthermore, in each room, a room automation station will be installed. These units will communicate with the main controller via BACnet/IP. Finally, occupancy, temperature and light sensors, other digital and analog input modules, as well as actuators for fan coils control and digital outputs will be connected to the room automation unit by employing a KNX bus, while DALI will be used for light dimming. Small control panels will be employed to show information about the ambient conditions in each room and for the local control of lighting level, conditioning, indoor temperature, etc.

In addition to the main SCADA of the SPM, a dedicated supervision station on a PC will be installed, running a Building Automation-oriented SCADA, which will allow a more detailed supervision of the building equipment.

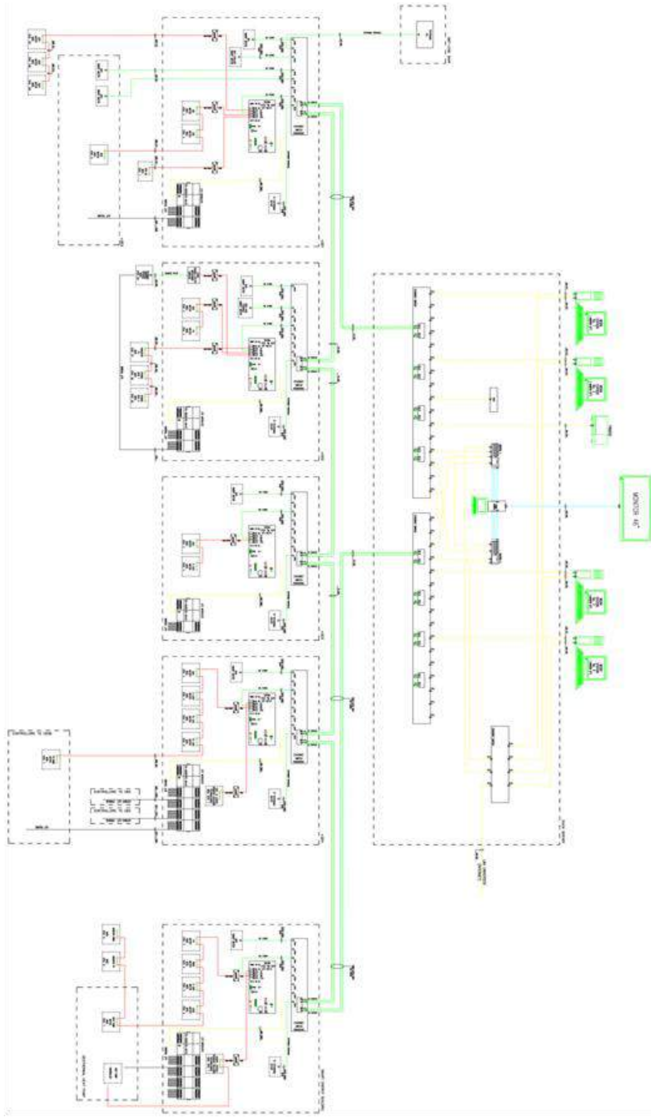

Figure 3: The SPM communication infrastructure

Key Performance Indicators for the assessment of the Savona Campus facilities

An overall assessment has been done in order to quantify some Key Performance Indicators (KPIs) for the Savona Campus, estimating the economic and environmental benefits due to the SPM&SEB infrastructures. In Tab. 1 the most important KPIs related to the yearly energy demands of the Campus buildings are reported, whereas in Figure 4, the environmental and economic impact of the SPM&SEB facilities on the Campus energy footprint are graphically highlighted. Moreover, Figure 5 shows how the different sources (SPM&SEB power plants and the public distribution grid) will contribute to satisfy the annual energy needs of the Campus, once the SEB also will be completed.

Energy mix	Building Type 1 (Lagorio, Marchi, Branca, Locatelli)	Building Type 2 (Delfino)	Building Type 3 (Library)	Building Type 4 (Residences)	Building Type 5 (Residences + canteen)
Air conditioning: cooling (% of the total consumption)	20%	10%	15%	15%	0%
Air conditioning: heating (% of the total consumption)	60%	70%	60%	50%	35%
Domestic Hot Water (% of the total consumption)	5%	5%	5%	10%	15%
Lighting (% of the total consumption)	15%	15%	20%	10%	10%
Appliances (% of the total consumption)	0%	0%	0%	15%	40%
Global consumption					
Total thermal energy consumption (kWh/y)	157000	447000	90000	170000 (electric)	247000
Total electric energy consumption (kWh/y)	73500	200000	40000	70000	210000
General features					
Final use (residential, offices,…)	Offices	Offices	Library	Residential	Residential
Number of dwellings	NA	NA	NA	24	17
Type of heating	District heating	District heating	District heating	Electric heat pump	District heating
Type of domestic hot water	Electric heaters	Electric heaters	Electric heaters	Solar panel + CSP + Electric heaters	Electric heaters

Table 1: KPIs for the Savona Campus buildings

Conclusion

In the paper the innovative and sustainable SPM&SEB infrastructures installed at the Savona Campus of the University of Genova have been described in order to highlight the importance of developing projects in the microgrid and the energy efficiency sectors. Such infrastructures permit to reduce the energy bill of the Campus, as well as its environmental impact, as assessed by the KPIs here reported. Furthermore, research activities on SPM&SEB could allow to test and offer important energy services such as peak shaving, load shifting, active power curtailment, and reactive power control. In addition, the engagement of the Campus users in the management and operation of the aforementioned facilities could promote sustainable actions also in the domestic sector.

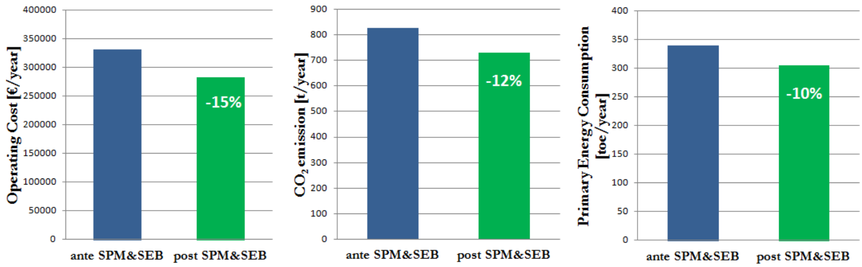

Figure 4: Environmental/economic KPIs showing the benefits given by SPM&SEB

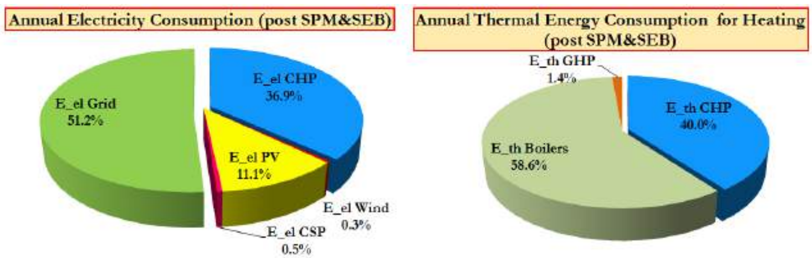

Figure 5: Contribution of the different sources to the Campus electrical/thermal load

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Cost-effective reconstruction of BIM from 2D scanned plan: experiments on existing buildings

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Abstract

The overall energy efficiency of existing buildings has to be significantly improved to comply with emerging regulations and to contribute to overcoming current environmental challenges. The effectiveness of renovation actions could be significantly enhanced through the systematic use of Information and Communication Technologies (ICT) tools and Building Information Modeling (BIM). But these solutions rely on full-fledged digital models, which, for most buildings, are not available. This paper gives an overview of the semi-automatic generation process of 3D models from existing buildings developed by combining 2D scanned plan recognition with assisted human interventions. The implemented process is able to extract information from 2D plans and to generate IFC (Industry Foundation Classes)-compliant 3D models that include the main components of the building: walls, openings, and spaces. This paper also highlights the extension of the methodology to cope with additional drawing conventions and to allow for more genericity. The results obtained with experiments on plans of existing buildings are encouraging and suggest that the mix of software assistance and focused human interventions may be a good trade-off for the quality of the resulting models.

Keywords

Building Information Modeling (BIM), Image processing, 3D building models, 3D reconstruction, model checking.

Introduction

In Europe, the households sector is the second consumer of energy (27% in 2009) just behind the transport domain (33% in 2009). Moreover, more than 40% of the residential housing stock was erected before 1960 and new buildings built each year represent only 1% of the overall stock (Atanasiu *et al.*, 2011). Therefore, renovation of existing buildings is a key enabler to any significant energy efficiency improvement of the European building stock (Pérez-Lombard *et al.*, 2008).

To improve the renovation relevance, one has to run computer simulation to optimize the coming operations. So the emergence of BIM (Building Information Modeling) and the evolution of AEC practices and tools such as decision-support systems for renovation actions can bring significant benefits in terms of cost and energy efficiency. One major hurdle however is the lack of 3D digital models for the majority of existing buildings, which calls for cost-effective and widely applicable methods and tools for the reconstruction of 3D digital models from available information.

A large set of techniques exists to create 3D models of existing buildings such as tape measures, photogrammetry, laser scanning, etc. (Volk *et al.*, 2014). These approaches differ in several aspects. The first is the cost and time required for data acquisition and process, including both the materials and the human resources needed. Further, all these techniques do not provide the same level of details. As shown by a recent review, the selection of the most adequate method will highly depend on the specifics of the project and context of future use of the 3D models (Gimenez *et al.*, 2015).

The aim of our work is to provide a methodology to generate 3D models of existing buildings that is say to rely on existing and easily available data and software processing by avoiding any time-consuming process and costly data acquisition. Hence our choice to focus on 3D model creation from 2D plans, which are available in most of the cases even if the result depends on the reliability of the plans. However, considering the large variety of existing plans, an exhaustive and fully automated process could be difficult to implement without implying huge and complex computation. To tackle such issue and containing the software cost, our solution proposes to combine the automatic generation of 3D models with focused manual interventions to minimize the time spent on manual corrections and to maximise their impacts.

The reconstruction encompasses the three components that are essential to generate complete and coherent 3D models: the geometry to define shapes and dimensions, the topology to define relations between features and the semantics to describe additional characteristics. In previous papers we presented the overall process to extract such information from real plans and validated the software tools for 3D models generation developed with a database of 90 plans (Gimenez *et al.* 2014). This paper focuses on a major improvement of our approach to deal with additional drawing conventions. The representation of building elements may actually vary significantly from one 2D plan to another, depending on the architecting company, the country, or the individual preferences of the architect. For example, a wall can be filled with white or black pixels, or even hatched. It is necessary to extend the methodology to deal with such variety of symbols and graphic standards, and to allow for easy parameterization of the graphical identification conventions.

In what follows, we first outline the semi-automatic process to convert 2D scanned plans into 3D building models and we focus on the extension of the prototype to deal with various representations and quality of the initial plans. Then, we give some results of the experiments led with plans of existing apartments.

Overview on the semi-automatic process

This section gives an overview of the semi-automatic process developed to generate 3D IFC models from 2D drawings by combining automatic recognition and guided human interventions. The second part is dedicated to the extension of this methodology to enhance genericity.

Motivations for introducing human interventions

The process is focused on the extraction and recognition of the three digital models components: geometry, topology and semantics. The complete process is described in Figure 1. The first step is based on the separation in the original image of text and graphic elements (Tombre *et al.*, 2002). Using the graphic elements images, building elements such as candidate walls and openings are identified based on methods of vectorisation and pattern recognition. A semantic distinction is made between outdoor candidate walls represented in red and indoor candidate walls in blue. To validate candidate walls, some rules help to verify the exact nature by calculating for example the density of black pixels in the original image.

Then, using results from the automatic recognition of text elements, the detection and identification of building elements, and some complementary assisted human interventions, the building model is created by reconstructing the outer shape of the building and indoor elements. Openings and spaces (yellow areas) are also recognized and their semantic is precised, e.g. door are coloured in pink while windows are coloured in green.

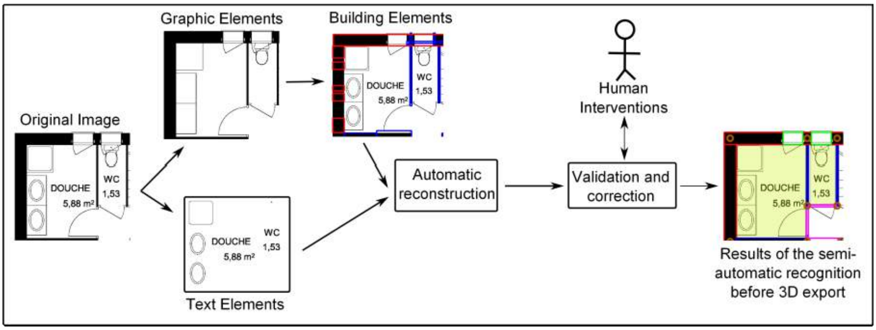

Figure 1: General process to convert semi automatically a 2D scanned plan into a 3D building model

During the recognition, a validation stage aims to detect automatically inconsistencies in the generated building model. Theses inconsistencies have been defined by creating an exhaustive taxonomy based on the geometry, topology and semantics using the most common errors found after a series of automatic tests. For example, confusing a door with a window is a semantic error while an intersection between two walls is a topological and geometrical error. Each detected error is stored in a specific file and an impact score is calculated according to its impact on future applications of the 3D building model like simulation purposes.

The system uses the impact score to determine the priority order of corrections. The highest priority is given to errors with a high impact level. For each error, several choices for correction are proposed to the user through a dedicated interface. He can then select the most appropriate correction, which is applied to the model.

At the end of the process, the building model is exported to a standard BIM 3D building model (namely the IFC – Industry Foundation Classes). This methodology significantly enhances the results of recognition while not requiring significant time to correct the model. The time to reconstruct a 3D building model is reduced compared to a manual conversion and gives better results than an automatic reconstruction, which would in any case be impossible given the vast variety of drawing and representation conventions that one may encounter.

Extension of the toolkit for enhanced genericity

The main limitation of the previous work was the lack of genericity to face a large variety of graphic representation for architecture symbols. Indeed, we have tested the first version of our prototype, with plans from a single database, which follow similar drawing conventions (see Figure 1). In order to evaluate the flexibility capacity of our approach, we have decided to develop an extension of the toolkit to enhance genericity and to perform additional tests with plans from other sources, featuring different drawing conventions. The evaluation has specifically been focused on recognition of walls, which can be represented differently depending on the plan (black, white, or hatched).

The rationale is to keep the algorithms tested with the initial set of plans and to add some preliminary processing to the source plan in order to generate a plan compliant with the initial conventions. In the specific case of walls representation, this consists in applying preliminary treatments that generate an image in which walls are represented by black pixels. This intermediate image is used during the conversion of graphical elements into building elements to validate candidate walls. Two additional types of wall representation have been considered: walls filled with white pixels or hatchings.

For walls filled by white pixels, contours are extracted in the original image. The drawback of this method is that all contours in the image will be identified, resulting in possible redundancies. It is therefore necessary to select those contours that are likely to represent a wall and to delete those corresponding to other elements, likes spaces. Our approach is to calculate the area of each generated contour and, to be considered as a wall and be filled with black pixels, the area has to be lower to a specific value. This specific value corresponds to the minimum room area of the building and can be set by the user.

The Figure 2 represents the different steps of the process for a wall filled with white pixels.

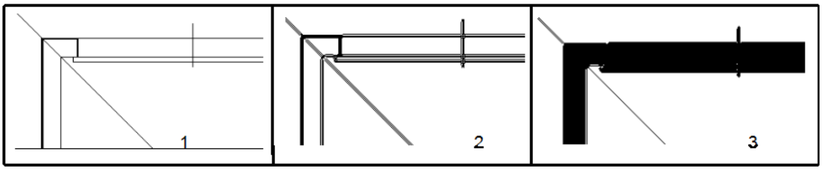

Figure 2: (1) Original image, (2) edges, (3) Final image

For walls filled with hatchings, the first step is to remove hatchings from the original image. A method is to analyse extracted segments from a previous vectorisation (Lladós *et al.*, 1997). The aim is to compute for each segment the couple (θ, L) where L is the length of the segment and θ the slope. Hatches are usually small and θ is around 45°.

Then, the method we propose is to identify in the set of remaining segments those that are parallel and close to each other (according to a predefined distance threshold). The region defined by the couple of segments is then filled with black pixels to comply with the constraint of our generic wall representation. The Figure 3 represents the different steps of the process for a wall filled with hatching.

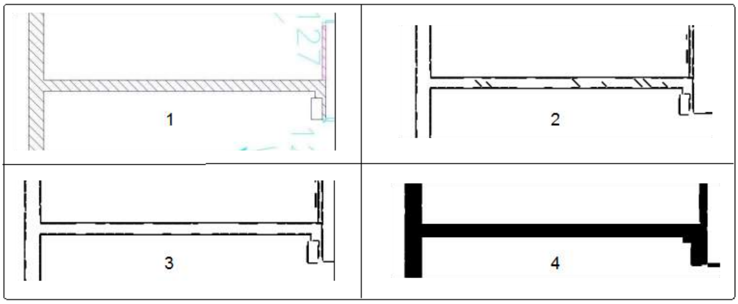

Figure 3: (1) Original image, (2) segments extracted with a Hough Transform, (3) Image after removing hatching, (4) Final image

This method has the advantage to be fast to run and easy to modify in order to be extended or improved when new representations will be encounter without modifying the entire prototype. However, the intermediate image cannot be used to identify precisely walls because of the large number of resulting artefacts. It only allows validating candidate walls and avoids the creation of graphical artefacts that do not correspond to any actual building element and that would be, in the subsequent steps, difficult to detect.

Experiments on existing buildings

To test and validate this extension, we have lead experiments on existing buildings thanks to floorplan images provided by a French real estate agency specialised in the sale of Haussmann style apartments in Paris[5]. Plans have been sometimes manually enhanced for a better quality with a low definition. In this article, the results obtained with two different plans are presented. The original images are shown in Figure 4.

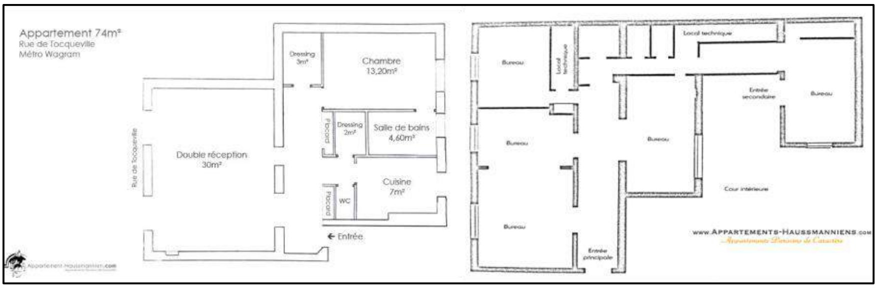

Figure 4: Two original floorplan images

The method applied to create an image with black pixels allows creating images for the two plans and resulting images are represented in Figure 5. These images are used to validate candidate walls by testing the density of black pixels for example. It cannot be used to find precisely walls because they are composed of artefacts and some walls are missing due to the constraints on the area of the contours detected.

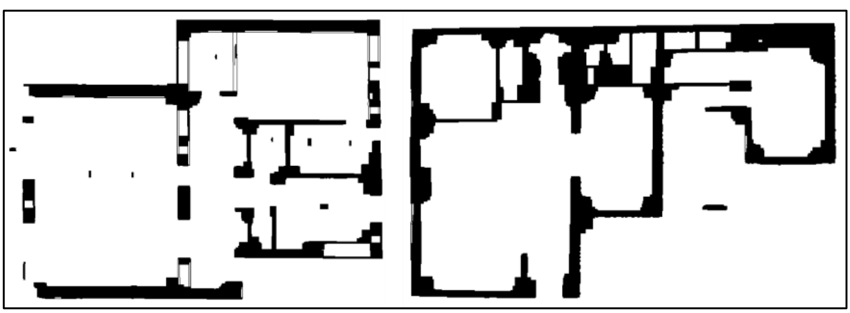

Figure 5: Images resulting of the process to identify pixels of walls

Results on the footprint reconstruction of the building and outdoor openings are displayed in Figure 6. In the left image, the reconstruction is good and all openings except one door have been well identified. In the right image, the reconstruction is less successful. This is partly explained by the low quality of the source, which globally impacts the recognition performance.

[5] http://appartement-haussmannien.com/

This process allows reconstructing a 3D building model in less than 10 minutes, including the automated reconstruction and the guided human corrections. It presents the advantage not to require any data acquisition on site using e.g. laser telemeter or laser scanners. Only little human intervention is necessary. Further tests have been performed using plans from additional sources, representing a complete building composed of two levels, which allows to reconstruct all the outdoor and indoor elements (walls and openings).

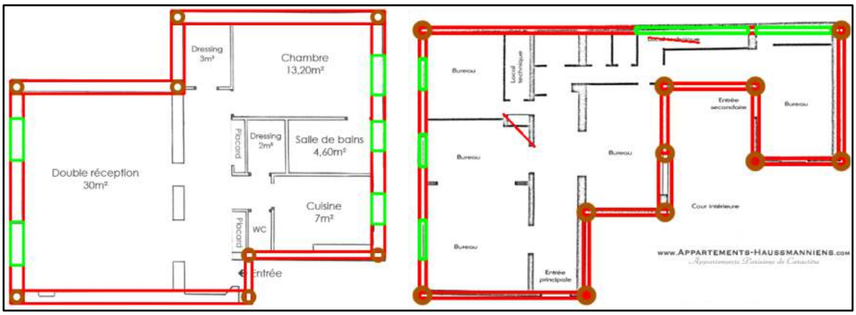

Figure 6: Semi-automatic recognition of outdoor elements. Red rectangles are outdoor walls and green rectangles are openings

Discussion

The improvement of our existing methodology allows to convert 2D scanned plans from various representations and qualities to 3D building models by combining automatic process with punctual and guided human interventions.

Our approach is able to identify walls with various graphical representations. However, there are other building elements whose representation can vary, such as doors. In the Figure 1, doors are represented with small black points but the quality is too low to be certain and to automatically find them especially if the image is filtered during the preprocessing. No representation is dedicated to opening in plans of the Figure 2, so it is almost impossible to detect automatically or manually doors.

Even if images resulting from the extension of the prototype are just used to validate candidate walls, the precision is dependent of the quality of the original plan. This method could be improved by selecting more precisely contours corresponding to walls to avoid the generation of artefacts

Tackling the diversity of representations in architectural plans remains a research challenge. By now, our work has been focused on walls because they are the most important components of buildings' geometry. However, other components, like doors, could be processed in a similar way.

A last issue concerns the third dimension such as height of the building and openings. There is often no information related to this point in architectural floor plans. To get the exact measurements, a solution could be to use results from façade images segmentation which allows recognizing building elements such as openings or balconies and approximating measurements using an object in the image which size is known (Ok *et al.*, 2012).

Conclusion

This paper describes a methodology to semi-automatically convert a 2D scanned plan into a 3D building model. The approach is characterized by a blend of automation and focused manual intervention in order to reach the best trade-off between the efforts spent on 3D models creation and the resulting quality. An extension of the prototype has been also presented to various floorplans representations in order to make our methods generic. One added value of the solution is an enhanced flexibility through the easy parameterization of 2D plans drawings conventions.

Future works will be focused on the improvement of the prototype extension to include others architectural representation types of building elements and to expand the 3D building models by integrating additional sources of data in the process.

Acknowledgements

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INTrEPID Project: a Pilot for Energy District Management

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Abstract

The INTrEPID project aims to develop technologies that will enable energy optimization of residential buildings, both performing an optimal control of internal sub-systems within the Home Area Network as well as providing advanced mechanisms for effective interaction with external world. This will be also including other buildings, local producers, electricity distributors, and enabling energy exchange capabilities at district level. In this paper we detail current activities, specifically the INTrEPID pilot, and why we think participation of the users as a pillar for allowing the transition to a more sustainable and flexible smart home system.

Keywords

Smart Grids, Energy Districts, Smart Home.

Introduction

Looking for the best technological and operational practices for a smart grid has been a goal shared by several research projects in the past years, see Covrig *et al* (2015) for the big picture. Several key aspects have emerged playing a relevant role in this contexts, one of these is the development of embedded intelligent systems for the home environment and implementation of middleware technologies for the integration of heterogeneous data coming from distributed sensor networks. Also variable conditions such as unpredictable renewable energy generation, different appliance usage patterns, or dynamic tariffs, contribute to enhance the complexity of the energy management problem.

INTrEPID, a three-year EUFP7 project started in November 2012, tries to solve these challenges by enabling the optimization of energy consumption in residential buildings, both at local and district level.

The main results of the project so far have been the following:

- The development of advanced energy monitoring systems, supervisory control strategies able to coordinate large subsystems (renewable energy generation, energy storage, appliance consumption, smart appliances etc.) and orchestrate operation of the different devices in such systems;
- The building of a Middleware infrastructure to deal with heterogeneous Internet of Things (IoT) systems, where different systems can cooperate seamlessly; different technologies have been adopted, based on Wi-Fi, ZigBee HA1.2, Z-Wave, Modbus over IEEE 802.15.4;
- The system testing (still ongoing) through a field deployment in a pilot of more than 50 homes (both energy consumers and producers), in order to check users' feedbacks and measure the acceptance of the proposed solution;
- Try to address users' needs in term of quality of experience while involving the users to actively contribute to the energy district optimization task.

Users involvement has been achieved with the development and distribution of a mobile application, which tries to actively engage them. Users can use it to inspect energy consumption by hours, days or months in the past and to understand specific appliance consumption. By means of a so-called "energy-watch" feature, which inspects the meter data in real time, is possible to understand consumptions of not directly monitored appliances.

The data are sent to an IoT platform (the INTrEPID Middleware), and they have been initially used to tune a recommendation system, which sends to the users activation time proposals for specific appliances.

The paper is organized as follows. In Section 72 we describe the pilot's users, how they are equipped with, and how they can interact with the system. Section 0 is dedicated to the data associated value and how it is possible to leverage this knowledge to enable sustainable energy district. We conclude with our final consideration in Section 0.

Pilot Description

Among all the interesting aspects, theoretical and technological, a project on district energy management should focus on; an essential part is the pilot phase where all the components are tested in a real environment.

In order to widen the project results relevance, the widest set of experimental settings has been chosen within the available sites choices.

Two countries have been selected for the pilot, Italy and Denmark, so that having demonstrators in different countries, with different climate zone, culture, lifestyle and home environment, would allow to extend the coverage of the potential different situations but also in order to identify benchmarks of equipment, algorithms and validation of the system architecture. Pilot sites were chosen in order to maximize differentiation of possible customers situations.

Figure 1: Pilot houses locations in Italy and Denmark

At the end of a survey campaign, four different typologies of pilots have been defined: 19 places in Denmark (17 houses plus 2 public entities), and 36 places in Italy (34 houses plus 2 demonstration sites) as shown in figure 1. Although not all the users are equipped with PV plants, the percentage of users with no PV generation in the Danish demonstrators is practically the same as for the Italian ones i.e. 65%. The main difference within pilot sites is in the variety of PV installation, actually 50% of demonstrators have a 6 kWp (power peak generation) plant, 17% of them have a 7 kWp and the remaining 33% have a 1.5 kWp production plant.

In addition of real users' houses, two other test facilities have been set up in order to perform preliminary tests and to ensure maximum effectiveness of the INTrEPID system, once it would have been installed in the field.

Users Device Equipment

Four solutions for the HAN - home area network (Advanticsys-ADV, Gorenje-GRN, Telecom Italia-TI and Seluxit-SLX) provided within the INTrEPID consortium have been integrated and tested. The HAN consists of a complex set of interacting components, all of them serving the purpose of collecting information about energy consumption, production and storage in the building as well as providing the infrastructure for controlling the appliances in order to increase the efficiency of the energy use and production together with maintaining or increasing user comfort.

The agreed architecture offers the advantage to integrate very different technologies with the help of software components (adapters) developed by each solution provider, which connect the different subsystems to the INTrEPID IoT Platform. Figure 2 shows the general architecture and the different devices used in the system.

The ADV solution consists of a "virtual" home gateway (ADV HG) that implements the logic to interact with the home devices/appliances by means of the Adapter and the Scheduler. The physical bridge between the home devices and the HG is supported by the controllers; these devices provide Modbus compliant communication and IEEE 802.15.4 support to collect the information from the end-devices (meters, counters, comfort sensors, smart-plugs…) and to deliver notifications messages.

Figure 2: General architecture of INTrEPID system and its devices

Gorenje solution is composed of two components: a Wi-Fi refrigerator and a Home Gateway that enables the smart devices to communicate with 3rd party devices/services via the INTrEPID architecture.

TI solution is based on the home automation framework Automation@Home (A@H) developed by Telecom Italia. The interaction between A@H framework and the other component of the system is accomplished through a home automation gateway (Smart Gateway) that manages the communication with sensors, actuators and smart devices within the HAN, comprising the ENEL's smart info device which communicates with the ENEL's smart meter through power line communication. For this system ZigBee Home Automation 1.2 standard has been used for RF communication among devices.

The Seluxit solution architecture consists of a home gateway which allows devices in the home to connect to Seluxit's MetaFlow platform and a RESTful web service that makes the device data available for a broad range of clients. The INTrEPID adapter is one of those clients and it handles the bridging between the INTrEPID REST service and Seluxit's web service. The RF solution is based on Z-Wave, a wireless communications protocol designed for home automation, specifically for remote control applications in residential and light commercial environments.

The interoperability between the different HAN solutions and with external entities and/or applications is entrusted to the abstraction created by INTrEPID platform, a cloud-based middleware which allows the multiple gateways for different technologies in each home or building to be logically aggregated and exposed to the control components in a consistent, secure way, while maintaining necessary levels of data privacy.

System Touch Points, engagements and feedbacks

The users can interact with the INTrEPID system through a mobile application. One purpose is for them to inspect consumptions. In the right side of Figure 3 "Graph" menu item is reported, it allows to inspect consumptions for the entire house or for monitored appliances. The left side of Figure 3 reports the so-called "energy-watch" feature which instead allows monitoring consumptions of each appliance (even the ones not directly monitored by a plug) by accessing the meter interface data in real time.

Furthermore, provided that home appliances have been equipped with smart-plugs, the system allowed the users to remotely turn on and off the devices and monitor specific consumption of each device individually; at the same time, the data feeding to the IoT platform have been initially used to tune the recommendation system to send to the users customized activation time proposals for specific appliances.

In addition to consumption awareness, the second step of the pilot, leveraging on all the connected homes, is being focused on understanding how to "move" energy consumption patterns of different houses forming a district, in order to control the cumulated load (i.e. the sum of consumption/microgeneration of all the buildings in the district). Since the pilot sites where spread in different locations, "virtual" districts have been defined as groups of users. In order to actively engage users to shift the appliance usage, the recommendations have been initially created starting from the users' habits. As a matter of fact, whereas finding a solution to the optimization problem holds technical challenges, see Grasso *et al* (2015), putting humans in the "control loop" might have strong implications in the comfort, since the more the habits are challenged, the less the user would likely be willing to cooperate, at least initially. While users empowering has a central role in the design of smart grid services, the behavioral change needs to be properly treated, see Geelen *et al* (2013). The recommendation system implemented in the district scheduler component of INTrEPID, then smoothly tries to move users habits, weighting more and more a generalized cost function of the district vs the habits "learned" from the user by means of machine learning techniques. The system is adaptive since reinforces its learning by means of users' answers to proposed scheduling through mobile app notification, confirming the users' centric role in the entire process. Incentives are provided to the users: an energy game supports a reward policy to stimulate the acceptance of unusual scheduling proposals, in order to gradually move users habits to meet the suggestions. Figure 4 shows mobile application related to these features.

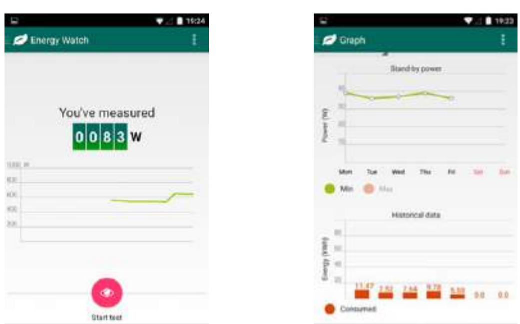

Figure 3: Mobile application user interface for real-time and historical consumptions check

As it emerges from what is stated above, that besides addressing energy optimization by means of technological developments and step forwards, the INTrEPID project is also trying to experiment how adaptive applications actively involving the users could accelerate the adoption of energy management applications.

Making Data Valuable

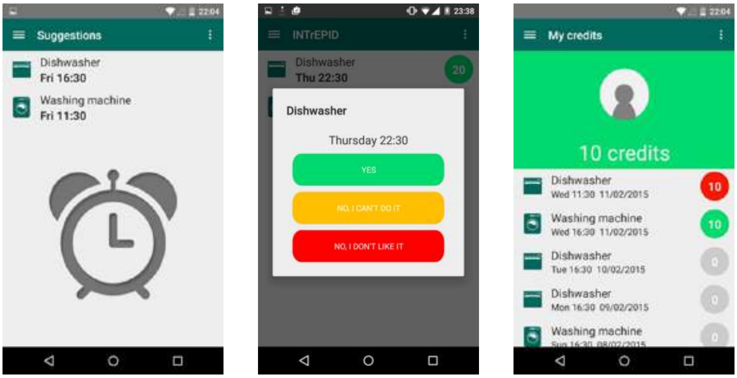

Figure 4: Mobile application user interface for schedule suggestions, responses, and scores related

Residential demand, for the high number of involved players and their distribution over the networks, represents a key element for supporting energy efficiency strategies, requested to all EU countries. The analysis of the INTrEPID data gathered from a real field trial confirms that advanced monitoring and control systems can support an increase of customers' awareness and allow significant energy savings by means of the efficient control of users' appliances. Analyzed pilot data show that, thanks to this solution, the availability of information about consumption by means of internet based 'friendly' applications allows tenants to consistently reduce their consumption. Zabalza (2014) states up to 8% by simply changing their habits in a report analysis of several EU projects in this field. Within the INTrEPID framework, customers are effectively enlisted as co-managers of the whole system. In addition, the introduction of INTrEPID System in buildings could trigger a considerable reduction of the energy demand for heating/cooling thanks to a more flexible management of heat request. Prospectively, the functions tested in the INTrEPID system will permit manufacturers of appliances to offer innovative devices able to self-organize with the cloud to interact efficiently in complex energy management systems.

Consumption awareness and thematic newsletters

Users consumption awareness, as stated above, has been raised through the INTrEPID mobile application. To the same extent an interesting approach tested was to make users aware, using anonymized data, about how differently other users perform. This is the reason why users have been periodically updated with bi-weekly newsletters reporting, as anonymized information (each user know its Buildin Unit ID), the comparison of existing usage in each home (and averaging, the per-capita), but also focused on specific appliances.

This comparison with other users provides a key additional level of understanding about their energy behaviors in respect with others.

Each newsletter has been also used as a valuable channel to take users up-to-date with tips on how energy pattern could be improved by little habits changes, making sustainable choices (they have also stimulated discussions with the project service designers). In the following lines a list of newsletter sent until the publication of this paper is shown:

- **Newsletter#1** - Understanding your standby consumption
- **Newsletter#2** - Your total power consumption
- **Newsletter#3** - Your fridge energy consumption
- **Newsletter#4** - Your washing machine energy consumption
- **Newsletter#5** - Your dishwasher energy consumption
- **Newsletter#6** - Your oven energy consumption.

As an example, an analysis about fridge/freezer usages which has been carried out in the third newsletter can be seen in figure 5.

Consumptions reported in Figure 5, related to a week-long temporal window during March 2015, need further evaluations in order to understand how users reacted after receiving such a comparison, if their reaction is a spike or if it lasts long, and ultimately if that represents a habit-moving trigger. We judge this kind of analytics really interesting for the design of future smart energy system.

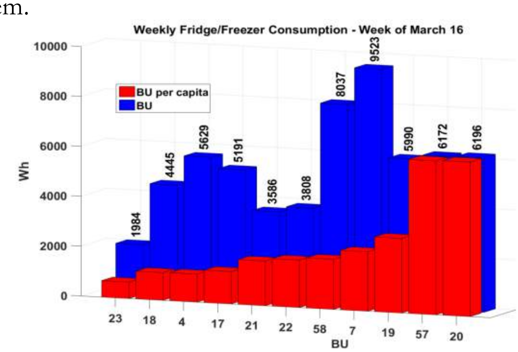

Figure 5: Fridge/Freezer consumption for an entire we for different Building Units (BU), and divided for the number of people per BU

Emerging Patterns/Habits

As it can be foreseen, patterns exist in how people use energy. Thanks to the pilot we have the chance to investigate even such aspects. For example, following the reasoning of "load archetypes" of Opower (2014) (which has carried out non-trivial task of data analysis), the energy consumption patterns of piloters have been tested on how they can fit into the proposed classification. We investigated some homes (Building Units-BU) as shown in charts of Figure 6. Notice that the different colour lines represent different days (weekdays and weekend) whereas the red solid lines represent the average consumption for all the examined days. Y-axis data are expressed in Watt. Depending on your energy personality, there are likely different ways to reduce the cost of your energy bill or modify your behavior.

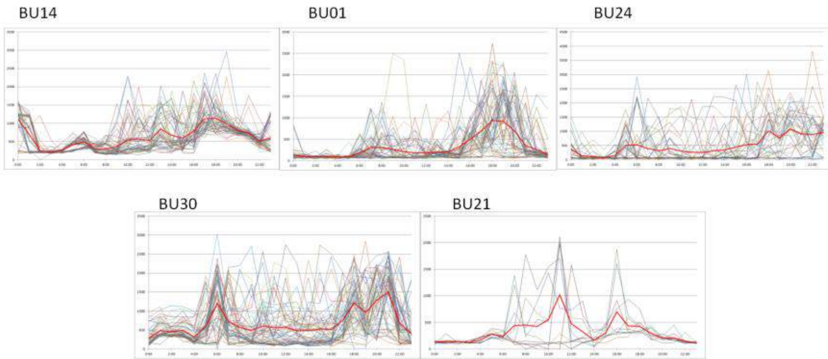

Figure 6: Energy personalities in some of the pilot Building Units (BU)

Drivers for moving habits

District consumption, especially its shaping, needs a proper orchestration to be operated in Demand-Response systems. Leveraging on all the connected homes of the pilot is tested how "moving" energy consumption patterns of different houses forming a district, in order to control the cumulated load (i.e. the sum of consumption/microgeneration of all the buildings in the district). The goal is to understand how ICT systems can really help to enable Active Demand services where the utility or energy provider might want the users in a district to follow a certain "cumulated consumption profile" over time to minimize energy costs.

In order to actively engage users to shift the appliance usage, the recommendations have been derived from the users' habits. By adapting the consumption of a district it is indeed possible to bring advantages to the energy retailers and to the users for accepting the time-shift in the energy use. As said above, habits change resistance add up to the technical challenges of the district scheduler optimization problem. This is the reason why the weight is gradually moving from users habits to the cost function, based on the recommendations acceptance rate. To this extent the reward system is playing a relevant role, each accepted recommendation give users as more credits as closer to the suggested time their appliances start. This mechanism let them understand how they contribute to their district overall score, compare their behaviors with others and reach symbolic energy achievements. Note that human in the control-loop by means of gamification approach is under investigation for the purposes of users understanding and engagement in other projects. As an example, one of these project is EEPOS, which allows multiple end-users tools to interface with neighborhood energy systems, as an example it develops a serious game by which incentive users with "Eco-points" for shift loads in valley time for energy prices.

Conclusions

The INTrEPID project is innovating smart energy application in several ways, with the implementation of a IoT platform (INTrEPID Middleware) able to manage heterogeneous technologies and systems and trying to apply new approaches to create benefits to the users and utilities through energy district optimization. In particular the project is validating how an adaptive system actively involving the users can accelerate the adoption of energy management applications and improve the engagement of people. The project is also investigating how improved analytics and machine learning techniques can be efficiently used to actively engage users to become an active part of the system.

From the first experimental data and feedbacks, the approach followed in the INTrEPID project based on user-centered system design and gamification appears to be a promising way to increase the user perceived value of smart grids applications and their acceptance in the mass market.

Acknowledgements

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Supply of thermal energy to District Heating networks from industrial waste heat and solar thermal energy coupled with Seasonal Thermal Energy Storage systems: Einstein and Pitagoras European funded projects

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Abstract

The Pitagoras project is focused on efficient integration of city districts with industrial parks through smart thermal grids. The overall objective of the project is to demonstrate a highly replicable, cost-effective and high-energy efficiency large scale energy generation system that will allow sustainable urban planning of very low energy city districts. The Einstein project deals with solar thermal energy and Seasonal Thermal Energy Storage (STES) systems and it is focused on retrofitting of buildings. The solar heat produced in summer is stored to be used in winter for space heating and domestic hot water (DHW). Both projects are closely connected to supply heat to District heating networks using energy source based on not fossil fuels. Waste heat and solar thermal energy will be exploited to reduce fossil fuel consumption and CO_2 production.

Keywords

District Heating, waste heat, solar thermal, seasonal thermal energy storage.

Introduction

The objectives of the European Union (EU) for the year 2020 in the context of its program "Climate Action: Energy for a Changing World" are to reduce energy consumption by 20% with respect to the 2020 business as usual forecast, to reducegreen house gas emissions by 20% with respect to 1990 levels, and to have 20% of total energy consumption in 2020 obtained from Renewable Energy Sources (RES).

Currently, about four out of five European live and work in a city, with the same share of energy use in cities being about the same (Eurostat, 2009). Within the EU, cities are responsible for about 70% of the overall primary energy consumption, and this share is expected to increase to 75% by 2030 (IEA, 2008c). There is no doubt that cities represent simultaneously a challenge and an opportunity for climate change policy.

In order to fulfil the above-mentioned objectives, the development of low energy solutions for thermal energy supply to cities is one of the main needs nowadays.

Today there is a vast set of sustainable technologies/equipment: solar thermal collectors, biomass boilers, photovoltaic panels in combination with heat pumps, co- or tri-generation based urban networks…etc. The suitability of these technologies depends mainly on the resources available locally or within the city hinterland.

Industrial waste heat and solar thermal energy are two energy sources with the highest potential nowadays. Industries are throwing away large amount of energy. It is said that as an average value, a 40% of the consumed energy in industries (considering the most consumer sectors) is waste heat. Besides, it is usually a very valuable energy (medium-high temperature heat), which is wasted to the atmosphere at present. There is no other solution more sustainable than the use of recovered waste heat for energy supply to city districts nearby. Solar thermal energy is as well a relevant energy source to be considered. It is free, infinitely renewable, available everywhere and it does not have dependency on fossil fuel prices.

The European funded Pitagoras and the Einstein projects aims at developing and demonstrating thermal energy systems based on waste heat and solar thermal energy. The main technologies that are used are not yet widely regarded as a reliable heating energy source (even they are already proven technologies), the application of these measures often fail even before cost issues are discussed. To change this negative view best practice projects are essential. In this context, the demonstration plants that are being developed in these projects will be essential.

The Pitagoras project

The Pitagoras project started on November 2013 and has a duration of 4 years. The main focus of the project is medium (near 600 ºC) temperature waste heat recovery from Electric Arc Furnace and the use of solar thermal energy to be used for District Heating networks. Two demonstration plants (in Brescia (Italy) and Kremsmünster (Austria)) at demonstration are being designed and will be built and tested during the project. Both plants will be connected to the city District Heating networks.

Demonstration plant in Brescia

The Pitagoras pilot plant of Brescia will contribute to cover part of the heat demand satisfied by the city DH network, which is estimated in 400 buildings approximately. Waste heat will be recovered from the Electric Arc Furnace, which is in operation 6,800 hours/year, this waste heat will be used in summer to produce electricity by means of an ORC system, and in winter, waste heat generated by the Electric Arc Furnace will be recovered and transferred to the Brescia district heating network.

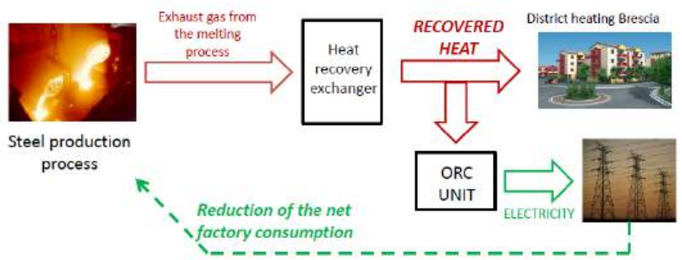

Figure 1: Scheme of Brescia Pitagoras pilot plant

According to initial estimations, around 68 GWh/year of thermal energy will be recovered. The produced electricity is calculated to be around 6,300 GWh/year with the ~2 MWe ORC and 30 GWh/year of heat approximately will be delivered to the city DH network.

The total heat demand supplied by the city DH network was about 1,4 TWh in 2012; it is estimated that around 2% of heat supplied will be covered by this pilot plant, reducing the heat supplied by fossil fuels.

According to first estimations, the total investment cost is expected to be around 12,6M€. Operation and maintenance costs have been estimated in approximately 100k€, taking into account the European funding, the payback time for this plant is estimated in about 8 years.

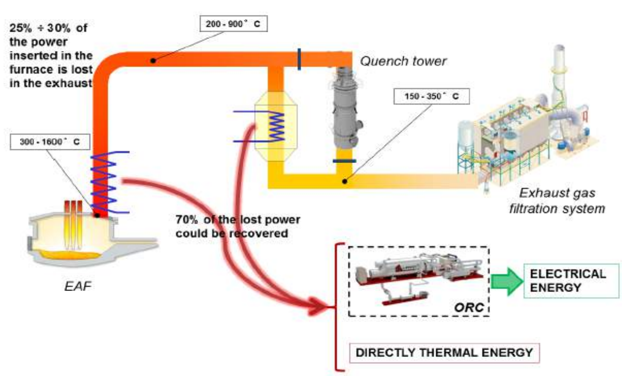

Figure 2: Plant concept of the pilot plant of Brescia

Demonstration plant in Kremsmünster

The demonstration plant in the city of Kremsmünster will be based on a large-scale solar thermal plant. The present facility is an oil well that produces gas and oil. This demonstration plant will work together with the CHP and the gas boiler used at present in the plant. According to first estimations a solar collector field of around 10,000m² will be installed, producing around 5GWh/year. The pilot plant will be connected to the municipal DH network. The heat produced will be partly used for heat supply to the DH network and partly for internal use at the industry (low temperature heat demand will be covered, increasing the efficiency of the solar thermal plant). A particular characteristic of the pilot plant is the Seasonal Thermal Energy Storage (STES) concept. The surplus heat in summer will be used to overheat the oil stored in the tanks (240,000m³), reducing this way the fossil fuel consumptions in wintertime. The oil is preheated usually to 25ºC, with the Pitagoras concept it will be overheated up to 35-40ºC with solar surplus heat in summer period replacing the fossil fuel use of wintertime. Up to 5GWh of savings on fossil fuels and a return of investment of about 10 years are expected.

Figure 3: Oil tanks for seasonal thermal storage at the Kremsmünster Pitagoras plant

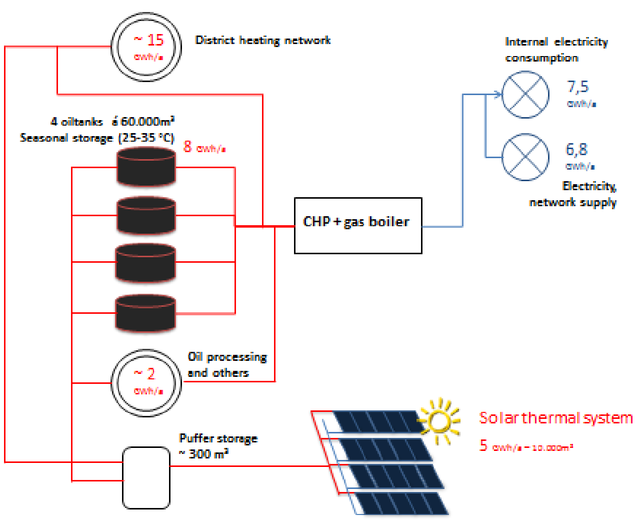

Figure 4: Plan concept of the pilot plant of Kremsmünster

This pilot plant establishes several sustainable benefits, as the followings:

- Substitution of fossil fuels of gas boiler (3.5 GWh/year)
- CO_2 savings of approx. 1,500 ton/year
- Individual system management of CHP plant
- Significant share of RES through solar thermal system in the city DH supply

Initial cost estimations indicate a total investment cost of around 4,4M€, including solar thermal plant (~1,9M€), other equipment such us piping, buffer storage, adaptation of existing oil tanks, etc. (~1,45M€) and other costs such as construction works, installation, planning, etc. (~1M€). Operation and maintenance costs have been estimated in approximately 7.000€/year.

The project started at the end of 2013 and currently the main activity is concentrated on the design of the pilot plants. The first monitoring results will be available by mid-2016. More information at http://pitagorasproject.eu

The Einstein project

The Einstein project started in January 2012 and will finish at the end of this year (2015). Two demonstration plants (Zabki, Poland and Bilbao, Spain) have been designed and built to demonstrate the research results of the project.

The project is based on STES systems. For solar district heating systems, STES are usually realized at large scale (Bauer et al. 2010 and IEA-SHC Task 45 2013). As larger are the systems, better is the economic feasibility. Althoug the pilot plants that have been built are small size systems, the results will be extrapolated to larger systems.

Four types of STES are presented below. In both plants the storages are over ground water tanks.

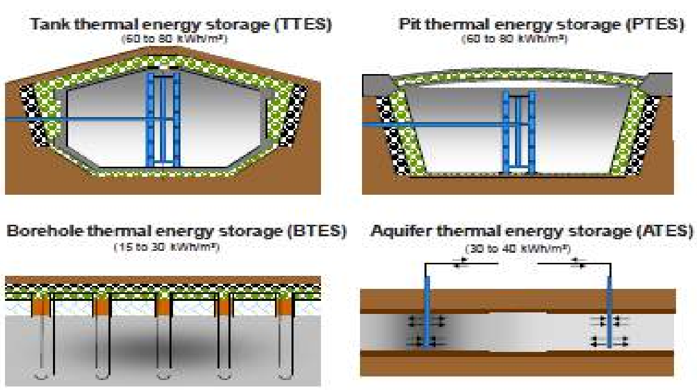

Figure 5: Four technologies for seasonal thermal energy storage

Both of the plants include a heat pump, which allows increasing the total amount of heat from STES utilized for building space-heating purposes.

Demonstration plants

The plant in Bilbao is designed for the heat supply of a building with an integrated over ground hot water store with a volume of 183 m³ and a collector area of 62 m² consisting of flat plate collectors. The pilot plant exclusively provides heat for space heating through an under floor heating system and air heating unit. The heat distribution temperatures are 45ºC on the supply flow and 35ºC on the return. A standard heat pump with a thermal capacity of 69 kWth using the refrigerant R410a is integrated into the system. As backup heating system a gas boiler is installed. The estimated annual heating demand is 83MWh/year.

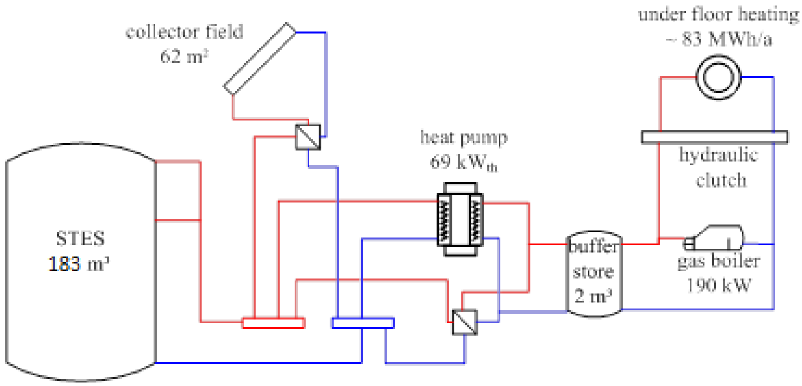

Figure 6: Simplified schematic of the pilot plant of Bilbao, Spain

Figure 7: STES and solar collectors in the pilot plant of Bilbao, Spain

The pilot plant in Zabki has been installed within the premises of the provincial hospital. The STES is connected to the existing space heating system of the Administrative Building. The system includes a small district heating network, an over ground hot water storage of 800m3, a ground-mounted solar collector field of 151 m2 of flat plate collectors and an innovative heat pump. In contrast to the plant in Bilbao, in which a commercial and standard heat pump was installed, a heat pump specially developed for this plant has been installed. It has been developed by the University of Ulster, it uses the refrigerant R245fa and achieves a thermal power of about 90 kWth for a maximum temperature of about 75°C in the condenser.

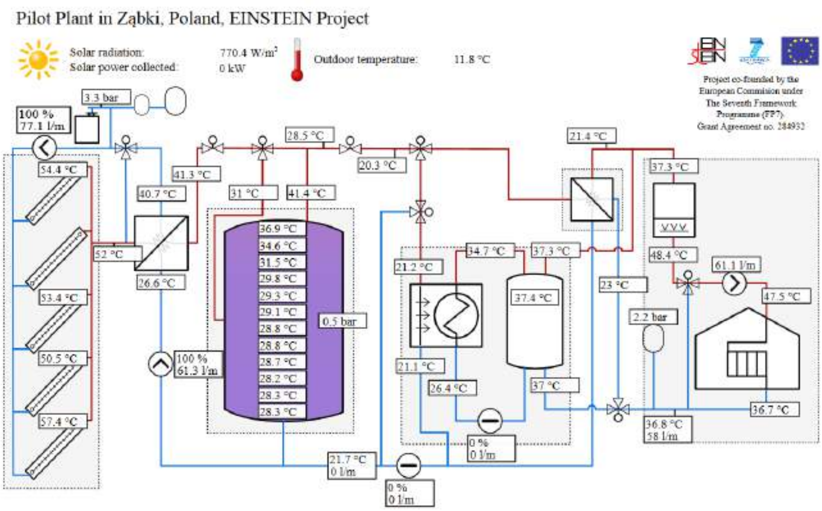

Figure 8: Simplified schematic of the pilot plant in Zabki, Poland

Figure 9: STES and the solar collector field of the pilot plant in Zabki, Poland

Several STES pilot plants have been built and monitored in the last years, most of them in Germany. The following figure shows the investment cost of several German pilot plants with different STES technologies.

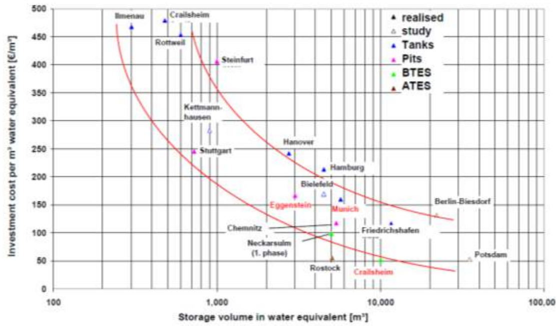

Figure 10: Investment cost per m3 water equivalent of German STES pilot plants

The investment cost of the Einstein pilot plants is 197k€ and 475k€ for Bilbao and Zabki, respectively, which gives a specific investment cost of 1.076€/m3 and 594€/m3. The cost is in both cases slightly higher than the German pilot plants shown in the graphic above. It should be taken into account, however, that the Einstein pilot plants have been realized in existing buildings and this has caused some overcosts. In Bilbao, for example, it has been necessary to remove part of the roof for the integration of the STES tank. In Poland, likewise, the installation of the piping system in an existing building area has slightly increased the total cost.

The pilot plants are under monitoring at present. The results on the real performance of the developed systems will be available at the end of the year (2015). More information on the project website: www.einstein-project.eu.

Conclusion

Demonstration activities that are being carried out in the European funded research projects Pitagoras and Einstein have been presented. Real applications of thermal energy systems with different technologies with high potential for the future to fulfil the European energy and CO_2 reduction objectives have been described. They are on-going projects and therefore final results are not available yet. The results concerning the Einstein demonstration plants will be available soon. On the project websites more information is available.

Acknowledgements

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Open-Source Modelling and Simulation of Microgrids and Active Distribution Networks

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Abstract

Distributed generation, and active distribution networks constitute an economic and technically viable alternative for reducing green house gases emissions and increase the use of renewable energy sources in local distribution grids. These active networks allow replacing large generators, usually located far from the consumption loads, thus considerably minimizing distribution losses and increase renewable energy penetration. However, designing and successfully controlling these complex networks, becomes a great engineering challenge; most computational modeling and simulation tools available for these systems are either focused on the individual generation components themselves, or the economic dispatch of multiple generators. Moreover, these tools often rely on closed source commercial software that use manufacturers' data for predefining the parameters of the models' components. This approach does not provide enough flexibility to users, since often is not possible to adjust these parameters. This paper presents object-oriented, component-based, open software components for simulating and optimizing the operation of active distribution networks, including multiple distributed generators and energy using the Modelica open-source modeling language.

Keywords

Modelling and Simulation, Distributed generation, Microturbines, Open Source, Smart Grid.

Introduction

In conventional energy supply systems; both electricity and sometimes heat are produced in large centralized power stations to be distributed to end consumers using overhead or underground cables and insulated pipes. However, smart grid developments, efficiency improvements in decentralized energy suppliers and the liberalization of the energy markets have made it more attractive for distributed generators (DGs) to produce energy closer to the consumption centers at reduced costs and improved reliability.

These new generators produce energy locally and use both conventional and renewable energy technologies.

There are several reasons that motivate the large penetration of DG; on the technical side, DGs offer increased efficiency, also increased reliability of the distribution network, improved power quality and help postpone upgrades on the grid. On the economical side, DGs help reduce transmission and distribution losses, increase the security of supply, reduce the electricity tariff and decrease the costs on spinning reserves through offering a more diverse energy supply capacity. Finally, one of the strongest motivators for DGs lately is their ability to effectively integrate renewable DERs, and thus, offer environmental advantages, such as the reduction of green-house gases (SOx, NOx, CO2) production, pollution reduction from large production plants as well as reduced environmental impact for extraction, refining and transportation of fossil fuels (Tan, Hassan, Majid, & Abdul Rahman, 2013).

These DGs have to be effectively integrated with the existing grid towards active distribution networks. However, efficient control of DERs requires the use of real-time tools to guarantee reliable operation of different DGs (Ferrari, Pascenti, Sorce, Traverso, & Massardo, 2014) and careful consideration must be given to interaction with the distribution grid in aspects of power quality, stability, reliability, protection coordination and power losses, etc., (El-Khattam & Salama, 2004).

An effective DG-Grid integration, therefore, requires the use of computational models that allow simulating different grid operation conditions with different levels of DG penetration. Distribution systems were not originally designed for allowing large penetration of DGs, therefore, most simulation and modelling software for this purpose, does not provide with the required computational models for this either. For instance, unbalanced power flow and transient analysis under these operation conditions are usually not supported by conventional commercial software packages (Martinez, de León, & Dinavahi, 2010).

Moreover, these software tools are often closed-sourced and the mathematical equation systems and simplifications used for calculating all the variables in a modelled system are unknown for the end-user. A possible approach is to use an open modelling equation-based approach (Vanfretti, Li, Member, Bogodorova, & Panciatici, 2013). By doing this, all the models and components are open and can be accessed and modified by the end-user. Additionally, equation-based modelling allows for straightforward development of new components and libraries by modifying and reusing existing models thus permitting the development of new customer-defined components.

One of the best tools available for this, and the one used in the development of the model components presented in this paper, Modelica, which is a freely available, object-oriented language for modelling of physical systems. Its language was built on acausal modelling with mathematical equations and object-oriented constructs to facilitate the reuse of models in order to allow for effective library development and model exchanges (Fritzson & Engelson, 2013).

In this paper, two components required for simulating the operation of large penetration of DGs in a LV distribution network are presented. The models have been developed in Dymola/Modelica and have been validated with real operation data from different physical components available at the polygeneration microgrid lab of the University of Genoa, located in Savona, Italy. These two models are part of a larger library for modelling and simulating DGs in low voltage distribution networks.

Distributed Generation Components

CHP Microturbine Model

CHP microturbines are small energy generators that usually range from 15 to 300 kWe and are based on the standalone joule cycle (Saravanamuttoo, H.I.H, Rogers, G.F.C. Cohen, H., Straznicky, 2008). Microturbines in general offer different features, for instance: high-speed operation, high reliability, low mainteinance and low NOx emissions (R. D. Corporation, 2001).

Microturbine Model

A model for a 65 kWe integrated combined heat and power (ICHP) natural-gas microturbine was developed. The model allows for thermal-following and power-following operation mode, however, the validation set only contained data for thermal-following operation mode, since it is the operation mode set at the SPM at the time of extracting the operation data.

The model was developed in a top-down scheme using the manufacturer's data for building the equation system. From the basic equation system, different performance derating curves were added fom manufacturer's data (C. T. Corporation, 2008), in order to determine the microturbine's maximum performance under different operation conditions (outdoor temperature, humidity, altitude, etc.). The resulting blocks diagram built in Dymola is shown in 0.

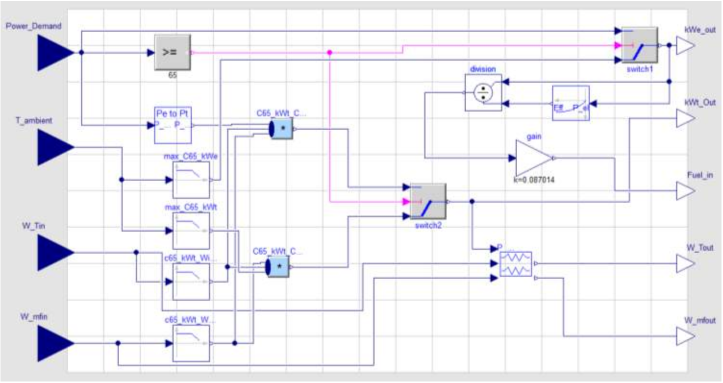

Figure 1: Capstone C65 Microturbine block diagram in Dymola

Solar PV Array

In order to predict the behaviour of the photovoltaic power plant under different environmental conditions (irradiance, temperature, load, etc.) it is important to be able to obtain the physical properties of the solar panels. Several methods (Chan & Phang, 1987; Hansen, Sørensen, & Hansen, 2000; Verbruggen & Roy, 2011) are based on extracting these properties from the panels I-V curves, however, as proposed by (Sera & Teodorescu, 2007), a photovoltaic panel model can be built from the information obtained from the manuacturer's data sheet.

Solar PV Array Model

The solar PV model has been built from the modelling approach proposed by (Sera & Teodorescu, 2007), where parameters required for the equivalent electric circuit of a photovoltaic cell shown in 0 are obtained from the manufacturer's data.

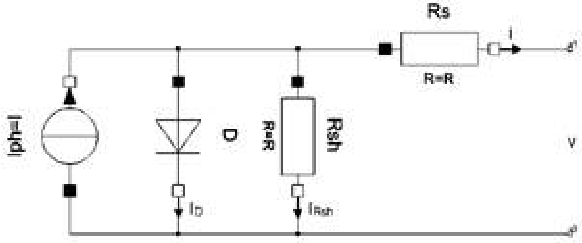

Figure 2: Equivalent circuit of a photovoltaic cell

Additionally, the global hourly irradiance on inclined surfaces has to be calculated. The hourly global solar irradiance, I_t, is composed of several components: the main beam I_{tb}, diffuse I_d and ground-reflected I_r. The main beam component was calculated from simple models found in the literature (Mehleri, Zervas, Sarimveis, Palyvos, & Markatos, 2010).

In the developed model, both the ground-reflected component and the diffuse component were not included, however, if the ground reflectivity is known, the equations used in (Mehleri et al., 2010) can be used.

Model Components Validation

Microturbine Model Validation

The Capstone C65 and C30 microturbines existing at the SPM are based on variable speed engines (up to 96,000 rpm), coupled with a permanent magnet generator. The generator supplies to a rectifier/inverter system in order to match the variable frequency and voltage from the turbine to the rated grid frequency and voltage. During start-up and cool-down phases the converter is reconfigured and acts as a variable speed drive while the generator is used as a motor. A recuperator n the microturbine allows extracting part of the heat in the exhaust gasses, thus making cogeneration possible. The electrical efficiency at rated power is 29% for the C65 model and 25% for the C30 model.

The validation dataset comprised of 3997 data points at 1-min resolution, obtained directly from the SPM's energy management system SCADA. Weather data were obtained from the closest weather station to the campus, located 15 kilometers northwest of Savona.

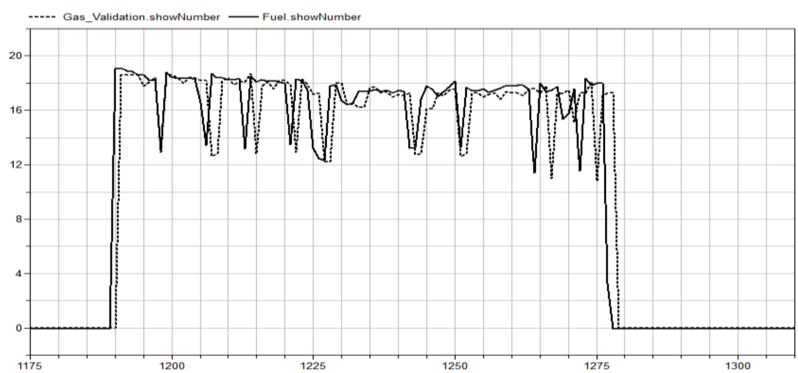

Figure 3: Simulated (solid) vs real (dotted) results for a daily profile

Simulated data for the fuel consumption follows the measurements obtained from the SCADA system. There is an existing 1-2 samples delay in the results, most noticeable during ramping-up and ramping-down of the microturbine. This delay could be reduced by including thermal delay and mechanical inertia parameters in the model as well as to check for data acquisition delays between the SCADA system and the database storing process, where the timestamp is assigned to each data sample.

Solar PV Model Validation

The photovoltaic field installed at the SPM is composed by 320 polycrystalline panels, subdivided in 20 strings, and mounted on the roof of the one of the campus' buildings. The solar PV array has the following technical characteristics:

Rated Power	49.9	kW
Tilt Angle	30	deg
Azimuth Angle	-30	deg
Module Efficiency	14.5	%
Open Circuit Voltage	37.92	V
Short Circuit Current	8.63	A
Voltage at Maximum Power	27.73	V
Current at Maximum Power	8.08	A

Table 1: Solar PV Array technical specifications (Bracco, Delfino, Pampararo, Robba, & Rossi, 2013)

The validation set consisted of 8865 data points at 1-min resolution intervals, obtained directly from the SCADA of the EMS at the control room of the SPM. Weather data was obtained for the closest weather station to the campus, located 15 kms at northwest of Savona.

Overall, the model captures well the behaviour of the PV array. Simulation results differ from the SCADA measurements mainly in cloudy days (0, right). This is due to the refraction and reflection effect of the clouds, as well as the reflected irradiance that was not included in the PV model's equation system.

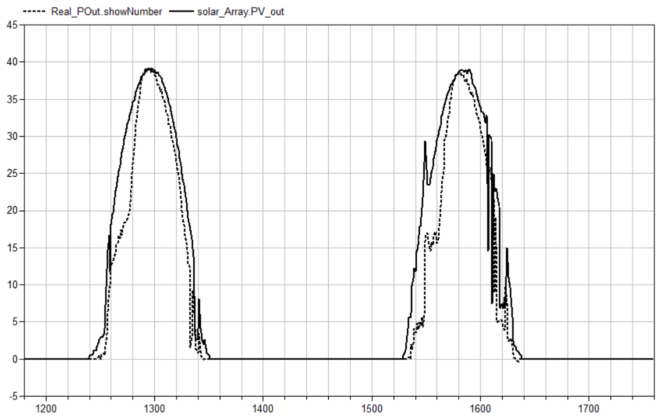

Figure 4: Simulated (Solid) vs Real (doted) power (in kW) output from the PV array

Interaction with existing libraries

One of the objectives of developing components for DGs using open-source, object-oriented tools, like Modelica is to be able to share models with other libraries in order to perform more complex simulations. The developed components have been tested successfully with the PowerSystems library (Franke & Ruedigerfrankedeabbcom, 2014) for performing simple balanced 3-phase power flow calculations. The authors will continue testing and developing this library further, in order to simulate faults and perform unbalanced power flow calculations.

Conclusion

Large adoption of microgrids and active distribution networks offer a promising solution towards a more sustainable power system, mainly thanks to its ability to effectively integrate DGs from different energy sources, including renewable ones. One of the main challenges for these networks to become more popular, is that the conventional distribution system was not designed to include large penetration of DGs. Therefore, the existing planning, modelling and simulation software packages were not designed for handling these new networks either. This paper presented the alternative of using the open-source object-oriented modelling language Modelica, for developing open components for DGs. The models were validated with real operation data obtained from the Savona Poligeneration Microgrid Lab (SPM) of the University of Genoa in Savona, Italy.

Results showed that not only this modelling approach is valid for simulating DGs, but also that they can be integrated with existing open-source libraries as it was with the case of the PowerSystems Modelica library that was used for testing the components. Future work includes developing more components and testing its performance with other libraries, in order to perform more complex simulations, for instance, to combine the operation of the power system with a local district-heating network, where both the electrical and thermal performance can be simulated and evaluated under different operation conditions.

Acknowledgements

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Sustainable Places 2015 > Conference Proceedings

Building a semantic-based decision support system to optimize the energy use in public buildings: the OPTIMUS project

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Abstract

The reduction of carbon emissions in cities is a systemic problem, which involves multiple scales and domains and the collaboration of experts from various fields. The "smart city" approach can contribute to improving the energy efficiency of urban areas provided that there is reliable data –from the different domains concerned with carbon emission reduction– to assess their energy performance and to make decisions to improve it. In the SEMANCO project, we applied Semantic Web technologies to solve the interoperability among data, systems, tools, and users in cases dealing with carbon emission reduction in urban areas. In the OPTIMUS project, the tools and methods developed in SEMANCO are being further enhanced and applied to the development of a decision support system (DSS) to help local administrations to optimize the energy use of public buildings.

Keywords

Energy efficiency, decision support systems, smart cities, semantic web, semantic interoperability, energy data models.

Introduction

The "smart city" approach can help to improve the citizens' quality of life in accordance with the objectives set by sustainable energy policies of the European Union with the target of reducing by 20% the CO_2 emissions by 2020. Smart cities rely on the availability of data. Although there is an increasingly amount of energy and other related data sets available, it is necessary to integrate them in order to provide the various stakeholders involved in the planning of energy efficient cities with the information they need to make well-informed decisions. In fact, the problem of carbon emission reduction in urban areas cannot be constrained to a particular geographical area or scale, or circumscribed to a particular discipline or expert: it is a systemic problem which involves multiple scales and domains and the collaboration of experts from various fields. In addition, having access to the data is not enough.

It is necessary to integrate data from different domains in order to understand the interrelationships between the various areas –energy, economics, health– that are involved in the reduction of carbon emissions in cities.

The application of Semantic Web technologies can help to overcome some of the difficulties which are intrinsic to the development of decision support systems (DSS), in particular those concerning the accessibility to the data and the integration of data from multiple domains. These technologies can be applied, mainly, to support data integration processes and to overcome the interoperability barriers between the data generated by the different users and by the applications in various domains. Currently, efforts are being made to deal with this problem in different areas related to smart cities. For example, the QuerioCity platform relies on Linked Data technologies to manage heterogeneous information stemming from different domains and formats (Lopez *et al.,* 2012). Another example is STAR-CITY, a system to aggregate heterogeneous real-time data with the purpose of exploring, analysing, and predicting traffic conditions in cities (Lécué *et al.,* 2014). Semantic-based interoperability approaches based on ontologies are an alternative to centralized standard data models whose limitations have already been pinpointed: difficulties to reach a consensus among a community of users; lack of flexibility of the data models to adapt to changes; and loss of information after exporting and importing data through applications (Sicilia *et al.,* 2014). Nevertheless, data interoperability is not only a technological challenge: it also involves devising and applying procedures to avoid doing redundant work, to reduce design errors, and to be replicable in other contexts. Therefore, the technological solutions need to be embedded in scenarios which encompass strategic goals, users and systems, along with the tools to analyse the data and mechanisms of data provision and data cleansing.

This paper contains a report on the development of a semantic-based Decision Support System (DSS) to optimize energy use in public buildings, which is being carried out by OPTIMUS project co-funded by the 7th Framework Programme. The goal of the OPTIMUS DSS is to suggest short-term decisions to optimize the energy performance of buildings based on the analysis of five types of data distributed by heterogeneous and dynamic sources: weather conditions, social behaviour, building energy performance, energy prices, and renewable energy production.

The work on semantic data modelling carried out in the OPTIMUS project is based on the results obtained in a previous project SEMANCO, carried out with the support of 7th Framework Programme from 2011 to 2015. These results refer to the procedures to design an ontology as well as to specific outcomes which are applied to the OPTIMUS project, such as the SEMANCO ontology and the ontology editing tools which were developed in this last project. With regard to the data being semantically integrated, the main difference between the two projects- SEMANCO and OPTIMUS- is that the first is focused mainly on static data needed to make middle to long-term planning decisions, while in the second one we are dealing mostly with dynamic data and short-term decisions making processes.

SEMANCO: the process to create a semantic-based platform to support decision making

The goal of the SEMANCO project was to create a semantic-based integrated platform to support the planning of energy efficient urban areas, with the participation of the different stakeholders involved: planners, policy makers and energy consultants. The reasons to use semantic technologies in this project were twofold: 1. From an instrumental point of view, these technologies enable the integration of distributed and heterogeneous data and 2. From a conceptual perspective, the process of designing an ontology enables groups of experts to jointly define the problem to be solved in terms of concepts and relationships between them. Therefore, in SEMANCO, the knowledge that a group of experts (energy consultants, planners, policy makers) had about energy efficiency planning in urban areas was formalised as an ontology created with the participation of the domain experts and the ontology engineers. Data needed to model the problem and to propose solution scenarios was integrated using semantic technologies.

Experts' knowledge is bound to the tools and methods in their particular disciplines, it is shaped by their experience, and it is constrained by the information they have at their disposal. To make this knowledge explicit, so that it can be formalised as an ontology, use cases were defined for each of the pilot cities participating in the SEMANCO project. A use case stands for a simplified model of a complex reality constructed with three components and their interrelationships: the data available to model the problem, the tools used to process the data and the experts who use the data and tools to model a problem and find the solutions to it (Madrazo *et al.,* 2013).

An ontology developed from the information captured through use cases stands for a formal representation of the knowledge that experts had with regard to the problem modelled through the use case. The ontology was developed in two stages: 1. Creation of an informal vocabulary to describe the problem at stake including the definition of terms, the data categories and relations between them which was structured in the Energy Standard Tables. These tables provided a link between the knowledge that experts had about a particular problem of energy efficiency and the information available (Corrado *et al.,* 2015)–, and 2. Creation of a formal specification of the terms and relations using standard languages of the Semantic Web such as Web Ontology Language (OWL). This was done by means of Click-On[6], an ontology editor developed within the project (Wolters et al., 2013).

The methods and tools developed in SEMANCO project are generic enough to be used in other domains. Planning energy efficiency buildings in an urban context is the domain of the SEMANCO ontology. However, this domain can be extended to include the energy performance of buildings in-use, as we have done in the OPTIMUS project.

[6] http://www.semanco-tools.eu/click-on

The development of the OPTIMUS DSS

The goal of the OPTIMUS project is to help local authorities to optimise the energy performance of public buildings by applying the measures suggested by a Decision Support System (DSS), which handles data obtained from a diversity of sources and domains. The application scenarios upon which the SEMANCO platform was built were aimed at supporting long-term decisions (e.g. urban planning) and were mostly based on the use of static data (e.g. building typologies, census, and cadastre). By contrast, the decision support system which is being developed in the OPTIMUS project is based on the interlinking of five heterogeneous and dynamic data sources: weather, social behaviour, building performance, energy prices and energy production. These data sources are integrated using semantic technologies and then used to propose short-term action plans, which enable energy, managers to optimize the building performance. For example, the DSS optimizes the boost time of the heating/cooling system taking into account the forecasting of the outdoor air temperature and the occupancy of the building. Accordingly, the DSS suggests selling/self-consuming of electricity produced by a PV system considering different scenarios of energy market and strategies (green, finance, intermediate, peak, load factor). Another example of a supported decision is the adjustment of the temperature set point, taking into consideration thermal comfort parameters (e.g., Predicted Mean Vote index) using occupants' inputs gathered with a mobile app.

The development process of the OPTIMUS DSS benefits from the experience and results obtained in the SEMANCO project, namely: 1. The tools used to create an ontology such as the editor Click-On, and 2. The SEMANCO ontology itself, which has been enhanced with the dynamic data required by the OPTIMUS project.

In OPTIMUS, the design of the DSS consists of four stages: 1. Defining the context, 2. Capturing the user requirements, 3. Identifying the dynamic data sources, and 4. Defining the application scenarios (Figure 1). Once the specifications have been defined, the DSS is developed consisting of the communication infrastructure (i.e. Semantic Framework), the DSS engine, and the DSS end-user interfaces.

The specification requirement process has been carried out in each of the three cities participating in the project: Sant Cugat del Vallès (Spain), Zaanstad (The Netherlands) and Savona (Italy).

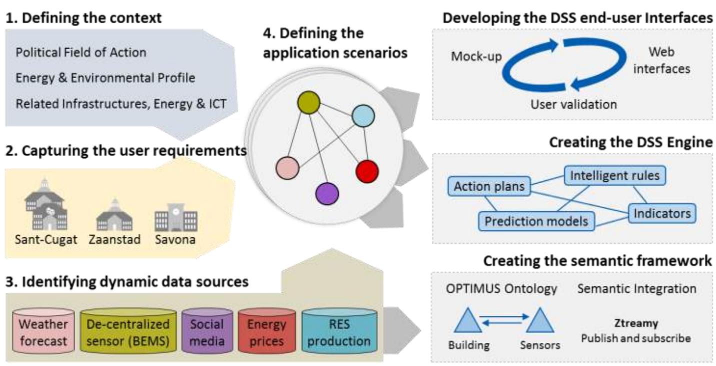

Figure 1: Process of the development of the OPTIMUS DSS

Defining the context

The first phase consists of defining the context where the decision support system will be used. This involves highlighting the strengths, the vulnerabilities and the opportunities present considering the current energy strategies, environmental policies, municipal facilities and related infrastructures of the city in which the decision support system is going to be used. Typically, cities are evaluated in terms of energy efficiency, CO_2 emission intensity, and cost savings. An assessment framework –Smart City Energy Assessment Framework (SCEAF)– has been developed within the OPTIMUS project to estimate the energy efficient measures based on the suggestions of a decision support system or of an energy management strategy (Androulaki *et al.,* 2014). The SCEAF can be applied several times to evaluate the progression of city in a period of time.

Capturing the user requirements

The user requirements capture is carried out in iterations with the participation of end-users who will use the DSS. The information available from the city is collated and the functionalities of the DSS are derived from the inputs provided by the DSS users. The requirements are captured by means of surveys and mock-ups of the user interfaces, which are discussed with the end-users to verify with them the specified requirements and functionalities. The output of this phase is a report, which includes the main features of the public buildings and their building energy management systems.

Identifying dynamic data sources

This phase is dedicated to identifying the static and dynamic data sources that might be needed to meet the user requirements. In this stage of the process, it is necessary to audit the data sources to see if they can be integrated and used in the application scenarios (see the following section). The data items of the data sources are characterized by the following attributes: name, description, type of datum (e.g., string, integer, number, real, etc.), source (e.g., sensor, web platform, etc.), availability (e.g., public, private with license, etc.), owner (e.g., university, meteorological agency, etc.), unit of measure, accuracy, time step, spatial scale (e.g., group of buildings, building, etc.), and recording period length.

Defining the application scenarios

The last phase has to do with the definition of the scenarios where the DSS is going to be applied. A scenario describes the components that the DSS needs to suggest the end-user a short-term action to reduce energy consumption and to optimize the performance of buildings: input data, prediction models, intelligent rules, action plans and KPIs. The input data can be dynamic (e.g., energy consumption) and static (e.g., building partitions) which have been audited in the previous phase. The prediction models use dynamic data to forecast the performance of a building in the future. Black and grey box models –implemented with linear and non-linear methods– are used to create forecasts based on the historical data. Intelligent rules use, both input and predicted data to find out possible short-term actions. An action plan is a set of actions suggested by the intelligent rules. Key performance indicators are used to evaluate the performance of the actions suggested by the DSS. These indicators are related to those used by the SCEAF to establish the baseline conditions in each pilot city.

The outputs of this phase are the specifications of a scenario encompassing the user requirements and the data sources previously identified. The mock-up previously developed during the capturing user requirements phase is included in the scenario specifications. Based on the specifications captured in the previous stages, the main components of the DSS are then developed.

Creating a semantic framework

The DSS relies on the interconnection of heterogeneous, dynamic data sources, which are used to suggest short-term action plans. Typically, these data are obtained from physical sensors installed in buildings, national agencies and web services. Moreover, the data comes from different realms (e.g. climate, energy costs) and have different characteristics (e.g. units of measure, aggregation level). A semantic framework is the communication infrastructure, which facilitates the transferring of data from the distributed sources, and the subsequent contextualization of the raw data in specific contexts. The development of the semantic framework encompasses: 1. The building of an ontology to model the different domains, and 2. The integration of dynamic data sources using a publish-and-subscribe system.

Ontology building process

An ontology is a formal shared conceptualization of one or various domains. In the OPTIMUS project, an ontology is the conceptualization of the energy performance of a building in operation. It embodies the terms and attributes to describe urban areas, neighbourhoods, buildings, building partitions, systems and metering devices, indicators such as energy consumption and CO_2 emissions, as well as climate and socio-economic factors.

A good practice in ontology design is to use terms based on norms and international standards and to reuse or expand existing ontologies. To build the OPTIMUS ontology we have relied on the urban energy ontology previously developed within SEMANCO project[7]. In this way, the conceptualization captured in the previous ontology could be re-used in the OPTIMUS project. This ontology captures the building and the technical system features such as building geometry, building thermal envelope, space cooling/heating systems, among others (Nemirovski *et al.,* 2013). To model real-time data sources, the Semantic Sensor Network (SSN) ontology has been chosen. The SSN ontology models sensors and observations. In particular, the ontology includes capabilities, measurement processes, observations and deployments in which sensors are used (Compton *et al.,* 2012). Since the SSN ontology provides only

[7] http://semanco-tools.eu/urban-enery-ontology

core concepts, it needs to be extended with domain specific terms. The resulting OPTIMUS ontology is being coded in OWL using the Click-On editor. Currently, this ontology contains new 74 terms and new 33 relations and it borrows 1000 terms and relations from the existing Urban Energy and Semantic Sensor Network ontologies.

Semantic data integration

Semantic data integration is a process to transform and integrate raw data into information, which acquires meaning in specific use contexts using semantic technologies. A data integration process consists of four steps: 1. Data capturing modules, which retrieve the raw data from its source and transform them into RDF, 2. A publish-and-subscribe system (i.e., Ztreamy server), which receives data from modules and ensures the connectivity with the DSS, 3. A Semantic Service developed within the project to contextualize the data sent by the modules, and 4. A triple store (i.e., Openlink Virtuoso Server) to integrate the data.

The data integration process starts with the data capturing modules gathering raw data from the sources (e.g., sensor, web service). Those modules transform the raw data into RDF following the ontology structure. The data is sent to the DSS with the communication systems. The Semantic Service obtains the RDF data, which is enriched with the context (e.g., where was measured, which property is measuring, which units, etc.). Finally the Semantic Service stores the contextualized RDF data in a triple store.

Creating the DSS engine

At the core of the DSS engine lie the intelligent rules. These are a set of procedures to check if the input data match certain patterns to derive an action plan. The main goal of the DSS engine is to propose an action plan for the end user. To do so, the intelligent rules have to be fed with predicted, real-time and static data. To predict the building performance, a set of prediction models can be applied to determine an output variable by establishing the relationships between the output and input variables.

The process of building the DSS engine starts with the identification of intelligent rules requirements, in particular the data needs. Prediction models need to be developed for the data sources, which are to be forecasted. The prediction models need to be trained with a large amount of historical data. The proposed action plans include the calculation of key performance indicators, which will be used later for comparing with baseline or target scenarios. Examples of indicators are the reduction of the energy consumption, the reduction of the CO_2 emissions, cost reduction for energy needs, and an increase of RES in the final use. Currently, prediction models have been developed to forecast energy consumption of a building, indoor air temperature, energy prices, energy production of photovoltaic panels.

Developing the DSS end-user interfaces

The development of the end-user interfaces starts during the requirement capture phase while the first mock-ups are developed and discussed with the end-users. Later, several iterations are carried out for mock-ups to be discussed and refined. When a consensus is reached, the mock-up is implemented in the DSS. Finally, an evaluation with the end-users is carried out. Figure 2 shows two mock-ups from different iterations (left side of Figure 2) and their implementation in the DSS in the right side. The next step in the development of the system is to apply it in real conditions to optimize the building energy performance during the third year of the project. Further developments are expected following the results of the implementation.

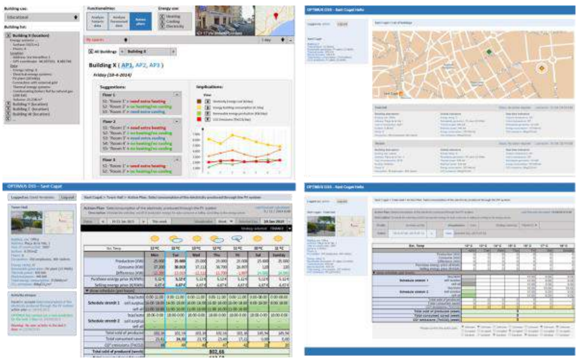

Figure 2: Mock-ups (left side) and end-user interfaces (right side)

Conclusion

In the OPTIMUS project, we are developing a semantic-based Decision Support System, which is based on the methods and tools previously developed to create the SEMANCO platform. A first prototype of the DSS has been created based on the findings of requirements analysis conducted in three pilot cities. Requirement capturing is not a one-off process. It needs to be continuously validated with end-users and domain experts. One of the difficulties encountered in the development process has been obtaining generic application scenarios from the user requirements and the available data sources in each city since every building has a different infrastructure, data sources, regulations, cultural environments, occupancy profiles, uses, schedules, and targets. The OPTIMUS DSS represents an innovation with respect to the existing systems in so far as it is able to interlink five types of heterogeneous data sources (i.e., weather conditions, social behaviour, building energy performance, energy prices, and renewable energy production) in real time in order to suggest short-term action plans that enable public authorities to reduce energy consumption in public buildings.

A first prototype of the DSS has been developed including three action plans, four prediction models, and data integrated from five sources. The next step will be the application of the first prototype version in the three pilot cities, operating under real working conditions.

Acknowledgements

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The BIM-GIS model for EeBs integrated in healthcare districts: an Italian case study

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Abstract

STREAMER is an industry-driven collaborative research project on Energy-efficient Buildings (EeB) which aims to reduce, using optimised Semantics-driven Design methods and interoperable tools for Building and Geo Information Modelling (BIM–GIS), the energy use and carbon emission of healthcare districts in the EU by 50% in the next 10 years (http://www.streamer-project.eu).
The paper summarizes the developing of a prototype Semantic BIM-GIS model based on the information from the Azienda Ospedaliero-Universitaria Careggi of Florence (AOUC), one of the four healthcare districts that will be used as the main platforms to demonstrate and validate STREAMER's design methods, tools and EeB technological innovations.
The paper deals with the documentation focusing on the project description, outlined planning, requirements, typology model/master plan, and it includes a conceptual building design in open-BIM format The result of this work is the elaboration of a first draft of the BIM model of the use case containing a data deriving from the classification of all the elements regarding the MEP systems and building space and envelope, and on the layout obtained during a desk and field survey carried out on the chosen pilot site building.

Keywords

Healthcare Districts, Energy Efficiency Building, BIM

Introduction

STREAMER is an industry-driven collaborative research project on Energy-efficient Buildings (EeB) with cases of mixed-use healthcare districts.

The main aim of STREAMER is to reduce the energy use and carbon emission of healthcare districts in the EU by 50% in the next 10 years by enabling clients, architects, technical designers, contractors, building operators and occupants to design new and retrofitted energy-efficient buildings integrated in the healthcare district energy systems using optimised Semantics-driven Design methods and interoperable tools for Building and Geo Information Modelling (BIM–GIS).

This paper summarizes the developing of a prototype Semantic BIM-GIS model based on the information from the Italian demonstration project: the Azienda Ospedaliero-Universitaria Careggi of Florence (AOUC), one of the four healthcare districts that will be used as the main platforms to demonstrate and validate STREAMER's design methods, tools and EeB technological innovations.

The nature of the information required depends on the purpose of the case study, practical validation and demonstration. Considering the planning of future interventions on the estate, the AOUC has chosen to use the oncology center named "San Luca", which consists of three buildings, as the case study for validating the research results. Within the plan for the new Careggi, the "San Luca" becomes the key area for the demolition and reconstruction interventions in order to release space to accommodate new buildings.

The oldest of the three buildings, the "San Luca Vecchio", has been built in the 60' and is arranged according to a simple body layout on three floors. The plan is characterized by a core and two opposite wings. This allows a proper distribution of functional areas within the building, and an easy implementation of the MEP systems, which trace the functional organization of spaces. The other two buildings "San Luca Nuovo" and "San Luca Volano" have been built in recent times (15 years ago about the first one, and around 2012 about the second one).

The STREAMER knowledge will be used to achieve the following objectives:

1. The enhancement of the SACS© (a custom Visual Basic software that manages CAD geo-referenced digital maps in order to feed a database that provides structural, technological and organizational information of the Careggi healthcare district) to take into account energy, applied on a single building at first, then possibly extended to other ones;
2. The evaluation of the older building, relying on BIM (definition and planning of building intervention);
3. The development of a better district-level planning and management of energy production.

The work reported here has been settled according to a four-step approach which comprises the identification of the buildings and use cases, the identification and definition of the information for BIM necessary for the uses cases, the choice of the Key Performance Indicators (KPIs) and the mapping of the STREAMER tools and third-party tools that will be used.

Careggi healthcare district

AOUC is a complex system of mixed functions that accommodates care, training and research facilities at the same time. Therefore, there are buildings addressed to care activities and others addressed to the research and training ones.

The Careggi hospital has been built firstly at the beginning of the 20th century as a satellite structure of the “Arcispedale di Santa Maria Nova”, the most important hospital of Florence at that time.

Since remote past time, the hill area where it was built has been well-known for its characteristics of being salubrious and healthy. This led some monks coming from other part of Tuscany to set up in 1218 a healthcare institution called “Ospizio del Pellegrino”, in an area near where the AOUC hospital was going to be built. The hill has been also subject in the past to the construction of many villas, among which Villa Medicea was built during Lorenzo il Magnifico lifetime, now property of the Healthcare Leadership since 1936.

Since its foundation, the Careggi hospital has been subject to many interventions, both regarding the building structure and the organizational structure. Indeed, as a result of the reforms regarding the healthcare at the end of the seventies, Careggi hospital became independent from the hospital of Santa Maria Nova in 1982. This led the new Careggi to become during the nineties “Azienda Ospedaliero-Universitaria Careggi - AOUC”, as we know it now.

Following this, a new strategic plan for Careggi called “New Careggi plan” was elaborated around 2000 to define the future development of the healthcare district. Indeed, this plan still operates to define the continuous renovation and transformation interventions. The “New Careggi Plan” involved the demolition of around the 60% of the existing volumes to allow the realization of new buildings well integrated with the environment and landscape from different perspectives.

The main purposes of the “New Careggi plan” are:

- Renovation of the buildings,
- Reorganization of the transportation network inside and outside the hospital area,
- Concentration of functions (care, teaching and management) to reduce the number of buildings and to merge university teaching and research activities with healthcare activities.

The plan is based on the design criteria of breakdown of hospital functions into sub-systems: internal sub-systems, operating within the facility, and external sub-systems that refer to the non-hospital context relations. Thus, all the dynamics at the level of individual buildings, the relationships between buildings and the interface with the city are considered and stressed. So far, the “New Careggi Plan” enabled (and enables) to tackle the complexity of the healthcare district relations’ system within the respect of the landscape and urban situation. (Del Nord, 2011)

The SACS© system

Considering the spatial and organizational complexity of the district, Careggi felt the necessity of elaborating a tool that could gather all the data and information regarding the facility, continuously evolving. SACS© has been created for this reason. SACS© is an informative tool which manages CAD digital maps in order to feed a database that provides structural, technological and organizational information of Careggi.

The SACS© system is a custom Visual Basic software that drives Autocad to manage and analyses digital plans of buildings coded on specific layers. Moreover, the system is linked to the georeferenced Hospital Information System (HIS) designed in Microsoft Visual Basic. The particularity of SACS© is the "everything inside DWG" approach: all data are stored inside the digital maps allowing anytime to rebuild the whole information having nothing but the DWG files. This allows a great flexibility of the system that offers the opportunity to elaborate pre-existing and not specifically SACS© -designed plans. (Luschi et al., 2014)

STREAMER Italian case study

Six months after the beginning of STREAMER project, considering the planning of future interventions on the estate, the AOUC has chosen to use the oncology center named "San Luca", which consists of three buildings, as the case study for validating the research results. Within the plan for the new Careggi, the San Luca becomes the key area for the demolition and reconstruction interventions in order to release space to accommodate new buildings.

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3. The development of a better district-level planning and management of energy production.

The work has been settled according to a four-step approach which lists the steps as here follows:

Step 1: Identify buildings and use cases
Step 2: Identify and define information for BIM necessary for the uses cases
Step 3: Choose the Key Performance Indicators (KPIs)
Step 4: Map the STREAMER tools and third-party tools that will be used

STREAMER, therefore, aims to implement a set of interoperable tools able to support the choices to be taken for a functional and technical improvement of the compound (renovation or demolition/rebuilding of the San Luca Vecchio) based on energy efficiency criteria. To build up the tools, it was firstly necessary to generate BIM and GIS models of the entire health district, and then to model the three buildings that constitute the oncology center, according to different Levels of Detail (LoD). Thanks to the availability of data and plans contained in the SACS© database, a first model has been developed and delivered to the partners of KIT – Karlsruhe Institute of Technology.

In order to get a LoD 1 block model of the complete health care district of the Careggi hospital in Florence, two different approaches have been tested by KIT:

1. Creating a city model according the CityGML standard
2. Creating a set of buildings according the IFC standard

The next stage was about the preparation of the three-dimensional model with LoD2 of the three buildings that constitute the San Luca complex, to be used as the basis for the implementation of BIM. The AutoCAD Architecture 3D model of the three pilot buildings (containing the "architectural" layer and the "windows/doors" layer) was made and transferred into Archicad 18, the BIM software chosen to model the Careggi case study.

The BIM model contains the data obtained during the desk and field survey carried out on the chosen pilot site building regarding the MEP systems and building space and envelope, and on the layout (Table 1). The survey was crucial as the information and data collected provide the basis for the development of the BIM-GIS model for the purpose of case study, practical validation and demonstration. All the data related to energy consumption, dimension, equipment, etc., of the three buildings were listed, the desk survey was done and the field survey took place only for missing data.

Each group of elements has been identified and all the different typologies of each element have been listed and described according to its characteristics. Therefore, a classification of these elements has been realized in order to define a coding system that could inform the space with relevant information for the STREAMER aim (the relevant information are attached to the spaces represented in the BIM). The aim of this work is to create a database of information that informs the BIM elements of the model with the codes defined within the table. Each code is assigned to each BIM element and will then provide useful data for the elaboration of future work such as an energy simulation.

Data	Processing	Software
Topography of the land	Geo-referenced model	Q-GIS 2.8 and Sketch-Up
Network of the roads	Geo-referenced model	Q-GIS 2.8
Network of the technical infrastructure	Geo-referenced model	Q-GIS 2.8
Functional areas and space units (room level)	DWG drawing	SACS
Organisational model (room level)	DWG drawing	SACS
Medical equipment (area of activity level)	DWG drawing	SACS
Shape of the buildings nearby the San Luca complex	BIM model	ArchiCad 18
Structural components	BIM model	ArchiCad 18
Windows and shields	BIM model	ArchiCad 18
Floors, claddings and ceilings	BIM model	ArchiCad 18

Table 1: Data and processing

The description of the hospital state of the art is enhanced by the adopted Key Performance Indicators. This is true both for the strict correlation between KPIs description and BIM approach and for the potential that an evaluation of KPIs supports. The fundamental – and agreed - KPIs are completed with others resulting from a specific procedure that has been developed for the sake of the research completeness to solve some incongruities. The choice of a wide range of KPIs shall be related to the awareness that an acute-care healthcare district is a complex system that always requires a multi-faceted/multi-discipline approach. It is true that from the energy point of view, there are many precise tools available for the designer/energy manager to allow a strict control in real time of the variables that govern the energy balance of the same district.

Finally, one of the main targets in the development of the demonstration case is the opportunity to improve, applying methodology and tools implemented in STREAMER, the SACS© system, including the assessment and management of energy efficiency and, potentially, some others management tools. With this aim the on-going work concentrates on the implementation of the BIM model, currently referred to one of the three buildings of the San Luca Complex, that is based on the information and CAD files available in the SACS© database. During the implementation of the BIM model it will be analysed the possibility to develop its configuration (i.e. classification and level of details of the BIM data) according to the possibility to increase and improve tools and functionalities of SACS© (Figure 1).

Within the plan for the development of the Careggi District, several areas and compounds will be analysed – taking into account both functional and financial aspects – to define strategies and policies. It is expected that the knowledge and the tools implemented in STREAMER will also be used in the interventions to develop in the San Luca Complex, to guide the choice between retrofitting and demolition/rebuilding of the older buildings, considering their energy-efficiency as well. Thus, one of the expected results, working on the San Luca Complex chosen as study case, is the possibility to use STREAMER tools for guiding the choice between retrofitting and demolition/rebuilding of the older building and to assess its suitability for the next destination considering the energy efficiency and the lay-out functionality.

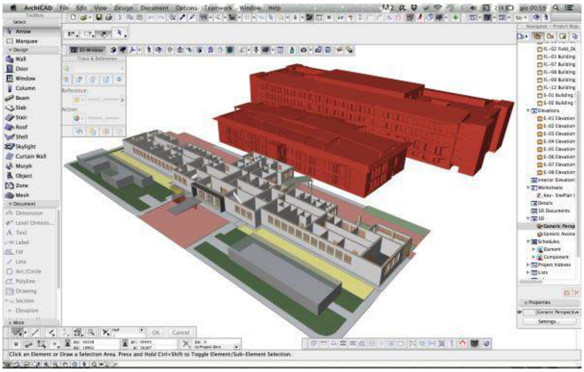

Figure 1: Snapshot of the San Luca BIM model

For the other two buildings included in the study case (and later for the whole district), the aim is to enhance functionalities of SACS© including into its tool box data and procedures for assessing, validating and managing the energy efficiency during the planning and design stage.

The energy efficiency strategies

By shifting the focus on energy, a brief introduction describing the characteristic of the case study may help in identifying its peculiarity: Careggi in fact, is already a leading hospital regarding the "green" features thanks to its natural gas fired Combined Heat and Power (CHP) trigeneration plant. Between CHP plants, trigeneration units show the highest efficiency since their potential to convert thermal recoveries into cooling during summer (assisted by absorption chillers). This lowers the primary energy needed for all the hospitals end uses, together with the associated GreenHouse Gases (GHG) and pollutant emissions. The last finding is particularly desirable, especially in case of hospitals.

Besides, the new trigeneration system, as a part of the plan of global retrofitting of the whole AOUC campus, is already keeping at high-efficiency all the energy transformation processes, directly at district levels, thanks to the thermal energy distribution network that is already in site. The CHP plant is a medium size cogenerator, having been dimensioned to produce 10 MW electrical power and about 15,6 MW thermal power. In the actual configuration the whole output is used to serve the hospital, but in the future a possible integration of the district system with neighbour facilities such as Meyer Hospital, could be achieved and today is under investigation. From the economic perspective, the operation of the CHP plant allows to save more than 1 Million euro per year.

To understand how important is the implementation of the efficiency of a plant like the one built in Careggi, it is essential to consider the considerable energy demand of a hospital of that size, which almost equals the one of a small city. This assumption is not strange if we consider the number of patients, doctors, nurses, employees, visitors, etc. that everyday live and/or just visit the facility.

In general, there is the necessity to define the 'as usual' scenario of the energy demand, at least split into electricity, heating and cooling, before evaluating any possible retrofit actions. Before the CHP plant started, the energy demand of AOUC was entirely satisfied though the operation of conventional systems, electricity from the local distribution grid, heating from boilers and cooling from chillers. The hospitals managers use to keep some energy recordings (e.g. energy bills), however, these data normally refer to the whole hospital campus, or to sectors that do not coincide with the San Luca pavillons; this has led to the necessity of identifying a specific top down indirect procedure to evaluate the energy requirements of the San Luca case study. Thermal energy demand of San Luca has been estimated considering oil/natural gas fired boilers (the systems that operated in Careggi before the start of the CHP plant). Since their primary energy requirements were acknowledged, we weighted them first considering the systems average efficiency and then through a top-down coefficient that takes into account the ratio of the volumes of the occupied areas both at that pavillon and district levels. The same task was easier for electricity since it was possible to evaluate the demand at San Luca pavillons level through specific readings of the local counter. Finally, the cooling demand has been indirectly evaluated by assuming that is has been fulfilled thanks to mechanical air ventilation where the cooling exchangers, used to cool and de-humidify the external hot air, request a continuous and energy intensive operation of compression chillers, themselves fed by electric power. The delta of the consumed electricity between the hot summer months and a standard 'fresh' period (e.g. April, taken as reference), yields the demand, that is likely to be ascribed to compression chillers – cooling end uses. This specific procedure has been assessed in the past in other researches (Bizzarri et al., 2006) giving reliable feed backs. Once assessed the benefits coming from a certain intervention (e.g. the CHP plant, etc) on a specific end use demand (electricity, heating, cooling), the reverse convertion from the same end use demand to the correspondant primary energy was made: for thermal energy simply considering the plant efficiency and for electricity through the application of the average efficiency of the 'equivalent Italian thermoelectric power plant', provided by scientific literature year by year. The findings of these procedures give the primary energy saving expected from every energy policy adopted by the hospitals, together with its related GHG and pollutant reduction benefits.

Finaly a study was made in order to breakdown the total electricity use into major electric end uses. The first step was to establish a list of the typical appliances and systems that normally operate in a hospital. Then a survey was conducted to obtain data about the usage pattern of all those appliances: a fundamental issue was to recognize which end uses was weather dependent (showing seasonal variations) and/or occupancy related (showing different behaviours during the typical working day or between working days and the week end). Then, all these end uses were grouped into five homogeneous categories in relation to the service they concur to provide: heating station, cooling station, ventilation units, lighting and miscellaneous electrical appliances (Bizzarri, 2006). The last study has been of particular help in the policy to reduce electrical requirements and providing fundamental inputs for the BIM platform as well.

BIM philosophy applied to energy simulation has the potential to enhance the possibility of testing preliminary design approach before developing the whole project. The energy demand of a certain portion of a building, in fact, depends on the envelope characteristics (e.g. U value, materials, etc.) and the typology of end uses (e.g. hot floors, industries, hotels, offices, etc.). The first parameters directly influence the thermal energy demand and are site specific, the latter items, instead, are more or less the same in the European countries, depending on the how much energy intensive are the activities that take place in the indoor spaces and can be well modelled once one has found and determined the items described in the paragraphs above.

The construction of a solid BIM platform, coherently with the parameters above, is hence fundamental, allowing to run the energy simulations simply having defined few basic retrofit inputs. Especially in the preliminary phases, this approach is enough accurate to provide reliable results and helps in understandanding if a certain retrofit option is desirable or not.

Conclusion

One of the main aims of the research is to define those parameters able to measure the energy performance of the building during its lifecycle and considering possible changes of usage. Especially during the audit phase, this goal can be achieved processing together typological/dimensional elements of the building (volume of the rooms, typology of the windows, etc.) and functional/organizational data (medical equipment, occupants, etc.)

The model to manage the parameters is a design BIM/GIS-based tool containing the whole lifecycle information of the building, including design, construction, operation and maintenance.

During the first period of the research, three types of data have been collected and processed:

i) geographical data of the district, including the exact shape of the buildings nearby the chosen case study;
ii) detailed dimensional and structural data of the chosen case study;
iii) organizational and management data related to the chosen case study.

Data contained inside the Geo-referenced model of the district (QGis) and data managed by the SACS system (through its own labeling system) have been imported inside a BIM model made with Archicad 18.

Aiming to the interoperability of the tools, processed information will be transfer to the SACS suite to enrich its functionality: SACS – through the AOUC Web portal, the Eureka search engine and the Careggi Smart Hospital smartphone App - is daily used by users and staff of the hospital.

Finally, BIM philosophy applied to energy simulation has a huge potential, especially in the preliminary phases, since it has been demonstrated that this approach is accurate enough to provide reliable results at preliminary design stage and helps in understandanding if a certain retrofit option is desirable or not. The energy simulations that are normally run in the energy analyses, in fact, require the same set of data that are collected and implemented in the BIM platform.

Acknowledgements

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Information on STREAMER project is available at www.streamer-project.eu.

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STREAMER semantic BIM design approach for hospitals: research case of Rijnstate Hospital in Arnhem, The Netherlands

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Abstract

This paper discusses the empirical research as a part of the EU FP7 collaborative research project STREAMER (www.streamer-project.eu). The project aims to develop semantic Building Information Model (BIM) methods and tools for designing energy-efficient hospitals. The research activities are dedicated to enrich the BIM with semantic data for energy performance simulation.

The preliminary findings discussed in this paper are derived from a real case study of Rijnstate Hospital in Arnhem, the Netherlands. The project focuses on the design process for a new extension of the existing building complex. In this case, the design requirement is developed using a web-based tool called BriefBuilder®. The requirement data are imported into a modelling software for BIM. Subsequently, the model is exported to the IFC open interoperability format, and enriched with semantic information that allows the user to perform an energy performance simulation using specialised software.

Keywords

Energy-efficient hospitals, Building Information Model (BIM), semantic data, IFC, open standard, design solutions, energy performance.

Introduction

This paper is descriptive and it presents the preliminary results of the STREAMER research project, which is co-funded by the European Commission within the topic of "Optimised design methodologies for energy efficient buildings integrated in the neighbourhood energy systems" under the 7th Framework Programme (FP7). The project started in September 2013, has a

4-year duration and involves twenty partners from nine different EU member states.

The STREAMER research project aims at the use and development of a semantic approach to design, based on using the combination between BIM and GIS. This paper highlights the preliminary findings from a real case study, which is the Rijnstate Hospital in Arnhem, the Netherlands.

In the following section, the STREAMER concept for designing energy-efficient hospitals will be explained, along with the research methodology. This will be followed by a brief description of the Rijnstate case study. The preliminary findings are presented and analysed; and finally, conclusions on the on-going research are drawn with an outlook towards future research activities.

Concept and state-of-the-art

The subject of energy-efficient buildings (EeB) is among the most urgent research priorities in the European Union (EU). In order to achieve the broadest impact, innovative approaches to EeB need to resolve challenges at the neighbourhood level, instead of only focusing on improvements of individual buildings. For this purpose, the design phase of new building projects as well as building retrofitting projects is the crucial moment for integrating multi-scale EeB solutions.

Healthcare buildings and districts are among the top EU priorities EeB since they play a key factor for a sustainable community and their energy use and carbon emission are among the highest of all building types. A typical hospital consumes, on average, from two to five times more than an office building. In Europe there are about 15.000 hospitals that are responsible for at least 5% of the overall European annual emission of carbon dioxide (equivalent to 250 million tons). Healthcare generates about 10% of the Gross Domestic Product and takes up to 60% on the total expenditure of a country (BPIE, 2011; EuHPN, 2011; HOPE, 2011).

In recent years, growing effort has been made in research on optimising the design process to deliver energy-efficient buildings. The semantic design within the STREAMER context is defined as a method of participatory design process, that is based on rational performance analysis of models that integrate design requirements, interpretations and knowledge originated from the design teams, stakeholders and users (Iadanza et al. 2015).

In an EeB design process, clients, architects, technical designers, contractors, and end-users altogether need new methods and tools for designing energy-efficient buildings integrated in their neighbourhoods. Since the scope of designing covers multiple dimensions, the new design methodology relies on the inter-operability between Building Information Model (BIM) and Geospatial Information Systems (GIS). Design for EeB optimization needs to stress on the inter-connections between the architectural systems and the MEP (Mechanical Electrical and Plumbing)/HVAC systems, as well as on the relation of Product Lifecycle Modelling (PLM), Building Management Systems (BMS), BIM and GIS.

Useful lessons can learned from recent and actual EU research projects in this area, for instance: PROFICIENT (www.proficient-project.eu) with the focus on user-friendly semantic BIM for neighbourhood design; PANTURA (www.pantura-project.eu) focusing on BIM and GIS combination for low-disturbance urban projects; INSITER (www.insiter-project.eu) focusing on reducing performance gap between design and construction by a BIM-based inspection technique; and HESMOS (www.hesmos.eu) that developed an ICT platform for holistic energy-efficiency simulation and lifecycle management of public facilities.

Research methodology through case study

The information flow during the STREAMER design process is demonstrated on the following scale levels, i.e.: neighbourhood/campus, building, functional area, room, and component level. The general concept of information flow is that information must remain preserved in the process and be available for the stakeholders. This is illustrated in Figure 1.

Within this concept, the information flow starts with the conceptualization of design requirements by the hospital. The hospital can be supported by consultants/experts, depending on the required level of complexity and expert knowledge. Ideas about room size, comfort requirements, energy profiles, materialization, furniture, etc. are structured and formalized by using a requirements tool, such as BriefBuilder® or dRofus®.

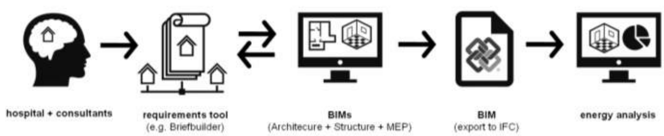

Figure 1: Information flow process

The architect, structural engineer and MEP expert translate these wishes and needs into an integrated design, which is represented by one or more BIMs. Each scale level has unique analysis possibilities, which are largely dependent on the amount and type of information that can be transferred from the native BIM format to IFC and gbXML format. Also, the readability and compatibility of this information with the energy analysis software is of outermost importance.

The data from the requirements tool is synchronized with these BIMs. From the BIM native environments (e.g. Revit, DDS-CAD, ArchiCAD, etc.), IFC exports can be made to allow energy analysis and model checking. By incorporating STREAMER knowledge into a BIM model in a presentable and useable format, and by testing the usability of the data for energy consumption analysis, the relevance of this STREAMER knowledge can be monitored.

Description of the Rijnstate Hospital as a case study

Rijnstate Hospital is a Teaching Hospital, which was opened in 1996 on the site of a former hospital. The current building measures 82,150 m2, in an area of approximately 89,000 m2. Its total energy consumption is 128.705 GJ/year.

The hospital is in need of expansion of 10,000 m2 to incorporate necessary services. With the knowledge that Rijnstate Hospital will need a midlife renovation around the year 2016 and knowing that the hospital will require future expansion, research has been started. In particular, it is investigated how to achieve these ambitions in a most sustainable and cost effective manner, reducing, at the same time, the output of carbon dioxide gasses as much as possible.

A master plan design process has been developed (for the planned extension of 10,000 m2) and parallel to that, the main infrastructure project was initiated. The outcome of the main infrastructure project includes five possible design scenarios. Later on in the process an additional scenario was added. Parallel to this, Rijnstate has stated its ambition to reduce the carbon footprint by 50% in 2020.

The scope of the Rijnstate a case study in STREAMER is as follows: the newly developed expansion 'North East' of 5,000 m2 (phase one of the above mentioned master plan) was proposed as real case, together with the final design of the MEP systems. As the real project was already partly developed, the STREMER case study is a so-called "shadow engineering project", meaning the design was already available in 2D drawings, and would be redesigned in semantically enriched 3D BIM. At the same time, Rijnstate started to make use of a requirements tool - BriefBuilder® software (Koster, 2014).

Preliminary achievements regarding the research questions

For the purpose of research in the STREAMER project, several research questions have been formulated. These questions are based on a three-stage approach, however, due to the current progress of the project, in this paper only the questions related to the first stage are discussed. The research questions regarding 'modelling and visualization' are as follows:

a) How can we create a model of buildings with layer properties?
b) How can we create an energy model of the hospital extension?
c) How can we create a model of functional areas with layer properties?
d) How can we create a model of rooms with layer properties?

The analysis of case study findings related to these research questions are presented in the following.

Research question a): How can we create a model of buildings with layer properties?

The building mass is modelled in a BIM modelling software (i.e. Revit). With regard to categorisation of spaces for energy performance simulation, four types of spaces are assigned as model properties, namely: Hotel, Office, Industry and Hot Floor. The model is enriched by information derived from the design requirements, which is done by adding the information from the BriefBuilder® software to the Revit model.

For energy analysis purposes, information that can be read from the BriefBuilder® output file contains: geometrical properties (such as: geographical location, area, gross floor area, gross surface area, gross volume) and expert knowledge (such as: building typology and layer properties).

Afterwards, this model is exported to the IFC open standard format. The resulting IFC can be seen in Figure 2.

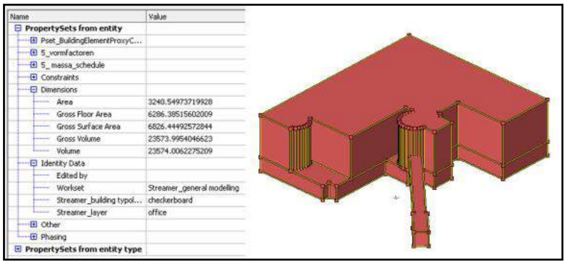

Figure 2: IFC model with properties: building typology and layer type

Research question b): How can we create an energy model of the hospital extension?

An important step in the early design process is to make some general assumptions about the properties of the building envelope in order to estimate the energy consumption without having to insert detailed information of the individual building envelope elements (windows, walls, doors, etc.). The building envelope properties can be associated with the building mass in the IFC model. After the glass percentage is provided, the modelling software automatically creates schematic window openings at every façade. For energy analysis purposes, information that can be read from the gbXML file exported by Revit contains geometrical properties, such as: location, surface areas of windows, walls and roofs. Using the current Revit 2015 modelling software, it is not yet possible to attach the U-values of walls and windows to a building mass. Therefore, this has been done at the level of building component. This is illustrated in Figure 3.

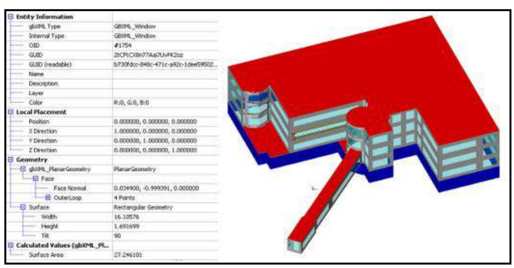

Figure 3: gbXML model with properties of a schematic window opening

Research question c): How can we create a model of functional areas with layer properties?

Currently, decisions about functional area layout are primarily driven by functional considerations. According to the STREAMER approach, it is useful to know which energy-related considerations can influence the functional area layout. Similar to the research question b), the energy labels of the spaces as described in STERAMER are attached to the model. In the Rijnstate case study, the area (in the Revit model) or IfcSpace (in the IFC model) serves as the information carrier in the BIM model, representing the design on functional area level. This is illustrated in Figure 4.

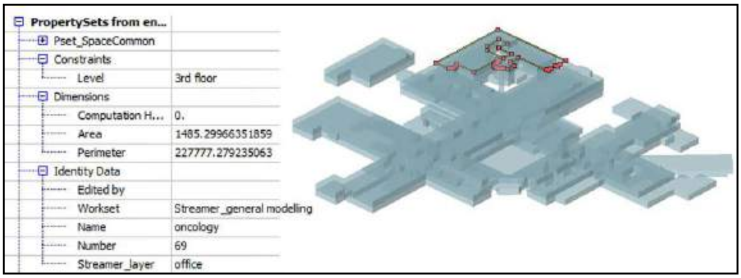

Figure 4: Geometrical and attached properties: name and layer type

Since the layout of the functional areas is one of the main factors influencing the energy performance of the building, it is important for the designers to make analyses during the design process. In the Revit modelling software, this can be done using 2D representation, as shown here below in Figure 5. For the design team, such a drawing can help to communicate whether or not the functional areas with similar layer properties have been grouped properly. In the example shown in Figure 5, the yellow area at the top is not connected to the other yellow areas, which will negatively affect the logistic efficiency. The design team can further explore possible re-arrangements of the rooms, and then make the decision together with the client. Similar graphic representations can be made for other properties associated with the functional areas, for example: energy profile and hygiene class.

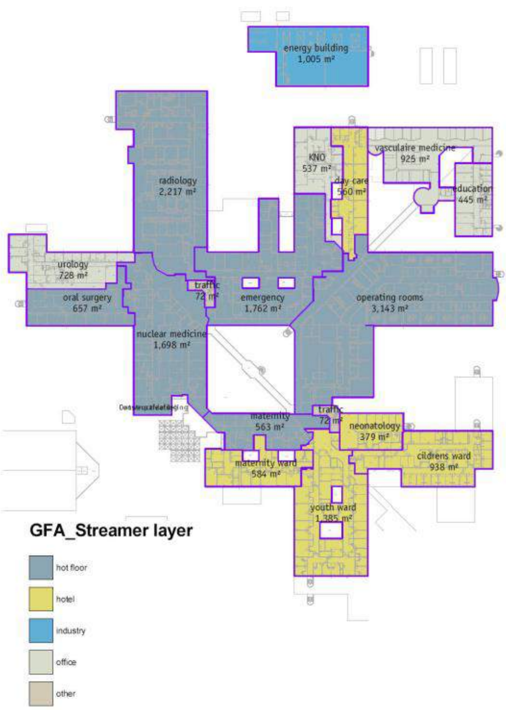

Figure 5: Rijnstate model in Revit 2015, showing the functional areas of the new and existing building. The colour scheme is set to display the STREAMER layer properties of functional areas

Research question d): How can we create a model of rooms with layer properties?

In a design process, the design solution for an efficient hospital working process is ultimately represented at the room level, which is more detailed than the building mass level. A room becomes, therefore, the most specific spatial element in the model, which contains rich information. Rijnstate has created a room list using BriefBuilder® software. In the Rijnstate case study, the room (in the Revit model) and IfcSpace (in the IFC model) is the information carrier in the BIM model, representing the design on the room level. This design unit is illustrated in Figure 6.

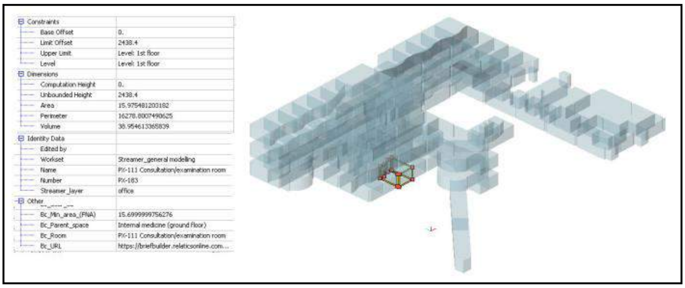

Figure 6: Geometrical and attached properties

For energy analysis purposes, the required information to be read from the file on the room level should contain: geometrical properties (i.e. surface area, height, volume, level) and various energy data included in the IFC file (e.g. heat gain per person, heat load values, specified power load per area). Additional energy-related labels can also be added as well as general information, such as: room name, room number, parent function area. The link with the room list in the design requirement software is given by adding an URL to BriefBuilder® database.

Figure 7 shows the graphical representation of the layout arrangement derived from the BIM model. In this image, a fragment of a hospital functional area is visible. This image shows that rooms with different layer properties than their main functional area can be found. The design team can subsequently make deliberations whether rooms of other types should be accommodated inside the assigned functional area, of should they be grouped and located in other spaces. For example: should rooms belonging to the "general services layer" be located inside the "medicine treatment" functional area, or should they be re-located to a more general location like a main entrance lobby. In the current example, such re-grouping might reduce the required space (less m2) as well as the energy consumption. Similar exercises can be done to assess the efficiency of different functional areas.

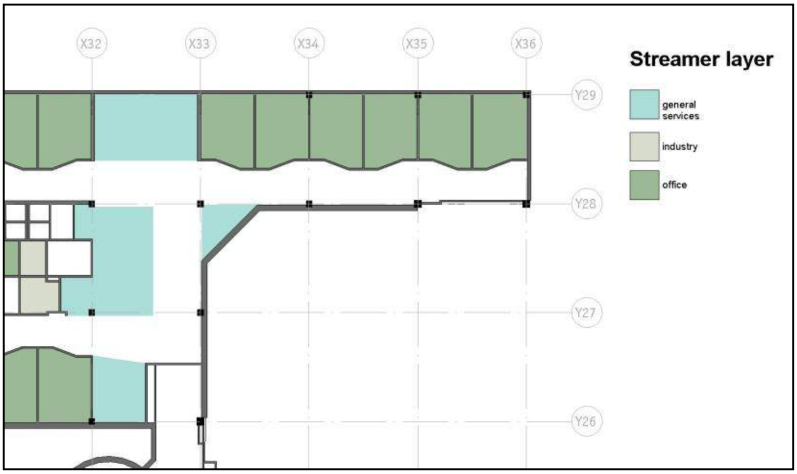

Figure 7: Rijnstate model in Revit 2015. The colour scheme is set to display the STREAMER layer properties of rooms by a typical colour

Conclusions and discussions

This paper has shown the preliminary research findings on how relevant information can be assigned in certain semantic layers in a BIM model, either within the modelling software (such as Revit) or in an open-standard format (such as IFC). Such a technique can support conceptual (rough) energy analysis by the design team at an early design stage..

Within the Rijnstate case study, energy-related properties are often attached to elements in the architectural model. It is important to realize that the real practice is a bit different. The members of the design team should be in control of their own aggregate BIM models and be responsible for their specific information. After deciding which Mechanical, Electrical, Plumbing (MEP) solutions will be implemented; more detailed analysis of the energy use can be made. The energy data will be compared with the calculated data as worked out in the design phase.

Follow-up research will be dedicated to perform energy analysis using the specialised energy simulation software. Special attention will be given to:

- Investigating which information from the MEP BIM can be used in the STREAMER research;
- Use of this information in combination with the Architectural BIM;
- Using the semantic label approach for the purpose of design configuration and validation;
- Further development of energy labels and apply this approach in BriefBuilder®;
- Organisation of a design workshop involving practitioners;
- Performing preliminary energy analysis; and
- Validating the results.

Acknowledgements

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Geothermal fed low-exergy 4thG-DHC grid in Heerlen

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Abstract

The mine water initiative in Heerlen (Mijnwater) is a geothermal project originating from the European Interreg IIIB NWE programme and the 6th FP project EC-REMINING-lowex. Because of the region's mining past, the project has a strong social/historical context: Heerlen used to be known as Energy Town of The Netherlands (NL). The abandoned coalmines are now giving the perspective to become an innovative green tech region, due to the sustainable geothermal energy that is contained in the groundwater reservoir. Mijnwater BV – a private company owned by the municipality of Heerlen – is building a successful business based on this concept and is rapidly expanding connections to the grid. Actually Mijnwater BV has two main developments:

1. Exploiting the huge water reservoir as a source of and storage for energy;
2. Expanding a hydraulic thermal smart grid, connecting buildings in the area mutually, to renewable sources and to the mine water backbone/reservoir.

The second development has emerged from the existence of the first.
In the strategic roadmaps of the EU and NL large-scale energy storage, geothermal sources and DHC-grids have an important role in reducing fossil energy consumption and fulfilling climate targets. Of all available techniques above-mentioned have the highest potential for growth. In this paper these developments are elucidated first, where basic principles are set for a successful implementation. Thereafter practicalities for the Heerlen site are given.

Keywords

Energy storage, Energy exchange, Carbon neutral areas, Geothermal, Smart grid.

Introduction

In the national energy balance higher shares of solar and wind are asking for advanced, large scale storage solutions. "Storage is one of a number of key technologies that can support decarbonisation. Thermal energy storage systems appear well-positioned to reduce the amount of heat that is currently wasted in the energy system" (Lott, 2014). For The Netherlands Underground Thermal Energy Storage (UTES) has the largest potential for cost effective energy storage. From cost and efficiency perspective thermal storage features on a district scale are a valuable link in the chain of green technologies. The urban scale however requires the connection by a thermal grid. Moreover the urban energy provision is a complex system; many actors and interests play a role. Most thermal grids originate from a major heat source (like waste heat or CHP) distributing heat by a high temperature grid. For modern highly insulated buildings these grids lack the support of cooling and could be operated on substantial lower temperatures as buildings have lower energy demands. As the exploitation of a grid asks for longterm investments, long-term source security should be considered. Sources for waste heat have a weakness, for instance due to future energy saving measures in industry. In a carbon neutral society the amount of waste heat and biomass will be limited and reserved for high exergy applications. Therefore a local grid with mutual heat exchange and local sources will be more reliable in its business case than traditional grids. Better efficiencies and less energy losses are gained from lowering the temperature in the grid, based on low exergy principles. The configuration of a low-exergy grid (cloud-based) differs quite from conventional grid configurations (tree-based). EU-wide there is little experience with these kinds of grids. Conventional DHC grids are developed in a top-down configuration (tree structure). A grid based on multiple sources and mutually exchange is more likely to be configured in a cloud configuration. In low-carbon solutions the influence of the energy demand side on the performance of the energy supply is much stronger then in conventional concepts. This underpins the importance of further linking the supply and demand side in future energy systems. Moreover the phasing out of fossil sources will induce a stronger interaction between Heating, Cooling and Electricity grids. The introduction of a concept based on heat pumps in all buildings can induce peak loads on the electricity grid, but also provides great opportunities for peak shaving. There will be an increasing share of electricity consumption in the overall energy supply. Thermal grid operators have the opportunity to embed electricity production in their supply process and to optimize multiple renewable sources in their business case.

For thermal smart grids in a carbon free future we face two major challenges:

1. Storage: One of the most important issues is to establish large storage facilities. These storage options have to be further investigated to improve efficiency, reduce costs and gain reliability and predictability.
2. System Integration: In the urban region all kind of interactions between thermal energy and electricity have to be utilized, as sustainable sources do not fit the demand profiles.

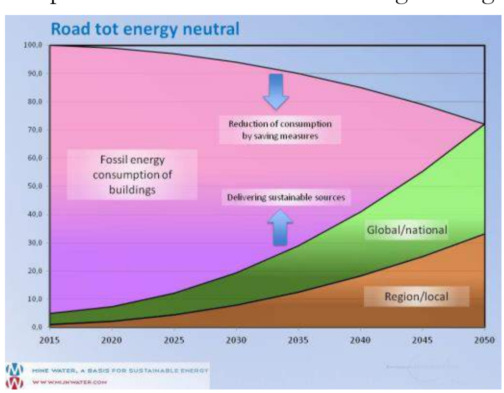

Figure 1: Road for reaching carbon neutrality

The building sector is still responsible for more than 30 % of primary energy consumption mainly used for heating, though cooling demand is growing. From a perspective of District Heating and Cooling grids a carbon neutral urban regions could be achieved by the following approach:

i. Building-level: Reduce the energy consumption by 1/3 through energy saving measures in buildings,
ii. District-level: Realise 1/3 reduction of the energy consumption by:
   a. Creating local sustainable sources,
   b. Enabling mutual exchange between consumers and
   c. Providing storage on regional level.
iii. National-level: Support green energy on national level for the resulting 1/3.

This might be interpreted as a Trias Energetica for the regional approach and will lead to a high security of supply and major reduction of greenhouse gas emissions at an affordable price.

Geothermal energy is providing 1,7 % of renewable energy in the Netherland now. This share has to grow towards over 20 % in the next 10 years.

The Mijnwater concept in Heerlen is widely recognized as innovative development, which might give substance to the road map of energy transition[8]. Mijnwater –as a Greenfield for thermal grids- is developing the concept to a modern intelligent hybrid energy infrastructure with a cluster approach. The cluster grids are supported by a mix of local sustainable sources, which are backboned by the mine water buffer. Within a cluster grid, energy is exchanged and maximally utilized, and the efficiency of the available sustainable sources is optimized by shared usage.

Energy Principles

Heading towards a new social context for local energy support some principles can be formulated as guidelines for the future development. The formulated principles are derived from earlier published principles as the Hannover Principles (McDonough, 1992) or the Oslo Principles (Spier, 2015). For the urban energy system we come to the following list:

- Everybody has the right to save, secure and continual access to energy;
- Energy should facilitate a healthy and comfortable life style and give opportunity for evolution and mobility;
- Everybody has the right to participate in, but also has a responsibility for the generation of our energy needs;
- Energy supply is based on infinite resources;
- A minimal impact on the environment is considered at the generation of energy;
- Revenues from energy benefit to the local community and are being fairly and evenly distributed (energy dependence may not lead to speculative or monopolistic profit for individuals or businesses);
- Energy is generated in the own region to prevent dependency on energy-producing countries or regimes and to save local money and employment;
- We strive -in a cycle of continuous improvement- to building knowledge and make this knowledge accessible to all stakeholders.

[8] http://egec.info/mijnwater-b-v-geothermal-innovator-of-2015

Trends

In regard of the ambition of many cities to become energy neutral the following trends are notified:

- Depletion of fossil resources. Since its discovery in the 1950s, natural gas dominates the electricity supply, domestic heating and industry feedstock in the NL, in particular in the petrochemical industry. Almost 98% of Dutch households use gas for heating. The remaining reserves cover 15-25 years at the current usage[9].
- EROI. "*Energy return on investment (EROI) is a means of measuring the quality of various fuels by calculating the ratio between the energy delivered by a particular fuel to society and the energy invested in the capture and delivery of this energy. The EROI for the world's most important fuels, oil and gas, has declined over the past one to two decades for all nations examined*" (Hall, 2014). Thus the effort, prize and CO_2-emission of winning fossil resources will increase in the future.
- Population growth, urbanisation. "*Globally, more people live in urban areas than in rural areas, with 54 % of the world's population residing in urban areas in 2014. In 1950, 30 % of the world's population was urban, and by 2050, 66 % of the world's population is projected to be urban. The global urban population grew rapidly from around 700,000 in 1950 to close to 3.9 billion in 2014 and is expected to reach 6.3 billion in 2050*" (Pelletier, 2015).
- Security of support and welfare. "*First, energy enters utility function as a consumption good, and therefore, energy price fluctuations have a direct impact on energy consumption and, consequently, on households' welfare. Second, firms use energy for production and, thus, the fluctuations in the energy price lead to increase the volatility of output, leisure and non-energy consumption, which affect ultimately households' welfare. In addition to the political and social costs, energy insecurity causes a significant economic cost*" (Manzano, 2012). Energy support systems based on 100% renewables are considered to be secure for the future if sufficient buffers are established. According to US DoE[10] 95 % of commercial storage is pumped hydro energy (23,4 GW), thermal storage is second (0,431 GW) (Ahearne, 2014). "*Governments can help accelerate the development and deployment of energy storage technologies by supporting targeted demonstration projects for promising storage technologies and by eliminating price distortions that prevent storage technologies from being compensated for the suite of services they provide.*" (Lott, 2014). Investments in infrastructure have a long depreciation period. These investments should be done in low exergy storage and distributions systems to secure delivery over the next 5 decades.
- CO_2/global warming/sea level rise. "*The most recent IPCC assessment report estimates that without further climate action global temperatures are likely to rise to 3,7°C – 4,8°C in 2100 compared to preindustrial levels. The IPCC estimated a total CO_2 budget of 3.670 Gt (gigatonnes) for a likely chance of staying within the 2 °C limit. The world has already emitted around 1.900 Gt CO_2*" (Alcamo, 2014). "*A third of oil reserves, half of gas reserves and over 80% of current coal reserves globally should remain in the ground and not be used before 2050 if global warming is to stay below the 2°C*

[9] http://aardgas-in-nederland.nl/de-toekomst-van-aardgas/aardgasreserves-en-verbruik/#2

[10] USA Department of Energy (DoE) Energy Storage Database 2013, www.energystorageexchange.org

target" (McGlade, 2015). According to the Economist the Cost of inaction on global warming are estimated as: *"Warming of 5°C could result in US$7trn in losses – more than the total market capitalisation of the London Stock Exchange - while 6°C of warming could lead to a present value loss of US$13.8trn of manageable financial assets, roughly 10% of the global total"* (Watts, 2015).

- International dependency and stimulation of local economy. The region Parkstad Limburg has 249,873 (2013) inhabitants and consists of 8 municipalities. Parkstad Limburg covers a total area of 211 km^2. Total energy consumption of Parkstad is 29.6 PJ including 369 million m^3 of natural gas and 1.272 million kWh of electricity (Jones, 2014). Parkstad Region spends M€ 500-550 yearly on imported energy.[11] A major saving would occur by investments in sustainable infrastructure, which would also lead to energy price stability for the future independent on international embroilment.
- Prosumentism (Uber, Airbnb, PV). There is a trend from large centralized services to civil initiatives. This trend is supported by advanced IT and increased awareness of citizens. It was seen in the IT-environment (from big servers to cloud computing) and is starting up in the E-net (due to PV-panels). If citizens become aware that their heat demand is generating cooling and reverse, every consumer is also a producer in the system with value. This idea might become a strong promoter for acceptance of DHC-grids. However, the infrastructure of the grids should be adapted to this mechanism.
- Value of buildings/flexibility/visibility. The best installation concept for a low-ex DHC infrastructure is low temperature radiant heating and high temperature cooling in buildings. This is for instance based on the activation of thermal mass (concrete cores), radiant panels or adiabatic air exchange. Utilizing large areas with small temperature differences to the interior air will create comfortable and healthy buildings (Olesen, 2012), (Schmidt, 2011). Due to the absence of radiators, convectors, e.g. the interior of buildings is more flexible and transparent envelopes can be realized. Investigation of life cycle operational costs showed that additional cost for higher BREEAM ratings can be paid back within 2–5 years (Yetunde, 2014). "*An analysis of nearly 1,100 recent rental transactions in the Dutch office market reveals that inefficient, 'non-green' offices realize an average 6.5% lower rent than comparable firms with 'green' energy*" (Kok, 2010). Many renewable sources, like solar panels and windmills, have an impact on the areal planning and raise growing resistance from residents. "*In the Netherlands the last two years more than 135 foundations and action committees have been set up to fight against the construction of wind farms in their area*" (Rengers, 2014). Geothermal and DHC-infrastructure is invisible in the landscape.
- Urban Heat Islands (UHI)/Air pollution. "*Most Dutch cities experience a substantial UHI, i.e., a mean daily maximum UHI of 2.3 K and a 95 percentile of 5.3 K. The city of Rotterdam, for instance, exceeds the heat stress threshold value for about 15 days per year*" (Steeneveld, 2011). "*Heat waves with temperatures that have a large deviation from the climatological mean maximum have been correlated with a sharp rise in urban mortality*" (Heusinkveld, 2014). "*Economic cost of premature deaths from*

[11] www.parkstad-limburg.nl/index.cfm/parkstad-limburg/ruimte/energietransitie

ambient particulate matter pollution and household air pollution in 2010 in the Netherlands are US$ 24,6 (billions)" (Satterley, 2015). Though there are many causes for these effects, apart from heating and cooling of buildings, the exhaust from fossil fuels and release of heat from air chillers may have a significant influence on these urban problems.

- Instability E-grid. "*More specifically, in the short term, integration costs from solar and wind consists mainly of additional costs for (i) ensuring the adequacy of the electricity system, (ii) the expansion and strengthening of the network, and – to a lesser extent - for (iii) balancing the system. An analysis of several international studies shows that, with a share of 10-30%, the total integration costs vary from 10-30 €/MWh for wind and from 25-50 €/MWh for solar energy. As a percentage of the overall production costs (LCOE) these numbers correspond with approximately 15-40% for wind and 15-35% for solar*" (Sijm, 2015). In the Netherlands a growth of PV-solar and wind energy is possible within the flexibility of the E-net to about 16% of total energy need (expected to be reached in 2023). Above this share additional major storage and net-balancing is needed.

Mijnwater Heerlen

The immense mine water reservoir in the underground space created by mine workers in the 20th century, provides a basis for Heerlen's future energy independence. Due to the raised temperature at a depth of 800 m, this reservoir is able to store a huge amount of energy without losses over a long period of time.

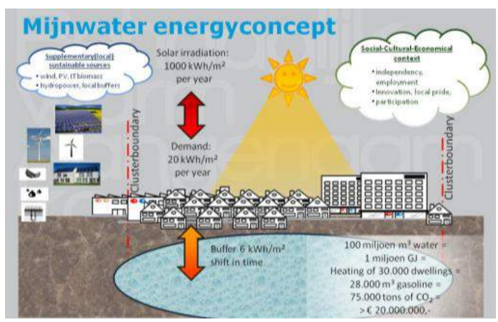

Figure 2: Mijnwater Energy Concept

For instance the thermal capacity of 1 m³ of water raised in temperature by 20 K is 25 kWh. This is comparable to 50 batteries of a normal car or 2,5 Tesla Power walls. The charge and discharge cycle for the water mass is infinite, while most electrical batteries lose capacity within 5 years. Mijnwater BV distributes this energy via its grid from the source to the clusters and further to the energy stations in connected buildings. A low temperature level is maintained along this route to avoid excessive heat losses from transport. In the buildings, the temperature is raised by heat pumps to the appropriate level, which depends on the characteristics of the building. The electricity for transport and heat pumps is increasingly supported by photovoltaic, wind power and other sustainable sources.

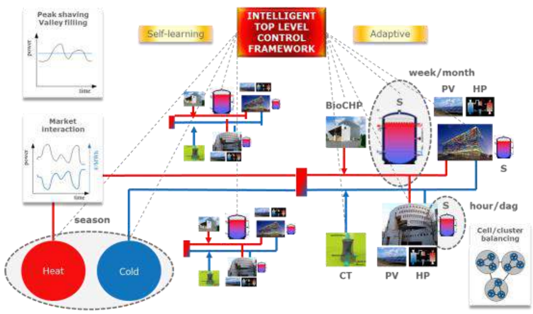

Figure 3: Mijnwater Control Strategy

The basic idea for the urban area is the incoming amount of solar energy covering about 30 times the total energy demand for buildings. If we can utilize 2% of this energy for heating and cooling, the use of external (fossil) energy sources is avoided. The key strategies to achieve this goal are a low-exergy approach, the exchange of energy where possible (avoidance of spilling), storage and regain at the right time, at the right spot and at the right temperature. To get this concept working (and learn about the behaviour of the system), the entire process is controlled by innovative and advanced optimizing multilevel controller software. For modern, well-insulated buildings the cooling demand -even in NL- is about 35% of the total thermal energy demand. To regain this cooling, 50 % of the heating energy must be extracted, transported (5 % loss), buffered (10 % loss), transported again (5 % loss) and adapted to the right temperature by heat pumps (15 % added at a COP of 7). Thus the net energy demand is 35 % (heat) plus (5%+10%+5%+15%)*35% = 12%. Therefore the exchange of cooling and heating will reduce the net energy demand with 53%! Moreover the DHC-grid with large storage capacity will improve the efficiency of renewable sources, like thermal solar, PV-solar, wind, bio-CHP, etc.

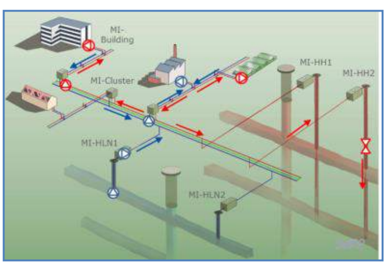

Figure 4: Mijnwater 2.0 smart grid: exchange of energy

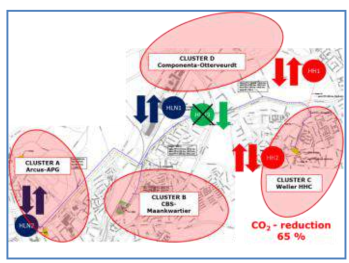

Figure 5: Mijnwater 2.0 clusters of buildings

This is caused by a better fitting demand profile on area level then on building level.

In the traditional business case a major amount of the selling price goes to the purchase of fossil fuels. In the NL, the selling price of DHC-energy is restricted by law (red line in figure below). Thus reducing the amount of purchased fossils creates financial space for investment in green technologies.

Figure 6: Mijnwater Business Case

Because Heerlen acts as a 'green field' for thermal grids from the beginning, the existing infrastructure and related financial proposition do not impose any constraints on the development. Moreover, the ambition to realize a sustainable energy infrastructure has always been a major driving force, because Mijnwater was established not as a commercial venture but as a public body. Nevertheless, the concept is commercially viable and can be used as a blueprint for replication in many urban areas in Europe.

Conclusions

For the region of Heerlen in the Netherlands a roadmap to energy neutral was set up, based on 1/3 reduction of energy demand in Buildings, 1/3 greening of urban area energy support by a DHC-grid and geothermal storage and 1/3 gained from national sustainable sources. Within the densely built urban environment the impact of the DHC-grid might raise to 65%, thus leaving national measures for rural areas. In finding solutions for a modern energy support strategy trends and principles can be formulated. Developments should be assessed against these principles and risks avoided or opportunities seized from the trends.

Mijnwater BV is operation a DHC-grid with geothermal storage in the city of Heerlen with 150.000 m^2 buildings connected and growing towards 800.000 m^2 in the coming years. The current grid is based on low-exergy principles, mutual energy exchange, long term buffering and intelligent control. In the future we want to evolve this grid, according to the formulated principles, towards a full 4-th generation DHC-grid, where the remaining needed auxiliary energy is provided from a multisource of local renewable energy technologies.

Financing these new kinds of regional-based energy provisions is a complex process. Many financial institutions are yet not capable of adequately estimating the risks of these developments. Nevertheless, financing is one of the main barriers in the energy transition process. Due to step-by-step expansion and proof by result, Mijnwater BV is able to build up financial trust.

The Mijnwater business case is based on long-term investment with a time horizon of 20–30 years for installation components and of 50 years for pipes and construction works. The existing gas and heat grids in the NL are nearly 50 years old and many need to be renewed. Regarding the quoted trends in this paper establishing Mijnwater-like infrastructures appear to be a fruitful long-term policy for the NL and wider in the EU. Due to a decision strategy based on integral total cost of ownership (TCO) and supply security, investing in a sustainable hybrid geothermal grid seems to be highly preferable to investing in gas infrastructure and/or replacing conventional heat grids.

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Open Software-Architecture for Building Monitoring and Control

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Abstract

Information technology can increase energy efficiency by improving the control of energy-using devices and systems. Awareness of this potential is not new—ideas for applications of information technology for energy efficiency have been promoted for more than 20 years. But much of the potential gain from the application of information technology has not yet been realized. Today a combination of new requirements for the operation of the electricity system and the development of new technology has the potential to cause a rapid increase in the pace of adoption of improved controls. In this paper we discuss one promising avenue for technology advancement. First, we review some basic concepts with emphasis on open software-architecture. Then we describe the components of XBOS, a realization of this open software-architecture. XBOS has the ability to monitor and control many different sensors and devices using both wired and wireless communication and a variety of communication protocols. Finally, we illustrate the capabilities of XBOS with examples from an XBOS installation in a small commercial office building in Berkeley California.

Keywords

building controls, building automation, open software-architecture

Introduction

Information technology can increase energy efficiency by improving the control of energy-using devices and systems. Awareness of this potential is not new—ideas for applications of information technology for energy efficiency have been promoted for more than 20 years. But much of the potential gain from the application of information technology has not yet been realized. In an earlier paper one of the authors (Blumstein (2011)) discussed some reasons for the slow exploitation of information technology's potential to increase energy efficiency. The earlier paper also suggested that a combination of new requirements for the operation of the electricity system and the development of new technology could cause a rapid increase in the pace of adoption.

This paper is about *open software-architecture*[12] for the control of energy use in buildings. Open software-architecture is a way of organizing the software that links together the physical elements of a building control system to allow the addition of other systems or components. The reason we are concerned about open software-architecture is that open software-architecture is the key to creating an environment that supports innovation. Proprietary and closed systems, which are prevalent today, typically create barriers to innovation.

To make this clear, consider a commercial building with a control system for its Heating Ventilating and Air Conditioning (HVAC) system. If you want to control the lighting in the building, the technology currently used for HVAC control cannot easily be modified for lighting control—in practice you need to add a completely separate control system for lighting. Further, if the control system for lighting includes occupancy sensors and you want to use occupancy to control HVAC, you cannot, as a practical matter, use the lighting system's occupancy sensors. Still further, if you develop new software for detecting faults in the HVAC system, you cannot easily install the new software in the existing building control software. These are all problems that can be solved with open software-architecture.

We will have more to say about how we addressed these problems in a small commercial office building in Berkeley California later in this paper. First we discuss in more detail the idea of open software-architecture, drawing on lessons from the Internet.

Lessons from the Internet

The most important lesson from the Internet is interoperability—the ability of the Internet to accommodate diverse devices and systems and enable them to work together. The practical effect of interoperability is that equipment suppliers and software developers can compete to supply established needs and can innovate to create new uses. This environment has fostered both cost reductions and rapid innovation. So, one may well ask, can we make building monitoring and control systems look like the Internet? The answer is, yes we can.

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[12] Readers should be careful to distinguish between open software-architecture and open-source software. Open software-architecture does not necessarily involve open-source software.

Doing this is facilitated by using the Internet's open architecture and protocol stack. The critical step is to move from a vertical to a horizontal architecture—an essential element of open architecture. Figure 1 provides a simplified representation of horizontal layered architecture[13] to help explain the concept. Each layer is independent, and thus creates modularity. The bottom layer in Figure 1, here called the hardware presentation layer, is where the control system connects to the physical environment. This layer interconnects sensors and actuators to the other layers through software adaptors called drivers. The middle layer—system services—organizes, stores, and transmits data from the hardware presentation layer and instructions from the application layer. The top layer, here called the application layer, has software applications that operate on data provided by the system services to produce outputs in the form of information (e.g., a dashboard) on the state of the building and instructions for the control of building systems.

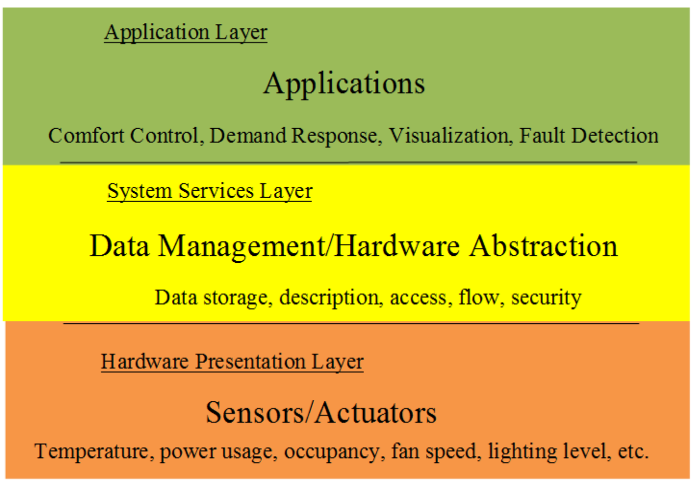

Figure 1: A simplified representation of layered architecture for building monitoring and control

Not all control is initiated on the application layer; some happens autonomously on the sensor/actuator layer—for example, lights might be directly controlled by an occupancy sensor. And not all instructions from the application layer are accepted. For example, a smoke alarm may override an instruction to open a damper. To make this more concrete, consider a building appropriately equipped with sensors, actuators, and applications. Suppose that the operator of the building wishes to minimize energy use during the peak time

[13] The phrase "layered architecture" does not refer to spatial relationships among the system's components; rather, it refers to logical relationships. The "layers" are an abstraction. Here we are using the word "layers" as a heuristic; it has more specialized meanings in other contexts.

on a hot day by precooling the building so it can ride through the peak time. An application in the application layer contains a model of the building that can predict the best time to turn on the air conditioning based on the outdoor temperature, the indoor temperature, the weather forecast, and other variables all of which are resident in a database in the system services layer. The application gets the data from the database and predicts the best time to turn on the chillers, say, 7:00AM. If sensors and controllers in the hardware presentation layer determine that operation is safe, the chillers will be turned on at 7:00AM.

The difference between horizontal and vertical architecture is not in the functions that need to be performed. Sensing and actuating, data management and applications need to happen in monitoring and control systems regardless of the architecture. The difference is in the separation of these functions. In a vertical system a "black box" might, for example, have hard-wired connections to sensors and actuators and have applications with built-in data structures that were inaccessible to other applications. Horizontal layered architecture can keep the functions from becoming entangled and allow devices and software from different suppliers to interoperate.

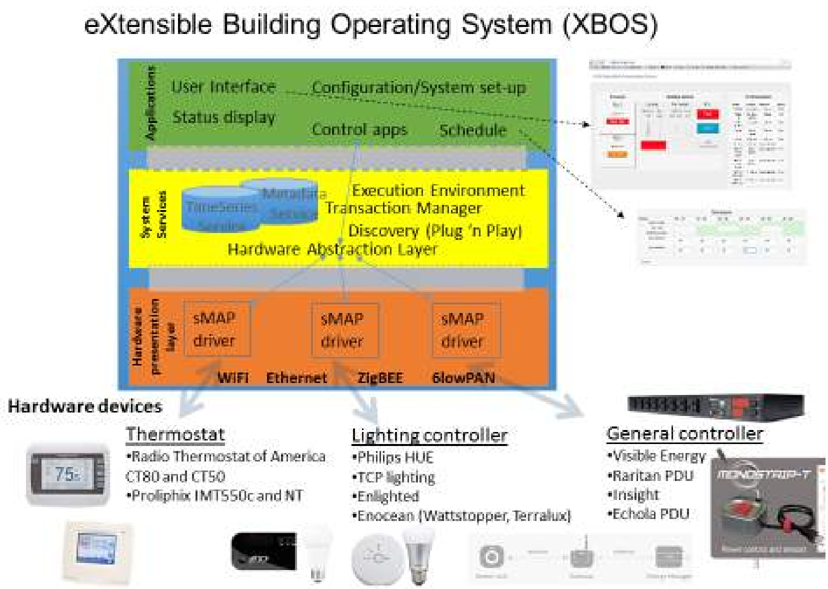

Figure 2: The XBOS layered architecture, consisting of Hardware devices, a Hardware Presentation Layer, System Services layer, and an Application layer. Drivers in the Hardware Preentation Layer present vendor supplied hardware devices (sensors and actuators) to the Hardware Abstraction Layer as canonical devices (for example, as a generic thermostat

Open Building Control Architecture—the XBOS Example

Figure 2 illustrates the eXtensible Building Operating System (XBOS) a realization of an open software-architecture control system. This program has evolved from several years of work at UC Berkeley (see Dawson-Haggerty *et al.* (2013)). A more detailed description of XBOS can be found in Fierro (2015).

XBOS is built on UC Berkeley's simple Measurement and Actuaction Profile (sMAP), an open-source information infrastructure for buildings and grids. The Hardware Presentation Layer, shown in Figure 2, includes drivers for network thermostats, lighting control, and general control, along with more than fifty other open source drivers[14] for energy metering, demand response notification, BACnet, Modbus, commercial BMS systems, weather metering, thermal monitoring, air quality monitoring, and so on.

While control systems based on open software-architecture are much more versatile than vertically architected systems, open software-architecture systems do present some challenges. An example is the need of recognizing new devices connected to the system. XBOS handles this problem with a discovery service, which automatically detects new devices on the network, finds and installs the appropriate sMAP driver, and configures it to that particular installation. This discovery service is similar to "plug and play" as it appears in various forms in consumer markets, such as plugging in a new hardware device into a PC or laptop. However, it does not depend on vendor products implementing a particular discovery standard. The discovery service receives notification of the presence of a new device, it probes the device using a collection of detection scripts to identify what it is; once identified, the service pulls in the appropriate driver for the device, creates the configuration file integrating the driver and the particular site, and connects the device to the system.

Vertically architected systems do not require a discovery service because, by design, they do not interact with initially unknown devices. Other challenges for open software-architecture are discussed in Fierro (2015).

[14] in https://github.com/SoftwareDefinedBuildings/smap/tree/master/python/smap/drivers

Installation of XBOS in the Offices in the Berkeley Kress Building

The research team developed a pilot test of the XBOS platform in a commercial building in Berkeley, California that was built in 1935. The 700 square meter top floor of the building holds private offices, open plan office space, a kitchen, and a conference room; a server room for the office is on the mezzanine level. The heating, cooling and ventilation system is provided by five packaged roof-top units each controlled by programmable thermostats. The overhead fluorescent lighting system is generally controlled by wall switches, with occupancy sensors in the private offices; some corridor lighting remains on permanently.

The XBOS platform installation consisted of a miniature computer (FitPC), Ethernet switch, and Wireless Access Point; this provided the means for all control systems and sensors—no matter what network protocol—to communicate with the computer. For example, some equipment required proprietary gateways (such as for ZigBee devices such as the Enlighted lighting controller and the Rainforest power meter); other equipment used simple USB dongles (EnOcean lighting controllers communicating at 902 MHz and the environmental sensors using 802.15.4). The computer held the sMAP drivers for communicating with all sensors and controllers, and the database, archiver, and services (such as discovery described above). A total of five smart thermostats, three different lighting controllers, two general controllers, 14 sets of indoor environmental sensors and one power meter were controlled by XBOS.

XBOS's integrated control system provides several advantages over vertical solutions. The unified interface greately improves user interaction as the building manager can access all the devices from a single dashboard. It is possible to develop such an interface, because data from heterogeneous devices is made uniform by the hardware presentation layer. Devices can be organized and grouped in different ways. For instance one can easily access all the lighting in the building or all the systems (HVAC, lighting, plug loads and additional sensors) in a room. This simple feature is not currently available in vertically integrated and isolated systems, since each vendor uses separate intefaces that require distinct logins. It is almost impossible to exchange data between commercial interfaces. In addition, XBOS develops a building-level scheduler to enforce policies on the whole building. For instance, when a calendar event occurs, all the devices are notified, synchronized and their setpoints adjusted. The ability of accessing external sensors allows creating customized control schemes. For example one can control the HVAC system based on temperature measurements in rooms that are actually occupied.

One example of application that takes advantage of the rich sensor environment in this field test is shown in Figure 3.

Smart meter electric data is combined with thermostat runtime and building operation hours to disaggregate energy use as a function of building activity. The program distinguishes the baseload energy use (standby power and constant operation of all the devices), the activity-based energy use (extracted using opening hours), the startup and lag energy use (before and after business time and above the baseload) and the weather-related energy use (calculated associating HVAC runtime with smart meter data).

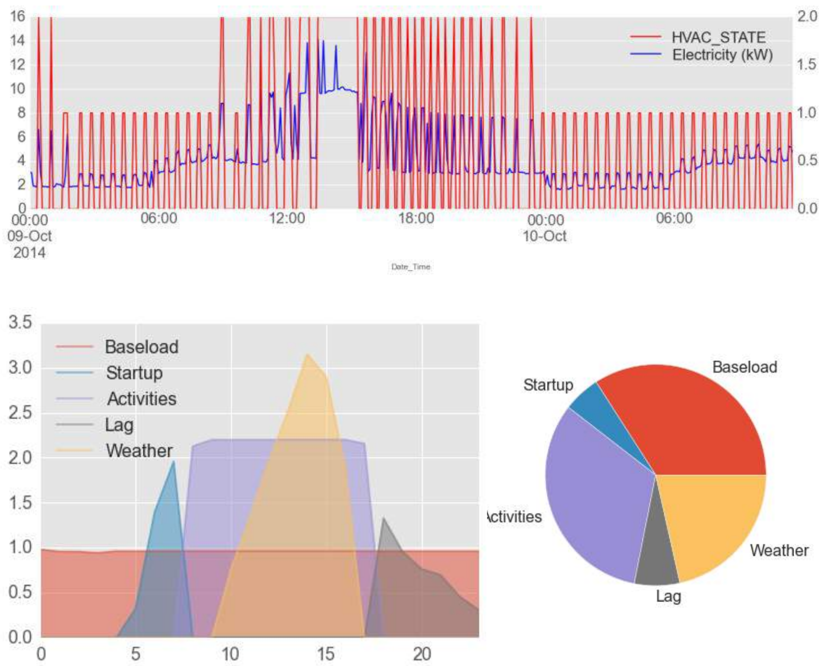

Figure 3: XBOS Energy Disaggregation Application. In the top graph, note the coincidence of spikes in KW consumption (left scale, blue line) and the HVAC state (right scale, red line). In this instance just one roof-top unit is operating. Small spikes occur when the fan comes on; larger spikes occur when both the fan and the compressor come on.

Another key features of XBOS is that it operates on a 'canonical representation' of a building, a generalized description of functional relationships between buildings components. Because of this feature, new applications can be easily written, without knowing the details of the different devices and their communication protocols. The Hardware Abstraction Layer provides a common interface to devices like thermostats or lighting controllers. This type of architecture, commonly used in information technology (for example in Android smart phones), has not yet been adopted in building systems.

Conclusion

We believe there is a compelling case for building controls based on open software-architecture. As we have noted, the practical effect of the interoperability that open software-architecture can provide is that equipment suppliers and software developers can compete to supply established needs and can innovate to create new uses. This can foster both cost reductions and rapid innovation. However, there are significant impediments to the widespread adoption of this technology. Once they make a sale, purveyors of proprietary vertically integrated control systems have a captive customer. Because only the original seller can perform maintenance and provide product upgrades, this customer lock-in is highly profitable. Companies with established products are not enthusiastic about changing their business models.

It is possible that there is more opportunity for open software-architecture in smaller buildings where the dominant controls companies do not have a large presence. This is part of the motivation for targeting XBOS at the small commercial building market. However, this strategy is not likely to succeed if the work is done in isolation. The XBOS software is open source[15] and we are hopeful that others will want to use it and continue its development.

Acknowledgment

The authors drew extensively from the work of the brilliant UC Berkeley graduate students in the LoCal and Software Defined Buildings research groups, namely Michael Andersen, Stephen Dawson-Haggerty, Andrew Krioukov, Jorge Ortiz, and Jay Taneja, as well as others. This work was supported by the National Science Foundation and the Department of Energy.

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[15] https://github.com/SoftwareDefinedBuildings/XBOS

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An integrated platform for collaborative performance-efficient building design: the case of HOLISTEEC project

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Abstract

HOLISTEEC is a EU FP7 project which objective is to design, develop, and demonstrate a collaborative building design software platform, featuring advanced support for multi-criteria building optimization. Conceptual phases of the design process are the ones addressed, taking into account external and neighbourhood-level influences. The platform offers, among other services, a unified IFC-compliant data model for BIM, a set of multi-physical simulation engines to evaluate the performances of the designed building at the different steps of the conceptual phases, and an open infrastructure for building design interoperability based on available standards. The design of this platform has relied and still relies on feedbacks by domain experts and on the currently adopted business models, while enabling at the same time a renewed and enhanced design process, to take current practices one step forward for an improved flexibility, effectiveness, and competitiveness.
This article presents the state of the works of the HOLISTEEC project to day as well as the functional and technical details about the features offered by the platform.

Keywords

BIM, IFC, Holistic design platform, Simulations, Cloud, Collaborative design

Introduction

HOLISTEEC is a EU FP7 project started in October 2013 with the objective of designing, developing, and demonstrating a collaborative building design software platform featuring advanced support for multi-criteria optimization of design choices. HOLISTEEC tools will therefore focus on multi-criteria performance assessment during the design phases. Thanks to a qualified validation process, relying on a set of selected real case studied, the platform is expected to bring valuable experience on workflows and on performance assessment activities based on the *Building Information Modeling (BIM)* process, yet tackled in very limited way in current practices, according to surveyed business conduct and literature.

This article presents the state of the works to day as well as the functional and technical details about the features offered by the platform. The idea is to present here an overview of the results obtained till now by a research project which is expected to have a direct impact at a macro level and on the construction sector as a whole.

User needs and objectives of the work

The study of the state of the art related to current design practices (Delponte et al, 2014) has shown how the increasing of complexity, multidisciplinary targets, and tools to be taken into account in the design process are requiring deep changes in the building industry. The HOLISTEEC project has identified the main critical issues of current design process, and a new methodology for building design has been proposed (Delponte et al, 2014). Its main features are:

a performance-based approach to requirements' setting;

a collaborative (i.e. integrated) approach to design in order to involve all the strategic stakeholders in the decision-making process;

a BIM-based design and evaluation process throughout design.

In order to support those features, better tools than the ones currently available are needed as well. HOLISTEEC platform is therefore meant to integrate the existing tools and to provide new ones to fill the identified gaps, to support the proposed enhanced methodology.

Related works

A literature review has been made to determine the state-of-the-art for collaborative multi-user platforms. According to Charalambous et al. (2012), the potential of BIM in combination with online collaboration platforms provides an opportunity for addressing many building industry obstacles (such as fragmentation, low innovation, and adversarial relationships). Different kinds of recent surveys, case studies and analyses consistently reported that BIM improves visualization, coordination of documents, communication, and that it can bring advantages such as cost savings, profitability, and time reduction (e.g. Kreider et al, 2010; Malleson, 2014; Finne et al, 2013; Bryde et al, 2013; Saini and Mhaske, 2013). However, much less information is available in literature about the degree of usefulness of BIM to improve the quality of the designed buildings thanks to the support of the management of performance aspects along the building lifecycle.

A literature review of software tools and research works allowing multiple stakeholders in design process shows that available market and research tools are mainly focused on sharing model-based data and information: main functionalities relate to design coordination among players and model data storage.

Only a limited number of tools are designed for project evaluation purposes: simulation capabilities or analysis features are not integrated in collaboration tools; performance evaluation tools currently exist but are mostly self-standing tools and are integrated -to some extent- into authoring software through data exchange mechanisms based on the *Industry Foundation Classes (IFC)* standard. Energy performance and thermal comfort have anyway gained significant relevance in the process of evaluation of the quality of the building design, thus currently playing a key role in the design process.

These needs and drawbacks are the ones the HOLISTEEC project wants to address and overcome.

Collaboration tools

Charalambous et al (2012) performed a study on short term opportunities for (UK) collaboration platforms to offer greater value under existing working practices. The work presents a reference list of functionalities that different studies have reported to exist or to be nice-to-have. Recently developed functionalities include workflow management, reporting tools, measuring tools, management of meeting minutes, e-bidding and e-procurement. Features labelled as nice-to-have are related to design process visualisation, social data integration, geospatial visualisation, clash detection, design and procurement integration and mobile applications.

Singh et al (2011) conducted a study about BIM-based collaboration platforms in Australia in 2007-2009 to explore theoretical requirements for multi-disciplinary collaboration platforms. The work summarises the technical requirements for BIM servers: a) model management requirements, b) design review requirements, c) data security requirements, and d) BIM server set up and using assisting requirements.

Design evaluation approaches

Aouad et al (2005) present a prototype of a *n*-D modelling tool aimed to aid in integrated, concurrent design, primarily in the design phase. The tool would encourage and support the project team to consider all elements of the product life cycle. The tool enables to systematically assess and compare the strengths and weaknesses of different design scenarios. Such *n*-D modelling aims to integrate number of design dimensions into a holistic model that studies knowledge capture, utilisation, and transfer without data loss. The focus of this work was rather put on collaborative design and project information management, but discarded performance evaluation and simulation issues, as HOLISTEEC wants to do.

From the user point of view, an assessment tool for assistive design must be easy to use, able to provide feedback in a quick way, and allow rapid comparison of design alternatives (Urban, 2007). Most existing tools, and even the one of Aouad et al (2005), do not meet these needs, usually because they were only intended for building modelling. User interfaces are often complex, simulations can take hours or days to prepare, run, and interpret results. Such tools are too sophisticated to use for design purposes, while designers mainly need something simple to use and that could address the open issues related to collaborative and integrated design and to performances evaluation.

Architecture of the platform

The following picture reflects the architecture of the platform, which has been designed by combining stakeholders' requirements, HOLISTEEC partners' technological background and already available commercial and research solutions.

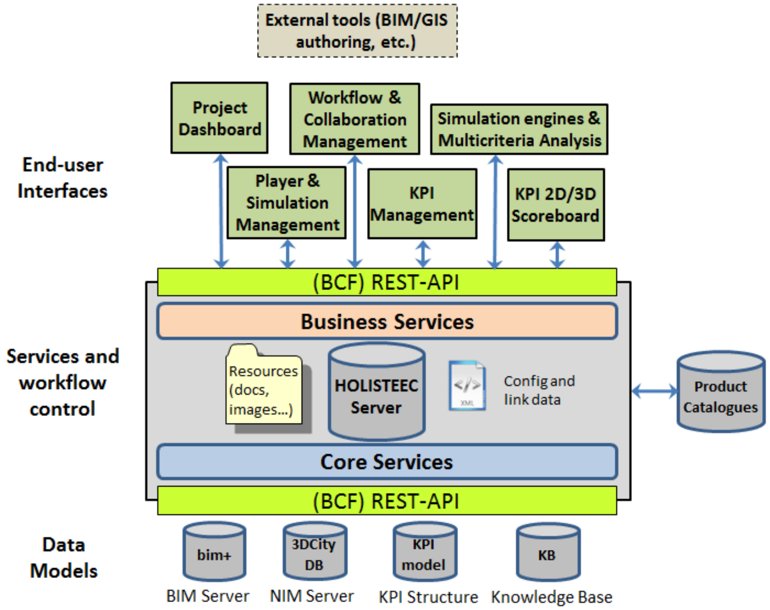

Figure 1: Architecture of the platform

The HOLISTEEC platform (Figure 1) is devised as a cloud-based infrastructure accessible through web services, which makes the different users involved in the design process interact by supporting the workflow defined in the newly-defined design methodology. Service layers are specified by following public standards, like RESTful[16] Application Programming Interface (API) and *BIM Collaboration Format (BCF)* REST API for supporting collaboration.

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[16] *Representational State Transfer (REST)* is a software architecture style for building scalable web services. More details can be found here: www.restdoc.org/spec.html

This approach allows a flexible and customizable evolution of the platform through pluggable and replaceable components, both on end-user and model storage side, the only condition for integration being the compliance with the platform REST APIs specification. From the business perspective it opens the way to third parties to enhance and enrich the platform with additional functionalities not currently offered.

The main HOLISTEEC server will be in charge of the workflow orchestration, project management and repository, tracking of the different projects' versions and variants, and the smooth connection to different storage models. A neutral layer of core services will enable the basic operations (create, read, filter, update and delete) for the different stored models, like:

- *Building Information Models (BIMs)* database, containing data about the designed building;
- *Neighboring Information Models (NIMs)* database, containing data about the surrounding environment where the building is supposed to be located;
- *Key Performance Indicators (KPIs)* database, containing the definition of the metrics to be used for the evaluation of design choices and relevant aspects;
- Knowledge Base (KB), containting the specification of domain and expert knowledge for design choices' evaluation and the generation of recommendations for design improvement;
- Product Catalogues contain the technical data related to commercial solutions or widely used products, to be used for building design.

Platform Services

The platform offers a collection of business services through REST API. Building model authoring is supposed to be performed outside the platform, through external BIM or *Geographic Information System (GIS)* tools. Platform aim is indeed to efficiently and effectively support data exchanges and make the required data available at the right time to the right person, for a faster design and simulation loop. Handling and comparing different variants in parallel is part of the offered functionalities. In order to reach the above-mentioned objectives, services include intelligent model transformation processes, which automate some manual tasks, e.g. the generation of different simulation alternatives. A list of offered service categories is presented in the following, with brief examples of the allowed activities; the platform provides tailored UI for most services, some developed from scratch while others adapted from solutions provided by project partners.

- **Project dashboard**: overview of the project, users, targets, project and document management.
- **Workflow and collaboration management**: exchanging requests, issues and feedback and project timelines.
- **KPI management**: KPIs configuration and status, calculation and target achievement (e.g. building energy consumption, acoustic isolation, etc.).

- **Player & simulation management**: generation and execution of different simulation variants.
- **Simulation engines**: performances evaluation w.r.t. domain: thermal (heat and energy consumption), acoustic (noise comfort), lighting (power consumption) and environment (pollution and environmental impact). Different level of granularity (from room (finest) to neighbourhood) according to the domain interest.
- **Multicriteria analysis (MCA) tool**: analysis of the data of the platform (BIM data, simulation outcomes) in order to give appropriate feedbacks to end-users such as risk detection, compliance checking or improvement suggestions.
- **Scoreboard**: data visualization, comparison of different design variants in terms of performance, visualization of MCA feedbacks and link with 2D/3D model visualizations.

BCF layer for service integration and extensibility

BIM Collaboration Format (BCF) REST APIs are designed to be an easy-to-implement way of exchanging BIM data between clients and servers. RESTfulness allows the APIs to rely on standard HTTP communications and on the *JavaScript Object Notation (JSON)* technology to describe and exchange BIM data. The communication flow is similar to that of email exchanges, with central servers acting as hubs for the communication between the parties: clients connect then to a server to create and retrieve BCF messages. Specification of the BCF REST API can be found here: https://github.com/BuildingSMART/BCF-API

BCF REST API is the way in which the different components of HOLISTEEC platform are integrated and exchange information. This modality allows to rely on a BIM-based data exchange standard (BCF is a standard adopted by the BuildingSmart Consortium, which is responsible also for the specification of IFC), and to extend platform services or tools through BCF-compliance as unique requirement. Indeed, most cases a BCF plugin for an already existing tool can be easily developed and implemented thanks to the BCF underlying standard technologies (HTTP and JSON).

Usage and workflow

Through Project Dashboard the project manager can setup the environment and control the different aspects related to the workflow of a project. It gives an overview of the involved stakeholders and of the status of tasks, design contents, building project objectives, model versions and variants and performances evaluation. The design phase-oriented workflow management helps the user to organize resources and items, to make efficient model assessment through the integrated simulation management and to focus on model variants' flaws and benefits by evaluating and comparing them through the scoreboard.

A typical scenario for model assessment would consist of a user selecting the performance criteria to consider for one or more building variants given the project design phase and model maturity. These criteria would then be automatically translated into a list of KPIs directly processable by the suitable simulation engines.

BIM models are then transformed (automatically, or with the intervention of simulation expert where needed) into an abstract *SImulation Model (SIM)* format representing the base input for all HOLISTEEC simulation processes. BIM data are "normalized" to adapt to simulation requirements (e.g., geometry, building elements representation and classification property are adapted), missing but simulation-relevant information are added (e.g. space boundaries, thermal bridges, etc.) and parameters for the domain-specific simulation engine are set.

Different drafts of building models stemming from the original BIM can then be created just-in-time, thanks to the paramters' setting features allowed by the Player-Simulation loop. Player allows the user to select the models he wants to "play" with and to assign products and the related physical attributes to a selected set of elements in the simulation model (e.g. choose facade glazing products for the northern facade of the building). Since Player SIM models are ready to be inputted to simulation engines and do not need further intervention by users or experts, the Player can feed the simulation services with a vector of temporary models to be evaluated in a row; this ease the task of evaluating different solutions where product permutations occur and these solutions can be explored over night and in parallel, if technological resources allow it.

Performances of different variants can then be quickly viewed in the Player and compared through the Scoreboard. If required targets are not met, the implementation of further products or solutions can be evaluated.

The MCA tool will alert the user of potential risks (e.g; design choices leading to comfort reduction, high energy consumption, conflicts with the current national/local regulations, etc.) and guide him through the selection of the best building elements and products according to the required criteria. Once the best solution configuration has been determined, it will be transformed back to the building model and made available to the user as part of final simulation results.

Once such an assessment is performed, the calculated KPIs result values will be available and can be visualized anytime within the Scoreboard. This allows the support of the decision-making process through the elimination of variants or the re-modelling of the bad performing parts of the building.

Conclusion

The platform here presented allows the design and performance evaluation of buildings during the early phases of the design process. Offered services are: a unified IFC-compliant data model for BIM process, a set of multi-physical simulation engines to evaluate the performances of the designed building at the different steps of the conceptual phases, a multicriteria analysis tool to assist the user during the process and, globally, an open infrastructure for the interoperability of building design tools leveraging on available standards.

The design of this platform has relied and still relies on feedbacks by experts of the fields and on the related business models. Further tests for evaluating utility and helpfulness of the proposed platform on real case studies provided by the industrial partners of the project Consortium are going to be conducted in the rest of the HOLISTEEC project (4-year duration, scheduled end September 2017).

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Enabling a Living Laboratory: Two Examples of Using Occupied Buildings as Test Beds for Smart Building Controls

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Abstract

The purpose of this paper is to describe how novel software enabled two existing occupied buildings to become "Living Laboratories" to test advanced building system control algorithms. Sensor networks and advanced controls in buildings can provide improved indoor air quality, better thermal comfort, and more satisfied occupants while saving energy. When developing and prototyping new sensors and controls algorithms, researchers commonly use models for simulation and test in a closed controlled laboratory environment. Field tests provide critical real world validation, but are often difficult to accomplish. Recently at the University of California, Berkeley, computer science researchers developed innovative software that allowed researchers to use existing occupied buildings as convenient real-life test beds of smart technology. The software enabled interoperability with lighting systems and Heating, Ventilation, and Air Conditioning (HVAC) systems in the buildings as well as providing monitoring capability. The results indicate that while using occupied buildings introduces hazards not found in controlled test beds, the benefits include energy savings, improved performance, and better visibility into building system operation.

Keywords

Energy, Buildings, Sensor Networks, Building Controls, Living Laboratories.

Background

With buildings providing a major contribution to greenhouse gas emissions, the building science community must continue to explore means of providing healthy productive indoor environments while reducing energy consumption. Researchers use many different tools to achieve improved building energy performance, such as math or software-based control algorithm development and software models of buildings or components. International and national building codes often require models in order to show compliance. For over 50 years, researchers and practitioners have implemented computer-based building energy models; examples include TRACE, TRNSYS, DOE/eQUEST, Energy Plus, and Revit (IBPSA (2015)). General software programs such as spreadsheets (e.g., Microsoft Excel) and algorithm development platforms (e.g., MATLAB) have been applied to model building components or systems. Laboratories, or specialized controlled research spaces, are also often employed for testing and to develop standards. Thermal comfort metrics, such as Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) (Fanger, (1970)), were derived from human subjects in laboratory settings in the late 1970s. In addition, early standards of ventilation requirements for buildings were based on the smell of the working class and of school children in laboratory settings (Cooper, 1998). Code organizations, such as International Building Code (IBC), American Society for Heating, Refrigeration, and Air-Equipment (ASHRAE), and California Energy Commission (CEC), rely on these models to help achieve compliance with building codes. Private comprehensive rating systems, such as green building rating systems (e.g., LEED, BREAM, DGNB) (Nelson and Frankel (2012)) are another driver of building energy performance.

However, conditions in the field are often not well represented by models and laboratories. Even supposedly green buildings with LEED ratings have a poor record for performing in operation as well as what was predicted during design. The afore-mentioned codes and rating systems seem to measure and reward the goal and effort rather than actual performance. Similarly, several studies suggest that thermal comfort metrics derived in laboratories do not adequately represent actual comfort conditions found in the field (DeDear, Brager, Cooper (1998)).

In the last 10-15 years, efforts have focused on the role of field studies in improving building performance. Actual energy consumption is measured in certain governmental benchmarking and rating systems (e.g., Energy Star, Energy Performance Certificate (EPC)). Monitoring-Based Commissioning (MBCx) is a process that uses energy use measurement to diagnose problems, account for savings, and endeavor to ensure the persistence of these savings (Brown, Anderson, Harris (2007); Brown, (2011)). Field studies drove the modification of the ASHRAE thermal comfort standard (Standard 55-2004) and the creation of the European Standard EN15251 to include wider allowable temperature ranges for naturally ventilated buildings (ASHRAE (2004); Nichol, Humphreys (2009)). Further efforts modified Standard 55 to allow higher air movement to improve comfort, also based on field studies (Arens, Turner, Zhang, & Paliaga, (2009)).

The term "Living Laboratory" was coined about 10 years ago (https://en.wikipedia.org/wiki/Living_lab), primarily to emphasize the role of the end user in research. The term is now in wide use, often describing newly constructed buildings with innovative designs where researchers see how these buildings perform in areas like energy use and occupant satisfaction. Here we are interested in a narrower definition of Living Laboratory as an occupied building—not necessarily new or of innovative design—that can be used for multiple experiments. These experiments typically involve sensing, developing, prototyping, refining, or validating systems in a real-life context. The concept here is to use existing occupied buildings, often outfitted with extra sensors and monitoring systems, as test beds for various research endeavors, such as developing control algorithms to improve comfort and save energy.

This paper describes two Living Laboratories developed at UC Berkeley, presenting some results for research conducted in these buildings.

UC Berkeley Living Laboratories

Researchers have developed two Living Laboratories at UC Berkeley: Sutardja Dai Hall, a seven story, 13,100 square meter on-campus building first occupied in 2009, and the Kress building, a two story, 3,200 square meter off-campus building constructed in 1935 and extensively renovated in 2000.

On-campus Living Laboratory: Sutardja Dai Hall

Shortly before completion in 2009, Sutardja Dai Hall, which houses the Center for Information Technology in the Interest of Society (CITRIS) headquarters, had US$200,000 of submetering infrastructure installed. About 10% of the building is dedicated to a nanofabrication laboratory; other uses include private and open plan offices, laboratories, conference rooms, auditorium, and a café. The building has over 6000 sense points, mostly from the Siemens Building Automation System. The building has a flex-fuel chilling system, with both an absorption chiller and typical electrical centrifugal chiller; chilled air is supplied to the building with 130 Variable Air Volume boxes, each with reheat coils. The nanofabrication lab and the office portion of the building are served by two air-handling units each.

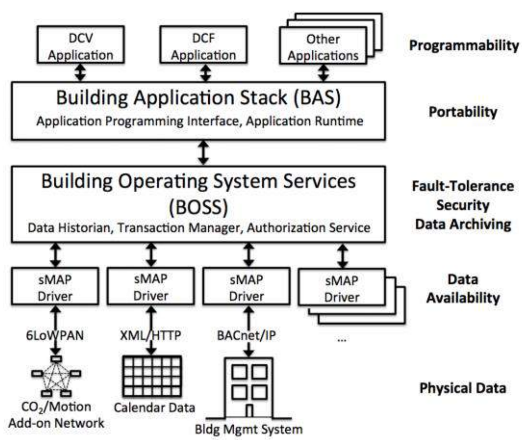

Figure 1: Platform for integrating sensors, Building Management System, and other data in a single time series data management system. From (Taneja et al, (2013))

Computer Science researchers developed a Building Operation System Services platform (BOSS) (Dawson-Haggerty et al, (2013)) that provides a data management system (simple Monitoring and Actuation Profile or sMAP) (Dawson-Haggerty et al, (2011)) to "tag" time-series data with descriptors or "metadata" and store these in a compact database that allows custom queries (Figure 1). These sMAP "drivers", just like printer drivers, are the interface from the hardware devices (e.g., sensors, actuators) that enable data from that device—no matter what network protocol (e.g., wired Ethernet, WiFi, ZigBee, ZWave)—to enter the data historian and storage system. The BOSS platform allows researchers to write applications on top of the existing BAS, as seen in the top layer of Figure 1.

In the last few years, researchers have implemented many advanced control algorithms in the building: energy efficiency strategies, ventilation optimization strategies, demand-controlled ventilation (DCV) and demand controlled filtration (DCF), demand response algorithms, dynamic supply air pressure reset, and dual maximum setpoint strategies. In addition, researchers created browser-based user interfaces for overhead lighting and a local temporary blast of heat or "coolth" from the nearest Variable Air Volume box.

For demand response events (two to four hour energy curtailment limited to the office portion of the building), the algorithms included automatic control of the Heating, Ventilation, and Air Conditioning (HVAC) system by increasing the temperature setpoint, decreasing the ventilation, and increasing the supply air temperature. Lighting system curtailment included dimming most zones to 33% and turning off end zones (near windows). For one event, some receptacle loads (e.g., large television monitors) were manually turned off and occupants asked to reduce energy use from their computer monitors, printers, coffee makers and so on.

Figure 1 above outlines the example of DCV and DCF. Carbon dioxide and motion sensors were installed in conference rooms throughout the building; data were tagged with location and deposited in the time series database. Meeting schedule data from an online calendar were scraped, tagged, and added to the database. A simple script written in Python interacted with the BAS to flush the rooms with air right before a scheduled meeting. The algorithm monitored the carbon dioxide levels in the room, and provided high air volume when levels exceeded 800 ppm. When no one was in the room, the ventilation levels dropped.

Off-campus Living Laboratory: the Kress building

The three story 3200 square meter Kress building lies a block off-campus in downtown Berkeley, California, and houses a Jazz school, book store, and offices, each floor metered separately. The Living Lab consisted of the 700 square meter top floor of the building, which holds private offices, open plan office space, a kitchen, and a conference room; a server room for the office is on the mezzanine level. The HVAC system is provided by five packaged rooftop units (RTU) each controlled by a programmable thermostat. The overhead fluorescent lighting system is generally controlled by wall switches, with occupancy sensors in the private offices; some corridor lighting remains on permanently.

Building on the work in Sutardja Dai Hall, researchers developed and deployed a BAS for small commercial buildings, entitled eXtensible Building Operating System (xBOS). xBOS takes an Internet of Things approach to building controls by networking thermostats, lighting controls, and appliance control—regardless of the connection protocol (e.g., WiFi, ZigBee, ZWave, Ethernet, etc.). The xBOS platform installation consisted of a miniature computer (FitPC), Ethernet switch, and Wireless Access Point; this provided the means for control systems and sensors to communicate with the computer. Some equipment required proprietary gateways (ZigBee devices such as the Enlighted lighting controller and the Rainforest energy monitor); other equipment used simple USB dongles (EnOcean lighting controllers communicating at 902 MHz and the environmental sensors (temperature, humidity, light, motion, carbon dioxide) using IEEE 802.15.4). The computer hosted the sMAP drivers for communicating with all sensors and controllers, and the database, archiver, and services (such as discovery for automatically finding and configuring the devices described above). Five networked thermostats, three different lighting controllers, two general controllers, 14 sets of indoor environmental sensors and one power meter were monitored by the xBOS platform. Figure 2 below shows a schematic of the platform that enabled the Living Lab in the Kress building.

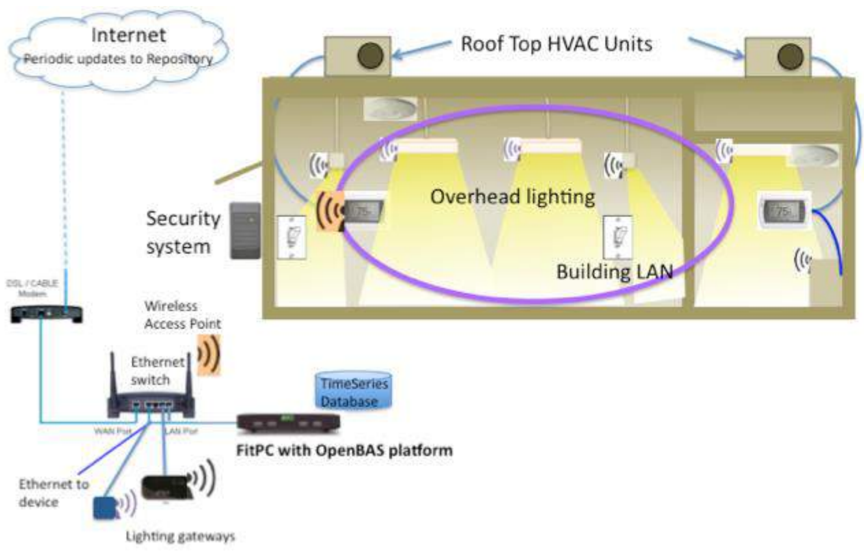

Figure 3: xBOS platform for 720 m2 floor of commercial building

Results

In Sutardja Dai Hall, over the course of implementing demand response various strategies, the researchers worked with the facilities manager to implement persistent energy efficient measures. The load on the air handling units supplying the office portion of the building dropped by 20 kW over the course of the project, mostly due to the dynamic minimum ventilation scheme. The load on the absorption chiller and associated pumps decreased by about 30 kW, probably primarily due to the new Variable Frequency Drives installed on the pumps, but some effect from the implementation of the temperature deadband (e.g., control points at 21-23.3C (70-74F) versus a single control point of 21C (70F)), increase of the supply air temperature to 14.4C (58F) from 13.3C

(56F), and the reduced ventilation. This amounts to approximately US$44k savings annually.

Several demand response events to curtail peak load were administered on moderate, warm, and hot days, with savings ranging from 18-29% (Figure 3). Not surprisingly, there was greater energy reduction on the hottest days, especially due to the configuration of the two cooling towers. (The second one turns on only during hot weather).

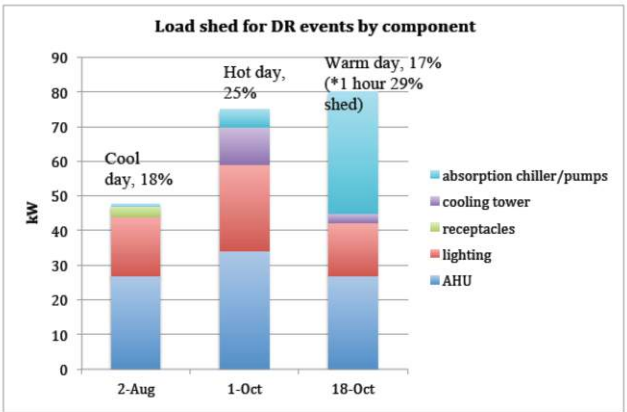

Figure 3: Results of three demand response events in Sutardja Dai Hall

In addition, air quality was improved and energy saved by 69% through the DCV scheme (Taneja et al (2013)).

In the Kress building, researchers were able to use the user interface to set a single schedule for all five thermostats—a major convenience and time saver. A visualization tool allowed the team to compare the electrical utility meter data with HVAC system state and temperature to determine how much power each of the five RTUs used. Corridor lighting that had previously been lighted all the time was finally controllable. Old non-functioning occupancy sensors were replaced with functional sensors. The unusable lighting interface in the conference room was replaced by a more intuitive interface. This work will continue—researchers are in the process of updating the platform and implementing new control algorithms.

Discussion

A good reason models and bench-scale tests are so widely used is because living laboratories can be difficult places in which to work. Sometimes algorithms, networks, or equipment fail, which can affect the satisfaction, comfort and productivity of the occupants. In Sutardja Dai Hall, one outside research group didn't understand the idiosyncrasies of the control system protocol, and instead of letting the temperature drift to 25.6C (78F) before cooling, accidentally *heated* the office space to 25.6C (78F). Multiple lighting control sequences sent simultaneously caused the BAS to ignore them all;

repeating the sequence at intervals solved the problem. During the final demand response event, when the savings from the air handlers was not as much as expected, the researchers discovered another researcher had started a dynamic ventilation strategy which decreased the baseline of the control day. Sometime occupants would override the lighting system, especially toward the final demand response event, possibly fatigued by the tests. Often occupants covered or unplugged sensors. Before allowing a new technology—office chairs that provide heating and cooling—the manager of one department in the building suggested the research team test the algorithm on themselves first.

In the Kress building, researchers had to deal with aging HVAC equipment. One thermostat had low voltage caused by loose wiring at the RTU; on another unit, a transformer went bad. Researcher-error played a role as well: at one point, the researchers discovered the heating system for one zone was not working because the wrong setting had been chosen on the thermostat. In addition, not all the Ethernet ports on the building Local Area Network worked properly, and sometimes the thermostats lost network connectivity.

However, the benefits outnumbered the difficulties. Researchers found that field tests conducted on or near campus are vitally convenient—no travelling long distances. Talking to users can improve the user interface and parameters of the control; some users didn't like the initial lighting control interface in Sutardja Dai Hall, but the researcher quickly modified it after numerous conversations. In both buildings, the general energy performance improved just from having so many researchers look at the data from systems in the building and refine settings. Researchers helped the facilities manager chart HVAC zones and map the lighting zones with WattStopper BACnet names. The researchers were also able to use data to diagnose problems in both buildings. At one point, the blower fan belt broke in one of the rooftop units of the Kress building and the researchers were able to diagnose the problem and direct the technician to quickly fix it. Similarly, researchers helped the facilities manager and commissioning agents at Sutardja Dai Hall diagnose a short-cycling chiller, a stuck economizer damper, and a faulty valve. The two buildings have been the subject of research conducted by faculty, students, and staff from various departments around campus, including Business, Architecture, Computer Science, and Mechanical Engineering.

Conclusion

While simulations and models can help researchers develop novel control algorithms or interfaces that improve building performance, field-testing in occupied buildings can provide critical real-life test results. This paper described the pioneering software that enabled two existing buildings—neither one an innovative design—to become convenient Living Laboratories to test advanced building system control algorithms. The software created an architecture that allowed interoperability between systems, providing a means of easily developing advanced algorithms to operate building systems. The results show that while the field-testing introduced certain risks (e.g., occupant discomfort due to errors), the benefits of this Living Lab included a convenient method of prototyping, testing, monitoring and validating research; providing university curricula; and improving comfort and saving energy.

Acknowledgements

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Evaluation of energy saving potentials for commercial districts served by distributed m-CHP units

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Abstract

This paper presents the results of an energy balance study for an innovative energy management concept for districts. According to this concept, the buildings in a district are interconnected by thermal and electric micro-grids. Heat and power are produced within district limits by a "swarm" of centrally controlled micro-CHP units. The energy conversion devices (gas boilers , ICE, Stirling, SOFC units and back-up gas boilers) are considered for two settings: a "Reference" (centralized system and gas boiler) and a "micro-CHP" (decentralized micro-CHP units) and for two primary energy factor settings (one constant electrical PEF of 2.5 and one setting with variable PEF).A commercial district type, located in Munich is examined. It is located in the more central/commercial part of the city, containing more buildings of the tertiary sector. The in-house developed, Matlab based, DEPOSIT software has been utilized in the present work. The importance of heat-led control and of a variable PEF for electricity is shown. A clear PEC reduction potential has been identified for all cases examined, ranging from 62.9% up to 66.3%. Moreover with variable PEF, savings from the m-chp operation can be increased by 9%.

Keywords

micro-CHP, Stirling engine, ICE, SOFC, district heating, performance monitoring, district operation management, Deposit code, forecasting

Abreviations:

mCHP: micro Combined Heat and Power unit
Power unit
PEF: primary energy factor
MFH: Multifamily House
PEC: Primary Energy Consumption
SOFC: Solid Oxide Fuel Cells
ICE : Internal Combustion Engine
SFH: Single Family House

Introduction

Achieving sustainable development in the energy sector in general and in building energy consumption in particular requires the reduction of non-renewable primary energy input and greenhouse gas emissions. One possible developmental path is decentralization of the electricity system. Distributed power generation in small, decentralized units is expected to help reducing emissions and saving grid capacity, providing also opportunities for renewable energy (Pehnt *et al*, 2006).

Recent technological advances have led to an increased interest in small CHP units, with the prospects of developing units that can provide electricity and heat for individual buildings Relevant technical assessment studies focus on the primary energy savings achieved by the operation of small Internal Combustion Engines (Onovwiona *et al*, 2007), (Haeseldonckx *et al*, 2007) and Solid Oxide Fuel Cells (SOFCs) (Alanne *et al*, 2006), (Hawkes *et al*, 2007). The corresponding performance of a Stirling engine mCHP system has been examined (Alanne *et al.*, 2010), both in terms of energy and cost savings.

District level energy simulation methodology

In order to acquire realistic energy (heat) balance data, a detailed energy demand and supply simulation in district level was performed on an hourly basis. The in-house developed, Matlab based, DEPOSIT software has been utilized in the present work. The tool performs an hourly-based numerical simulation of the district, the piping, and its heating and power generation units. It calculates the total district heat demand, including piping heat losses and pressure losses (pumping power). Various operating scenarios can be simulated for the CHP units, depending on the overall target: primary energy minimization, cost optimization, maximum CHP operating hours. Limitations and specifications of the micro-CHP units, such as thermal and electrical efficiency curves, start-up, gas- and electrical-consumption and modulation times, are taken into account by the simulation algorithm. Simulations result to an hourly analysis of the district heat management via calculated energy flows from each system (CHP, buffer tanks, back-up boilers). DEPOSIT also provides the expected energy savings as compared to the reference case of decentralized gas boilers, as well as the foreseen total fuel consumption. Moreover, in order to perform system operation optimization for the next few hours, specialized neural networks have been adopted in order to provide estimations of total heat demand. The DEPOSIT tool can provide useful information to a variety of stakeholders: energy authorities, municipalities, investors, district operators and end-users.

Heat Demand Side modelling

The modelling provides the heat required to cover the space heating needs of the buildings in 0.032 km² of the district considered, plus piping losses. Calculations are performed in an hourly basis for one year. The hourly district heat demand is provided by the component-based, transient thermal and electrical energy simulation platform (Trnsys v. 17.01), (Trnsys 17.00.00User Manual, 2012), which requires as input specific data regarding district composition, building characteristics and climatic data. The simulated Reference Case does not consider network-piping losses and is associated only with internal pipes, since there is no pipe network interconnecting the district buildings. On the other hand, the mCHP interconnected district cases take into account both internal and external pipe losses. The data input requirements for the hourly calculation of piping losses include the corresponding pipe length and diameter (internal and external – if needed), assumptions regarding thermal conductivity and soil temperature. A necessary assumption is that the water in the district heat network is kept at 70°C (max) throughout the year. During long shut down times (summer) the network cools down and is reheated at the start of the heating season.

The calculation of the hourly district heat demand was done with Trnsys v17.01 .The required ambient temperatures for Munich are acquired through the Trnsys databases.

The total building area consists of 20% multifamily houses, 5% single family houses (SFH), 30% hotels and 45% Offices. 3 different Multifamily house (MFH)-, 2 Office building-, 1 Single-family house- and 1 Hotel-geometries were used in the simulations. The composition is shown in Table 1.

City Munich		
District		Commercial Center
Number of MHF1		5
Number of MHF2		1
Number of MHF3		3 (1 high eff, 2 low eff)
Number of SFH		18 (12 high eff, 6 low
Number of Office1		12
Number of Office2		7
Number of Hotels		24 (6 high eff, 18 low
Districts created by the algorithm	District dimensions	500m x 150m
	Street Loops	17-18
	Block area	4500 m²
	Number of blocks	7
	Total Area	31500m²

Table 1: Composition of considered district

Heat Supply Side modelling

In this methodological stage, the systems that provide the required heat to the district are modelled. Separate gas boilers, installed in each building of the district, are considered as the Reference Case for fulfilling the district heat needs. The simulated district served by mCHPs also includes backup boilers and heat storage tanks; required input data includes tank geometry, heat conductivity and the temperature outside the tank and backup boilers.

Table 2 presents the main assumptions needed for modelling heat supply to the district for both examined cases. Reference boilers are assumed to have 75% average yearly efficiency, while backup boilers have 80% average efficiency. (efficiency includes oversizing and ramping losses according to (KENAK 2010).

District Type	Munich Commercial Center	
Case	Reference	m-CHP Case 1 & 2
Number of Gas boilers/m-chp units	1 Gas boiler per building able to cover peak demand	1 ICE and 2 Stirling units per MFH, 1 SOFC per SFH, 3 ICE per Office, 4 SOFC per high eff Hotel, 3 SOFC and 1 Stirling per low eff Hotel
Heat buffer size	none	100x500L

Table 2: Main assumptions for heat supply modelling

The eHe Whispergen Stirling units have 11.2% electric and 87% thermal efficiency (accounting for Lower Heating Value). The technical constrains of the Stirling mCHP unit include maximum / minimum thermal output (7.5 and 0 kW, respectively, with no modulation) and the time from hot start to maximum thermal and electrical output is 16-19min. The ICE units (AISIN SEIKI) deliver up to 11,5kW heat and 5,6 kW electricity with thermal and electrical efficiencies of 69% and 27% respectively. The SOFC units are micro chp units with a very high power to heat ratio and very low thermal output, targeting more high efficiency buildings. The fuel cell developed by TU Freiberg with a Staxxera stack within the framework of the FC-District program (FC district EU-Project (grant agreement no. 260105)), delivers 1,5 kW of electricity and 2,5 kW of heat with efficiencies: 50% thermal and 30% electrical. A voltage degradation of 5 mV/1000h was assumed.

The Stirling units are operating at an on-off basis with not heat modulation and in the simulation case 2 are able to be switched off and on sequentially but are not allowed to be shut down more than 10 times per 24h according to the manufacturers' guidelines. The SOFC units can modulate but cannot operate under 40% operating capacity. Moreover they cannot be switched off to avoid the deterioration of the stack due to thermal stresses The SOFC units will be switched off only 1 a year for the whole summer period in order to minimize heat dumping. The ICE units will modulate from 0 to 100% operating capacity at certain operating setpoints.

Primary energy

PEFs are used for calculating resource consumption and energy efficiency. They are fixed values, based on theroretical calculations and are used to approximate the total primary energy (primary resources) required for the production of 1 energy unit of a consumed final energy type (electricity, gas, oil). Recource extraction, transportation, storage and efficiency losses (e.g. power plant efficiency) are included in the calculation. PEF of electricity is given as a constant for the entire year. This makes the primary energy savings calculations not correct, due to the variability of electricity generation. (Wilby and Gonzalez,2014)

In the present simulation two approaches were examined with the Deposit software and simulated.1) A constant PEF for electricity (value=2.5) which reflects an estimated average efficiency of 40% of its generation among Europe (Directives 2006/32/EC, 2009/28/EC, 2010/31/EC). 2) The PEF was a random function of the horizontal solar radiation in Munich (Germany). Goal was to show the difference between a constant and a more realistic variable PEF in the energy savings calculation. Moreover the advantages of the DEPOSIT control code, in terms of demand forecasting and PEF evolution can be better understood and depicted with a variable PEF for electricity. The two simulation settings (constant and variable PEF), have the same yearly average PEF sothat direct comparison can be made.

Operating strategies

(a) Reference Case

In the Reference Case, the gas boilers are simply assumed to have the ability to modulate instantly to any demand.

In the mCHP case, the coupling between district heat demand and supply is performed through alternative operating strategies of the mCHP units.

The present work considers two types of mCHP “swarm” operation:

(b) Case 1: Intermittent mCHP operation (allowing individual control of the Stirling units with shutdowns according to achieving the minimum primary energy during each timestep). Units can be divided into 3 main groups. Each unit type can be ramped, or switched on and off simultaneously with no option of individual control per single unit. The strategy in this scenario can be described as heat and primary energy following. Then the algorithm determines which unit types shall operate at this timestep and at which fraction of the output to avoid overproduction of heat. At this combination of units in different statuses (starting, shutting down , or operating etc) the efficiencies are determined, the electric output and the thermal output is calculated and the primary energy is deducted according to the PEF for electricity and natural gas The algorithm decides if it is environmentally benefitable to operate the units as chosen, or if it would rather shut some of them off or ramp some unit groups down and use buffer energy or backup boilers. It must be noted that,if the PEFs are constant, the algorithm will always choose as its first priority, the cogeneration units , due to the high PEF (2.5) of produced electricity. The remaining uncovered demand (if any) is covered first by the buffer tank and then by the backup boilers.

(c) Case 2: Intermittent mCHP operation with demand forecasting

In Case 2 we implement forecasting. Heat demand for the following 33 timesteps is foreseen. The average PEF is also foreseen for the 33 timesteps ahead. Matlab neural network toolbox is used for the forecasting, with parameters such as historical data (previous values), weather forecast data etc. A Narx (nonlinear autoregressive network with exogenous inputs) is a recurrent dynamic network, with feedback connections enclosing several layers of the network. The neural network is used, with 4 hidden layers and 1 input delay and 13 feedback delay variables, for time series forecasting. Some results of the forecasting algorithm can be depicted on Figure 1. The forecasting follows the trend very nice, despite the very few training data of 8761 hours. The R^2 for the test data of the closed loop network is ~80% depending each time on the initial random weights.

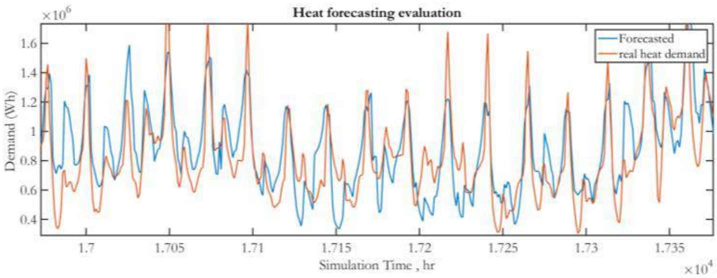

Figure 1: Heat demand data vs forecasted values for non-training data

Case 2 is very similar with the second scenario, but after 1 year when the algorithm has enough historical data to train the neural network, the heat demand of the next 33 hours and (if necessary the PEF of electricity of those hours) are estimated. Afterwards Case2 uses a decision routine according to these nearly future values, and displaces thermal and electrical generation to times where the PEF is very high to charge the buffer tanks, and so, avoid production of cogenerated heat, at timesteps where electricity production is not sponsored with high PEF. Moreover the third unit group can individually control its units in Case 2 and adapt better to the demand. Units can be shut down with a 10% resolution.

Results - Discussion

Simulation results-overview

One reference case has been simulated and m-chp cases 1 and 2 have been simulated twice, for constant and variable electricity-PEF respectively. In operating case 1 with constant PEF, the ICE units cover the majority (nearly 67%) of the part of the demand, which is covered by the m-chp units in the constant PEF case, while the SOFC's cover 27% and the Stirling units 7%. The low fraction of the Stirling units is mainly due to their lack of modulation. In the second case where the forecasting algorithm commands the units to cover parts of the thermal demand before they are actually requested and the buffer tanks are charged, we can see that the fractions develop to 50%, 25% and 25% respectively. This can be justified by the high thermal output of the Stirling units which helps cover the demand of the following hours, as well as by the possibility of the Stirling units to be shut down sequentially. Thus they can be utilized to adapt better to the demand and thus the algorithm uses them more. It can be seen that due to the lower thermal efficiency of the units compared to the reference case boilers, the fuel consumption in the cogeneration cases (1 and 2) is higher. (fig, 2) . The positive effect of displacing grid electricity, with its high PEF, is decisive towards providing PEC savings up to 66.3%.When considering the PEC savings, operation case 2 provides a fair reduction (35.5-35.7%) compared to the operating case 1.

Constant PEF for electricity

In Case1 the algorithm operates the m-chp units, the buffer tanks and the backup boiler, in order to minimize PEC during each timestep. In Case2 the algorithm acts preactive and operates units in order to achieve best PEC savings for the forecasted timesteps. This operation, even under a constant PEF makes savings up to 35,7% compared to Case 1 possible. But even Case 1 with the step by step optimization manages, with the correct dispatch of the cogeneration units to achieve PEC savings of 42.3% compared to the Reference case. Fuel consumption rises from 367x10^3 m^3 natural gas for the reference case, to 494 x10^3 m^3 and 453 x10^3 m^3 for cases 1 and 2 respectively. This is mainly due to the lower thermal efficiency of the cogeneration units.

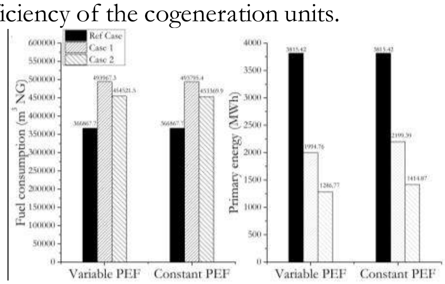

Figure 2: Fuel consumption and Primary energy consumption for all cogeneration and backup units per simulation case

Variable PEF for electricity

Due to the different PEF, the fuel consumption of the Cases 1 and 2 changes as well as the primary energy consumption, because the DEPOSIT algorithm chooses to operate the units otherwise. Due to the forecasting of the PEF value and the heat demand, the Case 2 scenario reaches a PEC saving of 66.3%. The variable PEF, gives the algorithm the opportunity to increase PEC savings by displacing thermal and electrical output to times where the PEF is very high and charge the buffer tanks, and by doing so, avoid production of cogenerated heat, at timesteps where electricity production is not subsidized. The PEC saving of Case 1 on the other hand is 47.7%.

Conclusions

The present work utilizes an in-house developed simulation tool (DEPOSIT) in order to assess the energetic performance of an innovative energy management concept for districts. Actual building characteristics were assumed, providing input to dedicated heat demand calculation software. Overall, the PEC saving of the mCHP case is realized through: a) the high total efficiency of the m-chp units and b) avoiding central generation emissions when the m-CHP electricity is exported to the grid. The comparative analysis identified a clear potential towards decreasing the PEC up to 62.9% when the constant PEF for electricity was used, provided that all the electricity produced is utilized. However, using a constant yearly PEF factor of the displaced grid electricity is incorrect since, it is uncertain what kind of generation takes place at the specific time of the m-CHP export to the grid. In other words, one cannot be confident how efficiently the grid-kWh produced at any specific moment was. Thus a second simulation was implemented with a variable PEF.Due to the nature of the PEF supplied, which correlates to the sun irradiance, which is inverserly proportional to the Heat demand, lower primary energy consumptions were found in both cases. However under a different timeseries of PEF for electricity the case 1 sumulation would have a higher total primary energy consumption compared to the constant PEF case. So the simulation with forecasting (Case2) would outperform even more the Case 1 by rising m-chp usage during high PEF and using the stored thermal buffer, at periods with lower PEF.

Moreover PEFs affect the results enormously. A district setup that provides great saving in a country with a "dirty" electricity network, would perform very poorly in countries with very low PEF for electricity and could even increase PEC.Moreover simple operating strategies are outperformed by far by optimization strategies with heat load forecasting, which are the only way for achieving energy savings in countries with low PEFs for electricity. The DEPOSIT control algorithm, can operate under real fluctuating PEF for electricity, and provide accurate energy saving assesments but also with help of time-series forecasting, a more optimized dispatch approach can be implemented and larger primary energy savings can be achieved.

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Interoperable energy systems – research and innovation strategy for ICT

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Abstract

European countries and cities are increasingly adding to their targets to improve sustainability. Opportunities are seen for improving energy efficiency via integration and linking of different energy systems. Efficient energy use and sustainable energy supply are increasingly included in the cities' targets and realised in their planning, decision making, daily operation and development projects. Efficient energy use and supply are strongly linked and integrated to other operations and actions by municipalities by various ICT solutions. Municipalities foster the integration of different city systems to maximise their synergy impacts.

The READY4SmartCities roadmap suggests how ICTs can support and enable holistic design, planning and operation of energy systems in smart cities. The roadmap proposes research and technical development and innovation activities in short, medium and long term for ICTs. One of the main issues addressed is a strong need for broad collaboration, communication and interoperability within various stakeholder networks. This requires standardisation (both for interfaces and systems themselves) to enable cross-organisational operation. The role of open energy data and its utilisation can also bring significant benefits.

Keywords

ICT, research, innovation, roadmap, energy systems, smart cities, interoperability.

Introduction

The European Union has created a set of targets to mitigate the climate change. The key objectives of these targets are to reduce the greenhouse gas emissions, to increase the share of renewables in energy production and to improve the energy efficiency (European Commission, 2015). The optimal and sustainable energy use requires smart energy management, collaboration and interconnections among various systems and stakeholders in a complex operation environment.

Roadmaps suggesting research and development actions for increasing the energy efficiency of buildings and neighbourhoods have already been created earlier. However, there is also a need for efficient energy systems at the city level. The adaption and development of Information and Communication Technologies (ICT) solutions for such systems is investigated in the READY4SmartCities project. The project focuses on the future energy systems of smart cities and especially on how ICT is enabling and supporting them. This paper summarizes the proposed research and innovation strategy for interoperable energy systems.

The most important sources of information for this paper are the READY4SmartCities vision (Cavallaro, 2014), the draft roadmap (Sepponen 2014) and the implementation recommendations (Sepponen 2015). The paper is structured as follows. First, the methodology used for creating a roadmap for ICT supporting energy systems in smart cities is described. Then, the vision is presented. Next, an overview of the interoperability concept is given and a general solution approach is discussed. Finally, the highlights of the roadmap are provided and the conclusions of the main findings in the paper are drawn.

Methodology

The roadmapping methodology was developed based on the experiences from previous roadmapping projects in the field of ICT for energy efficiency and buildings. Related roadmap projects are e.g. REEB (2010), ICT 4 E2B Forum (2012), REViSITE (2012) and IREEN (2013). The roadmap was developed by a top-down approach, with the following development steps:

- The framework and the main scope of the roadmap were set. Integration possibilities between different energy systems in cities were identified.
- A main vision for the roadmap was created. First, earlier visions in projects related to the smart city topic were analysed. Then, future scenarios were identified and developed. Finally, after expert interviews giving feedback on the developed scenarios, the vision was validated.
- A draft research and innovation roadmap for experts' feedback was created. Roadmap topics sketched the development needs towards vision.
- Implementation recommendations based on the roadmap were suggested. These were further discussed and developed. The development was also supported by the inputs and feedback derived from the related experts and stakeholders, and by the guidelines and recommendations by Radulovic et al. (2015).
- The roadmap was finalised by taking different viewpoints into account, e.g. feedback from experts.

Stakeholders and experts were involved in the development of the roadmap. The targeted stakeholders were initially identified by Fìes (2014) as the key actors to be involved in the proposed ICT technologies, decomposed into four distinct groups: citizen, building sector, energy sector and municipality.

Vision for energy systems in smart cities

The READY4SmartCities vision is that energy systems in cities are planned and operated with a holistic and sustainable approach in the READY4SmartCities' vision. The core content of the vision is shown in Figure 1, consisting of visionary scenarios that represent the viewpoints of citizens, the building sector, the energy sector and municipalities. The expected outcomes of the vision are lower emissions, increasing energy efficiency and improved performance of energy systems in cities.

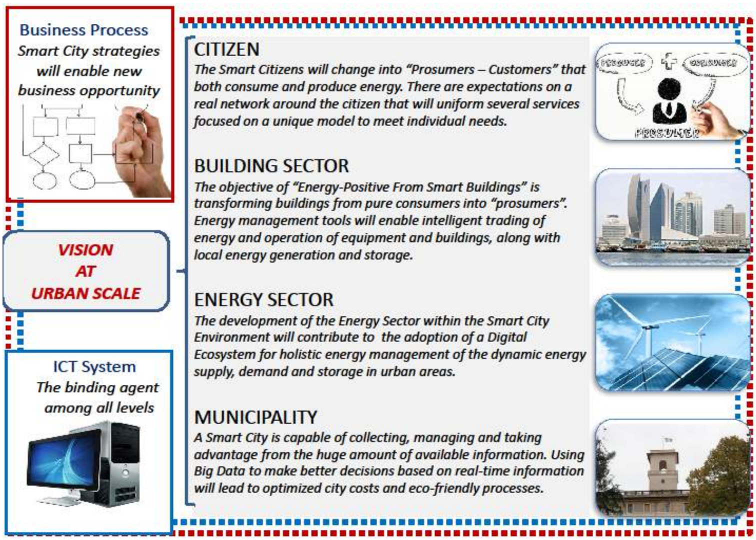

Figure 1: The R4SC vision (adapted from Cavallaro et al, 2014)

The proposed visionary scenarios are elaborated with the using data interoperability to support optimised energy systems from following viewpoints.

Citizens take a more active role in the optimisation of energy systems by taking a possibility to adjust their energy usage, and also potential on-site energy production, in an easy and efficient manner according to their own preferences. They minimise their electricity bills by cutting their electricity usage during expensive times. This can e.g. be done manually by shutting down some of the equipment based on a high electricity tariff, or automatically according to the set electricity usage limits for electrical equipment based on electricity price tariff levels. These solutions can be developed and tested e.g. via urban living labs and pilots.

The **building sector** (facility managers and energy service providers) plans and manages energy efficient and even energy positive buildings as the basic constituent of the city layer energy system. The building manager can manage the energy demand of buildings in collaboration with the residents and users.

Buildings can also be "prosumers", having on-site energy production and being able to sell energy to the grid. In that case, the manager needs tools or services and systems (Building Energy Management Systems (BEMS), Building Automation and Control Systems (BACS) or smart meters and smart fuses) for managing the internal energy balance, and communicating energy tariffs, as well as energy production and demand with the energy grid.

The **energy sector** (grid operators, energy producers and energy service providers) is closely interconnected with the building sector at its city scale systems. Energy providers, storage and grid managers are aiming for optimal energy supply from various sources with profitable cost level and avoiding high cost peak electricity supply. They need solutions for balancing energy supply, demand and storage. The energy provider forms the common interface between energy users and the energy grid. The interactions with the energy provider mainly consist of selling and buying energy and exchanging information on energy behaviour and tariffs. For example, they could provide real time energy tariffs for energy consumers.

The **municipality** plays a key role in energy efficient and sustainable city planning. The municipality manages public buildings, and other sectors using energy, such as mobility (public transportation systems, a fleet of electric vehicles) and street lighting. The municipality can minimise energy costs via the load balancing of its network and interact with an energy provider.

Open data and interoperability for cities' energy systems

Interoperability of energy systems is one of the key issues in upgrading cities' energy systems to operate more efficiently and holistically. Data interoperability is the basis for communication as it is built on agreements between the sender and receiver on how to exchange and interpret a specific set of information. These agreements have been implemented in several domain areas on a more or less individual basis. However, it has turned out that it becomes difficult to extend the scope or to adapt such specific agreements due to the different technologies chosen to solve specific interoperability problems at hand. Today, this situation is a main barrier towards a more flexible ecosystem for energy-related data and the development of new services, being able to integrate and evaluate the data sources.

Data interoperability scenarios for energy systems in cities

In order to act towards these targets, the following solutions are needed:

- Data extraction and access to:
    - Open real time data about buildings' energy demand. Now this data is mainly available by energy sellers. With clients' permissions, they could publish it in an anonymised way, without compromising privacy.
    - Open access to external environmental data and weather data.
    - Multi-level electricity price tariffs for the energy user available from power grid operators.

- Two-way electricity billing: electricity bought from and sold to the grid, enabling buildings to act as "prosumers".
- Services for forecasting on-site energy production and consumption in buildings, district and at a city level.
- Services for the real time optimisation of the energy grid balance: needs both real time data and forecasted information about local energy production, consumption and storage in the district/city.
- BEMS or BACS system giving access to detailed data about the energy demand, including real time demand, average demand, peak loads, and ability to separate different uses of electricity, and heating and cooling energy (i.e. space heating, cooling, lighting, HVAC, hot water, white goods).
- Services supporting decision making: Systems proposing strategies for reducing the energy expenses based on simulation and forecasting capabilities and then helping the user to decide whether it is better to store the local production, to use the energy stored, to buy it from the grid, etc. This can be used in demand side management and energy balancing, e.g. via shifting the timing of energy load peaks.

Recommendations for data interoperability

Semantic web technologies can provide a basis for enabling data interoperability, in particular when taking into account that there are many different stakeholders and data sources that are of interest for the envisaged use cases. A main principle of the Semantic web, and more specifically of the linked open data approach, is to make data available in such a way that other stakeholders can easily make use of it in order to provide added value services. A first analysis of the target domains in the context of smart cities indicates that there are already quite advanced solutions to support data interoperability. However, the domains utilise a plethora of diverse technologies, thus leading to interoperability issues when trying to integrate such data with data from other domains.

The linked open data approach is based on the following compliance levels (Berners-Lee, 2012, Radulovic et al, 2015):

1. Make your stuff available online (whatever format) under an open licence
2. Make it available as structured data (e.g, Excel instead of image of a table)
3. Use non-proprietary formats (e.g. CSV (comma separated values) instead of Excel)
4. Use URIs to denote things, so that people can point at your data
5. Link your data to other data to provide context

A survey on available linked open data has been carried out (Radulovic et al, 2014, Weise et al., 2014 and Birov et al., 2014). The survey indicates that now there are only a few data reaching the fifth level. The lowest level for publishing data is level 1, but many datasets have already reached level 3 (structured data using non-proprietary formats). The technical barrier to achieve next level is often low, but can have a high impact on establishing a new ecosystem of reusable (energy) data.

The survey also showed that there is lack of knowledge about linked open data. In many cases, data owners are not aware of the technology or do not know about the benefits and how to make use of them. However, the impressing rate of 70 % showed interest to learn more about linked open data. This is an indicator that as soon as the existing technologies become more mature and standardized to satisfy the different domain requirements, it can be expected that stakeholders will make their data available as linked open data.

Another major finding of the survey is that in nearly 70% the usage terms of the data are not specified or unknown. One reason is that data ownership is not clear in about 40% of the cases. This lead to another non-technical barrier: the legal aspects that need to be considered and clearly specified when making data available for reuse by third parties. The different stakeholders interested in publishing their data may select the suitable license agreement that will cover most requirements of data owners. However, the identification of the right license along with the awareness of all the consequences is a noteworthy barrier. To be clear, this is a general problem when publishing data and not a special issue of linked open data. Moreover, not all data sets can be published due to privacy or security issues.

Highlights from the reseach and innovation strategy for ICT

The roadmap proposes research and technical development and innovation activities in short, medium and long term for ICT supporting energy systems of smart cities. It is structured into four main domain area roadmaps, representing the views of the stakeholder groups, and one integrating section related to energy data and its usage. Each roadmap section introduces relevant drivers, needs and requirements, vision, barriers, expected impacts and key stakeholders.

The repeating theme throughout the roadmap is a strong need for broad collaboration, communication and interoperability within various stakeholder networks. This requires standardisation of both interfaces and the systems themselves, to enable cross-organisational operation. The role of open energy data and its utilisation is also included here. (Sepponen et al, 2014)

Based on the roadmap result, implementation recommendations for how ICT can support energy systems in smart cities have been suggested. The following six implementation ideas are proposed an enabling technology for many of these. The target outcomes of the ideas are as follow:

1. ***Decision support for energy efficient smart cities***: To identify interventions that could be integrated based on the city priorities. To guide the city stakeholders in the selection of the most suitable interventions to achieve the targets identified.
2. ***Open building and energy data ecosystem***: To develop global ICT ecosystems that enable both development and downloading applications based on energy data. The applications could give insights in their energy behaviour and for helping to save energy, costs and emissions.
3. ***Optimal management of city's energy production, distribution and demand:*** To create common market structures and recommendations for a legal framework that defines the relations between grid operators, energy providers and energy consumers. This

would facilitate the optimal management of energy production, distribution and demand in cities.

4. ***Electricity matching in real time:*** To improve the balance in the power grid, and to reduce the need for using peak power production units.
5. ***Integration of electrical vehicles to power grid:*** To integrate electrical cars into the electricity grid and thereby achieve a better grid balance.
6. ***City planning enabling maximized energy efficiency***: To take a more holistic approach to city planning, and thereby increase the energy efficiency in the city. The earlier in the planning process the energy efficiency measurements are taken into account, the larger are the impacts.

The implementation recommendations suggested rely on the actions of the stakeholders involved in the development of optimized energy systems in smart cities. Since all of the recommendations involve several stakeholder groups, flexible coordination and collaboration between the stakeholders are important for the realization of the recommendations. Thus, a city that wants to become a smart city has to understand the perspective of the different stakeholders. Well-defined, joint targets for the stakeholders are also important. Such targets may offer an opportunity for monitoring of the progress made by cities and stakeholders and for verifying that they have kept their promises.

Furthermore, there are lacks on the energy grid side, such as solutions for multi-tariffs of electricity prices and sharing of this information. This would be needed for better electricity balancing and for minimising the peak loads. Moreover, there is also a need for ICT solutions to manage overall local energy supply from various sources, its distribution, storage and use in an optimal way.

Conclusions

European cities and countries are increasingly adding to their targets to improve the sustainability of their energy systems. Opportunities are seen for improving energy efficiency in cities via integration and linking of different energy systems. The READY4SmartCities suggests how ICT solution can support energy systems and their development towards sustainable smart cities.

The proposed research and innovation roadmap for interoperable energy systems has multiple goals. It suggests how citizens' involvement and their active role could be increased in the daily operation, use and decision making related to energy aspects. It also suggests that building systems are developed into active participator in the city energy system, and optimized to balance their energy behaviour to maximise the comfort of the inhabitants. For the optimised city energy supply, the interaction and synergy between the different energy systems and other city infractructure should be increased, and in this both data and system interoperability are key issues. For the municipality, the roadmap suggests how to integrate different city systems to maximise their synergy impacts.

In all the suggested development and innovation needs, interoperability and related ICT communications enable different energy systems and networks to be optimally operated. Data interoperability allows for information exchange and communication between the different networks, devices, components and applications of energy systems. The development of optimized and interoperable energy systems requires also collaboration between several stakeholder groups, and in that it is crucial to have well-defined targets, which are shared among all stakeholders.

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