Towards sustainable and smart communities: integrating energy efficient technologies into buildings through a holistic approach

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Towards sustainable and smart communities: integrating energy efficient technologies into buildings through a holistic approach

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Abstract

As the EU energy industry is clearly moving towards a new era of reliability, availability, and efficiency that will contribute to the improvement of Europe's economic and environmental sustainability, smart technologies provide the opportunity for new applications with far-reaching interdisciplinary impacts: providing the capacity to safely integrate more renewable energy sources (RES), smart grids and distributed generators into the network; delivering power more efficiently and reliably through demand response and comprehensive control and monitoring capabilities in order to achieve zero energy targets. The integration of smart technologies requires a holistic approach that takes into account all aspects of sustainability.

The methodological approach is based on a cycle expansion of three phases: 1. the users/consumers aspects, focusing on smart and zero energy buildings analysis, 2. the smart grids penetration at community and city level, offering the technological platform for fast moving towards sustainable communities by exploiting the ICT and energy systems development in the maximum degree 3. development of smart applications and smart grids optimised operation.

This paper analyses the three-phase approach addressing issues of providing optimal operation and adaptation to ICT technologies. It also highlights the principles of integrated design procedure and links the process with smart building technologies. Energy efficiency methodologies and innovative techniques applied at building level are also presented.

Keywords

smart communities, smart buildings, smart grids, integrated energy design, zero energy communities

Introduction

The effects of global warming and climate change are evident in every societal level to such a degree that immediate actions for reducing greenhouse gas (GHG) emissions is no longer an option but rather an imperative. Buildings are responsible for 40% of energy consumption and 36% of EU CO2 emissions. To help address climate change, in March 2007, the European Council set clear goals for 2020, known as the 20/20 targets: a) reduction of 20% of energy used (below 2005 levels), b) 20% contribution of Renewable Energies to total energy use and c) 20% reduction of GHG below 1990 emissions. Therefore a number of further research and development activities need to be initiated now, in order to deliver applications and solutions for the long term perspective of 2050 and beyond. To move towards an increasing low-carbon economy, European electricity networks will need to evolve to provide support for possible future energy vectors, for effective introduction of carbon credits, taxes and trading, for generating buildings integrated with energy distribution and finally for massive combination of renewable generation in the built environment. In this context, the SMART GEMS EU funded project contributes towards this perspective by providing the necessary knowledge and state of the art uptake to move towards smart grids integration in a large scale. It also raises awareness and improves understanding of the public with respect to the social value and the potential of smart grids towards a safer and healthier environment. The project intends to show that smart grids and smart communities are technologically feasible, environment friendly and economically sustainable.

Smart grids are electrical power grids that are more efficient and more resilient — therefore, "smarter" — than the existing conventional power grids. The smartness is focused not only on elimination of black-outs, but also on making the grid greener, more efficient, adaptable to customers' needs, and

therefore less costly [1], [2]. Smart grids incorporate the innovative IT technology that allows for two-way communication between the utility and its customers/users. As a result, the sensing along the transmission lines and the sensing from the customer's side is what makes the grid "smart". Like the Internet, the Smart Grid will consist of controls, computers, automation, new technologies, smart buildings and equipment working together, but in this case these technologies will work with the electrical grid to respond digitally to the users' quickly changing energy demands.
Smart Grids open the door to new applications with far-reaching inter-disciplinary impacts: providing the capacity to safely integrate more renewable energy sources (RES), smart buildings and distributed generators into the network; delivering power more efficiently and reliably through demand response and comprehensive control and monitoring capabilities; using automatic grid reconfiguration to prevent or restore outages (self-healing capabilities); enabling consumers to have greater control over their electricity consumption and to actively participate in the electricity market.
In order to implement these technologies in building and city scale a methodological and holistic approach is required ensuring effectiveness and sustainability.
A three-phase approach addressing issues of providing optimal operation and adaptation to ICT technologies through integrated design procedures is analysed in the present work.

The principles and benefits of Integrated Design

Integrated Design is an approach that considers the design process as well as the physical solutions, and the overall goal is to optimize buildings as whole systems throughout the lifecycle. For the purpose of reaching high sustainability performance, the alternative building and technical solutions should be developed and discussed by an integrated, multidisciplinary team [3].
ID emphasizes a decision process rooted in informed choices with regard to the project goals, and on systematic evaluation of design proposals. This approach for building design is paralleling the principles of environmental management referred in the international ISO 14001 standards. Here, identifying and prioritizing goals, and developing an evaluation plan with milestones for follow-up, are central issues. A shift of approach emphasizes that the very early phases need more attention because well informed decisions here will pay off in the rest of the design process as well as in the lifecycle of the building. Well informed planning from the start can allow buildings to reach very low energy use and reduced operating costs at very little extra capital cost, if any. Experience from building projects applying ID shows that the investment costs may be about 5 % higher, but the annual running costs will be reduced by as much as 40-90 % [4], [5]. The process of ID emphasizes that the performance of buildings should be assessed in a lifecycle perspective, both regarding costs (LCC) and environmental performance (LCA). Figure 1 indicates the importance of the Integrated Design process at the early phases (www.integratedesign.eu)

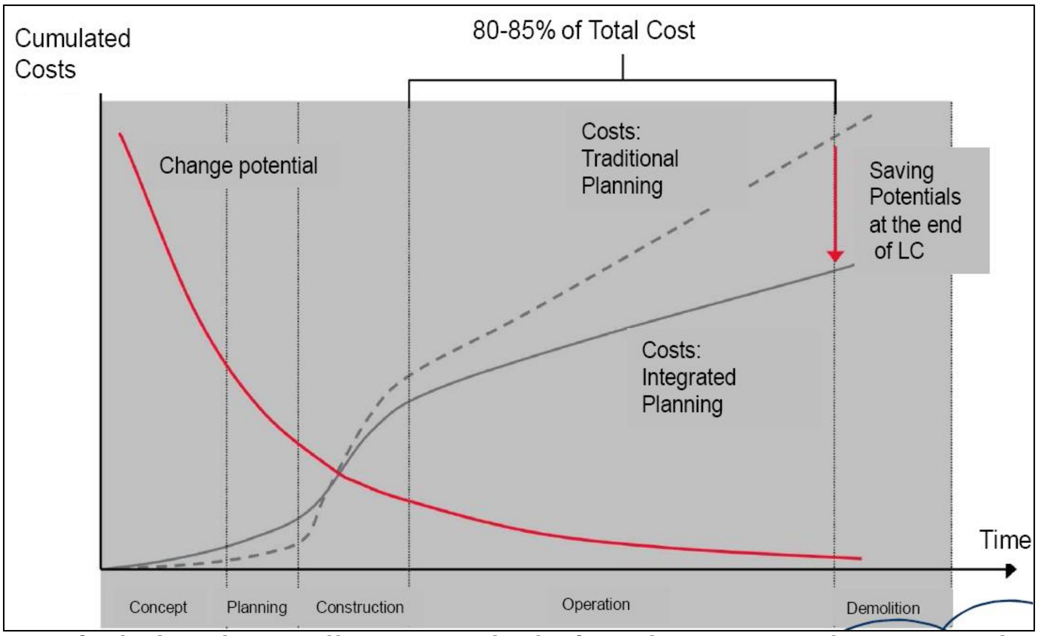

Figure 1. Early design phases offer opportunity for large impact on performance to the lowest costs and disruption. Therefore, a shift of work load and enhancement to the early phases will probably pay off in the lifecycle of the building.

An Integrated Design approach that combines smart, passive design, thermally efficient building skins and effective space planning to reduce energy demands as a first step, combined with highly efficient systems, provides a cost-effective alternative to bolt-on systems installed on an otherwise under-performing building.
Six steps can be identified for a successful Integrated Design implementation:

1. *Project development:* discussion of the project ambitions and challenge initial client presumptions, initiating ID process and preferably make partnering contracts.
2. *Design basis:* selection of a multi-disciplinary design team, including an ID facilitator, motivated for close operation, analysis of the boundary conditions. Also refine the brief and specify the project ambitions, preferably as functional goals.
3. *Iterative problem solving:* facilitate close operation between the architect, engineers and relevant experts through workshops etc. Use of both creative and analytical techniques in the design process. Discussion and evaluation of the multiple concepts and finalise optimised design.
4. *On track monitoring:* Use goals/ targets as means of measuring success of design proposals, make a Quality Control Plan, evaluate the design and document the achievements at critical points/milestones.
5. *Delivery*: Ensure that the goals are properly defined and communicated in the tender documents and building contracts, motivate and educate construction workers and apply appropriate quality tests, facilitate soft landing. Make a user manual for operation and maintenance of the building.
6. *In use:* Facilitate commissioning and check that the technical systems etc. are working as assumed, monitor the building performance over time regarding e.g. energy consumption, user satisfaction etc.

Integrated Design processes result in higher energy performance: optimization of building form, orientation and facades is reached through open multidisciplinary discussions and design decisions in early project phases, where knowledge about important conditions is exchanged to inform the design of the building. It also contributes to the reduction of embodied carbon as optimized design is given priority before advanced technical systems and control mechanisms. Indoor climate is significantly improved: the building and technical systems work together in a logical symbiosis in order to achieve sufficient indoor air quality, temperature control and daylight access/ solar protection. Running costs of the building are reduced: simplified technical systems are more cost efficient, both in terms of investment costs for manufacturing and installation and in terms of running costs and maintenance. Another aspect is the reduction of risks and construction defects as improved planning leads to less building faults. Thus; less claiming and money saved. Early involvement of users and inclusion of user needs in the design process may improve the following performance of the building in the operation phase, as well as increase user satisfaction. A high performance building can yield higher rental costs which can be compensated for by a lower energy bill thus the sales value of the building will increase. A green image can also benefit the building owner or tenant organization.

Methodological approach of ICT integration

In order to ensure the that Integrated Design takes into account recent trends and developments in Information and Computer Technology a methodological approach is designed by taking into account the potential role of smart grids.
Smart Grids can create a revolution in the building sector. The accumulated experience of the last decades has shown that the hierarchical, centrally controlled grid of the 20th Century is ill-suited to the needs of the 21st Century. The smart grid can be considered as a modern electric power grid infrastructure for enhanced efficiency and reliability through automated control, high-power converters, modern communications infrastructure, sensing and metering technologies, and modern energy management techniques based on the optimization of demand, energy and network availability. The role of buildings in this framework is very crucial. A since the vast majority of smart grids' potential customers are buildings (residential, commercial, retail and industrial) and communities the smart grids' challenges on building and community level is of major importance.
The methodological approach's phases are (see Figure 2):

1. Phase 1: Zero energy buildings and integrated design: How to design buildings that can be easily integrated with smart grids.
2. Phase 2: Zero energy communities' components: Energy production and Energy demand.

3. Phase 3: Successful integration of zero energy buildings and communities with smart grids.

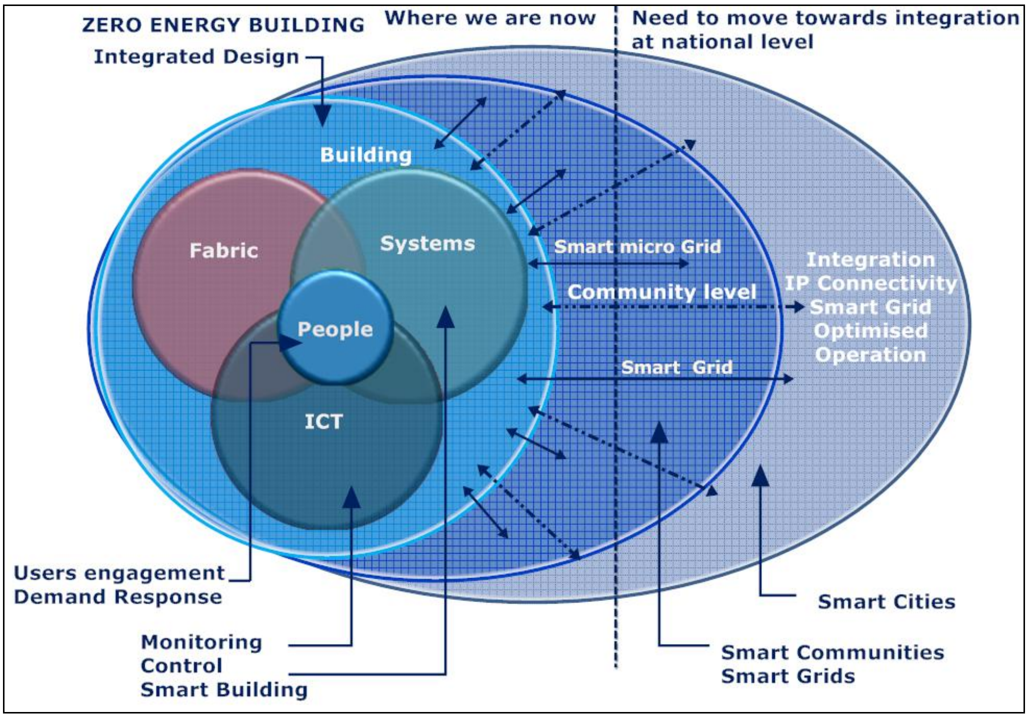

Figure 2 The methodological approach of smart technologies

Phase 1: Zero Energy Buildings

Phase 1 starts from the users'/consumers' aspects by focusing on smart and zero energy buildings' analysis [6]. This is a mandatory requirement based on the fact that by 31 December 2020, all new buildings shall be nearly zero-energy consumption buildings. New buildings occupied and owned by public authorities shall comply with the same criteria by 31 December 2018[7], [8]. This is the core of the cycle approach.

ZEBs are buildings that work in synergy with the grid, avoiding putting additional stress on the power infrastructure [9]. Achieving a ZEB includes apart from minimizing the required energy through efficient measures and covering the minimized energy needs by adopting renewable sources, a series of optimised and well balanced operations between consumption and production coupled with successful grid integration [10].

In the framework of Phase 1 the following topics are investigated:

- *Integrated design (ID) and low energy buildings*

Since buildings are major consumers in smart grids, the integrated design task will assist to develop a collaborative method for designing buildings for smart grids. The integrated design process requires multidisciplinary collaboration, including key stakeholders and design professionals, from conception to completion. Decision-making protocols and complementary design principles must be established early in the process in order to satisfy the goals of multiple stakeholders while achieving the overall integration design objectives.

- *Smart buildings and smart technologies*

Smart buildings' operation is essential in order to assist the promotion of smart technologies. For example, smart controls and advanced monitoring for buildings' operational phase are analysed. Energy storage based control strategy development and implementation in the ZEB are implemented.

- *Zero energy buildings and integration in smart grids*

This includes the implementation of energy load predictions and outdoor conditions' predictions in order to evaluate load shaving applicability in conjunction with ID. The role of smart meters is emphasised.

Phase 2: Smart Grids Components and Zero Energy Communities

Moving from the building to the community level, the requests of the future communities are very demanding. They should be places of advanced social progress and environmental regeneration, as well as places of attraction and engines of economic growth based on a holistic integrated approach in which all aspects of sustainability are taken into account [11].
In Phase 2 research is focused on the various smart grids' [1], [2], [12], [13] components to expand the cycle by the smart grids' penetration at community and if possible at city level. EU has a long tradition of being active in the field of urban development and regeneration and has taken on a major role in supporting cities and regions in their quest for competitiveness and cohesion. European cities should be places of advanced progress and environmental regeneration, as well as places of attraction and engines of economic growth based on a holistic integrated approach in which all aspects of sustainability are taken into account. In this context smart grids offer the technological platform for fast moving towards sustainable communities by exploiting the ICT and energy systems' development in the maximum degree. Figure 3 depicts the smart grid components and their application to smart communities. More specifically the following points are investigated:

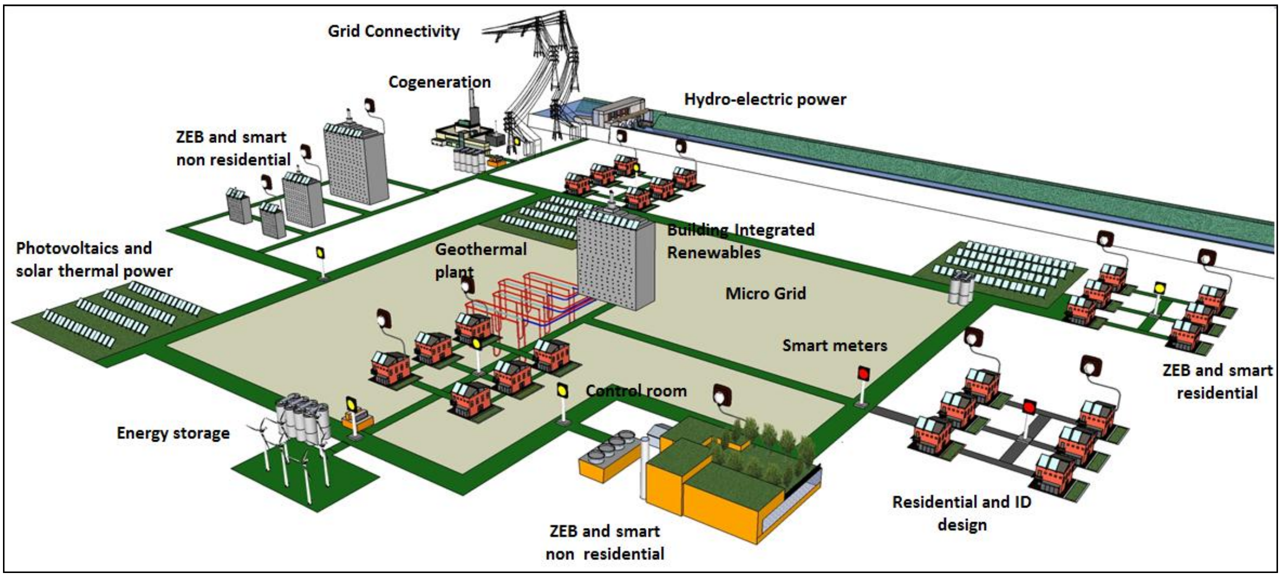

Figure 3 The smart grids components and the application to smart communities

- *The role of renewables for smart grids*

The aim of this research is to understand the sizing and positioning as well as the effective operation of renewables for smart grids. Existing renewables installations are analysed. Effective communication of the renewables operation with the smart grids is examined. Improvements via advanced control and monitoring protocols are established.

- *Cogeneration and district heating/cooling*

In this research existing knowledge concerning the cogeneration technologies and the applications of district heating and cooling for smart grids is analysed. The role of multi agents [14], [15] in smart grids and IT technology are exploited.

- *Study of existing smart grids*

The aim of the task is to analyse and monitor benefits and drawbacks of existing smart grids. Algorithms for energy management and asset management, successful exploitation of smart meters in smart grids, via mobile connectivity, as well as data mining techniques and energy predictions are developed and tested. Advanced modelling methodologies for district and community levels will be shared among the participants.

Phase 3: Integration of components

The integration of all components is performed in Phase 3 targeting to the development of smart applications and IP connectivity as well as smart grids' optimized operation. Moreover, since the smart

grids provide an excellent field for career development, funds' raising opportunities as well as development of spinoffs in collaboration with the academic institutions are exploited via the industrial partners' competences.
In this phase the following research is performed:

- *Integration of smart grids.*

This research gives the opportunity of a merging collaboration, brainstorming sessions allowing the transfer of concluding knowledge via interaction between industry and academia. Optimisation mechanisms, conflicts' management and major criteria for smart grids optimal operation will be put under the microscope for analysis and evaluation. This aims to significantly contribute to the Smart Cities concept.

- *Innovation management skills and future collaborations*

This work will become the leverage for future collaborations. The innovation management skills acquired during the previous phases will have assisted the establishment of a common language among the participants and strategic decision making for career development, investments in time and resources and further promotion of smart grids. Existing research products outlined in previous works will be followed up by innovation and entrepreneurship competence building.

Conclusions

Measures and changes in the building modus operandi can yield substantial energy savings minimizing the buildings' carbon footprint. Moreover buildings in the near future should be able to produce the amount of energy they consume, i.e. become zero or nearly zero energy buildings (ZEB). This is a mandatory requirement based on the fact that by 31 December 2020, all new buildings shall be nearly zero-energy consumption buildings. New buildings occupied and owned by public authorities shall comply with the same criteria by 31 December 2018.
Smart Grids and Integrated Design can be considered very promising for the energy and built environment industry among others due to the physical proximity between consumers and micro energy sources which can help in increasing consumer awareness towards a more rational use of energy.
Finally, smart grids can offer new opportunities for gas emissions reduction due to the creation of technical conditions that increase the connection of devices and renewable energy resources at the low voltage level.

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