

WHITE PAPER AP15

SUSTAINABLE CONSTRUCTION

EXECUTIVE SUMMARY

The concept of sustainability moves from cultural sedimentations that are differently dated and that, as a whole, express the synthesis of a social wish and a trend for which Research, in Italy, in Europe and in the world has an important role with the aim to understand the possible applications and to prepare an "intelligent" implementation. The Construction sector seems to be the core of the problem, but also the solution, representing a sector of primary importance in the context of national and European energy and environmental policies and much attention is addressed to this sector.

The activities of the Project Area, hereinafter PA, are related to the national and international context of the construction sector concerning technologies, systems, products and materials, primarily aimed at the improvement of performance levels and safety, as well as the optimization of the final use of energy. The approach, mainly experimental, is developed along two main thematic lines. On the one hand, there is the technological complexity, which concerns materials, components and systems at building scale to the city as a whole. On the other hand, the problems of new construction and those of functional and energy retrofitting of existing building stock and its enhancement are investigated.

These are all technical-scientific objectives with high added value concerning economic and social aspects that are clearly aimed at ensuring the transferability of results in terms of technological innovation. The activities are aimed at the definition of strategies, methods and tools concerning the regeneration of the city and the conscious improvement of integrated energy and environmental and therefore sustainable management of metropolitan areas. Particular attention is addressed to make the performance of buildings measurable in working conditions and in the laboratory.

The approach presents an interesting level of multidisciplinary and lends itself to contributions of specific scientific competence that DIITET is able to make available internally (e.g. sensors, advanced modelling, ICT, advanced electrical systems, etc.). Training, technical information and transfer of know-how are topics developed across all research and development activities.

The relationship with the academic world and interactions with different national and international research Institutions allows the development of activities in line with current trends.

1. STATE OF THE ART OF THE RELEVANT SCIENTIFIC AREA

Since the oil crises of the 1970's the scientific community and the worldwide governments have been involved in the debate on thermal and energy performance of buildings attempting to define new strategies for optimization. Despite efforts the subject is still of topical interest. Nowadays buildings in the EU contribute for approximately 40% of energy consumption and 36% of CO₂ emissions. About 75% of the building stock in Europe is energy inefficient and a more extensive renovation of existing buildings has the potential to lead to a reduction of EU's total energy consumption by 5-6% and a reduction of CO₂ emissions by about 5%. The revision of the 2010/31/EU Energy Performance of Buildings Directive introduces targeted amendments with the aim of accelerating a cost-effective renovation of existing buildings with the vision of a decarbonized building stock by 2050. The revision also supports the deployment of infrastructure for electrical mobility in buildings' car parks and introduces new provisions to promote the diffusion of smart technologies and technical building systems. The most recent analyses and projections highlight future scenarios in which both total primary energy consumption and CO₂ emissions are set to grow. In particular, the total energy demand is rising from an increasing number of buildings and an increase of global population is expected as well. In this scenario the main challenge is to reduce the energy consumption. For this reason the improvement of energy efficiency of buildings has become a pillar of international energy policies. In particular the overall objective is to enhance energy savings leading to reduced greenhouse gas (GHG) emissions and fossil fuel utilization. This aim is pursued by introducing constraints on building requirements in terms of properties of building components (including technological plants) and exploitation of renewable energy sources. In this context the role of nearly zero energy buildings (NZEBs) has established as the

standard reference for the target achievements in terms of balance between needs and self-sufficiency for a building under service conditions. As for electrical systems the research effort is centered on both the efficiency improvement of specific components (e.g. power electronic converters, electrical drives, etc.) and on the development of new electrical architectures for power distribution (e.g. DC-based nanogrids), suitably governed by intelligent energy management strategies. A major leap forward in the field of power electronics will be possible by the use of the new wide bandgap semiconductor devices (e.g. SiC, GaN). They have better energy performance with respect to silicon devices and are considered the cornerstone of the development of a new generation of power converter with enhanced efficiency and power density. Furthermore, as for motor drives used in building applications (water pumps, heat pumps, elevators), a viable solution to optimize their operation is the implementation of appropriate minimum-loss control techniques. As a result, a reduction in electricity consumption of users is expected. Similar considerations apply to the exploitation of renewables (e.g., photovoltaics and micro wind energy conversion systems) for supplying the building's demand; for these systems, the adoption of new maximum power point tracking (MPPT) techniques, taking advantage of Artificial Intelligence, would lead to an increase of self-production and the related cost savings. As for buildings' electrical architectures, the majority of nanogrid literature is focused on the control and hardware. In order to explore technical issues and to verify the potential returns of nanogrids (especially DC ones), the development and operation of suitable laboratory test prototypes is considered today an essential point. In addition Energy Management Systems (EMSs) have been introduced to perform optimized operations of the electrical grid infrastructure. However the EMSs proposed so far are not conceived to foster their widespread and fast adoption. Several issues are still to be tackled: EMSs should seamlessly integrate with the ecosystem of building devices and appliances; they should interfere as little as possible with the customer's comfort and habits. Moreover, the energy management algorithms should also allow achieving concurrent advantages for both the end-user and the grid operator. Due to the heterogeneity and the high volume of data involved in building management, big data analysis techniques have to be leveraged to perform a quick and secure access to data that cannot be handled with the traditional approaches of data management. This activity will make predictions available from GSE more efficient, effective and reliable by considering real time energy needs with higher precision. This will improve both offer for the energy market and an accurate purchase strategy for building managers. According to the EU Renewable Heating&Cooling (RHC) platform definition, a hybrid system is *"a system combining two or more energy sources to provide heating, cooling and hot water to buildings or industrial processes"*. Hybrid concepts represents invaluable opportunity for harnessing the full potential of the EU-renewable energy sources (RES) to cover the heating and cooling demand at building scale with a large potential of energy savings and GHG emissions reduction in the building sector. Today renewable sources can augment existing fossil systems. A new main vision to go a step beyond is the deployment of a new generation of hybrid systems combining mainly renewable energy sources, thus increasing the RES share. This objective can be pursued by the development of early-design tools, based on LCA and LCC, to be used in the field of refurbishment of buildings towards the NZEB target. A multi-disciplinary approach taking in consideration different variables and aspects usually neglected in practice will be followed. The tools' databases will also be useful for the development of guidelines for building refurbishment based on models calibrated on a large base of monitored data. In order to face energy efficiency issues, the Distributed Cogeneration can provide a partial solution; anyway their specific and infrastructural costs related to distribution and storage of produced heat are still prohibitive. In order to reduce the negative impact of this last aspect it is possible to reduce the size of these systems by bringing them closer to the final users (microcogeneration); this however leads to an inevitable reduction in electrical efficiency and to an increase of specific costs with significant difficulties in achieving the economic balance point. Moreover the modest electrical efficiency makes it very difficult to match the generation system with the needs of homes in terms of the different thermal to electrical energy ratio. The widespread knowledge of the building stock characteristics is crucial for the development of effective energy policies aimed at reducing energy consumption and GHG emissions. This led over the years to the development of a branch of research with the purpose to identify methods and tools able to characterize the urban fabric from the energy point of view, moving from the assessment of the individual building to the district and the city as a whole. This change of vision permits to plan targeted operations and to direct the resources to the most significant interventions.

2. CONTRIBUTION TO THE RELEVANT SCIENTIFIC AREA

Starting from available multidisciplinary skills, as well as previous experiences and an availability of medium-large sized equipment, the general objectives of the PA are related to different operational developments that concern a complementarity of the expected results from the different active research groups. The PA deals with the various themes of both advanced sector entrepreneurs and users, developing issues that concern preventive diagnostics, product, process and system optimization, technological and environmental quality, durability, safety, technical suitability for the use of innovative technologies, new experimental processes, correct installation and maintenance, technical information, ... In accordance with the concept of smart and sustainable cities, the topics of Horizon 2020, starting from the monitoring of the territory and the study of new methodological approaches, issues of environmental quality, reduction of energy consumption, etc., technological solutions applicable at building, microurban and urban scale are developed. At the same time advanced facilities will be developed aimed in particular at assessing the thermal and energy performance of building solutions also with integrated green and at quantifying the maintenance of facade performance under the effect of seismic action.

It is also planned the development of international interest topics related to energy efficiency and smart monitoring of buildings in accordance with the Horizon 2020 objectives, based on decades of experience gained in research groups and enriched by new emerging technologies according to an IoT approach.

The main contributions that the Project Area intends to provide can be summarised as follows:

- Tools and methodologies aimed at: a) assessing sustainability at urban scale; b) designing and verifying buildings correctly from an acoustic point of view; c) managing the processing and dissemination of technical information, including through new training profiles; d) building or retrofitting accessible and assisted environments through the use of home automation solutions integrating technologies and services within the housing ensuring greater safety for the person and the house, comfort, technical organization and communication; e) investigating seismic vulnerability; f) defining procedures for the technical management of post-seismic emergencies and for the management of repair-reconstruction activities; g) developing activities on non-destructive thermal tests aimed at the building and cultural heritage sectors; h) verifying the behaviour of buildings or parts of them under working conditions; i) defining adaptive environmental comfort requirements according to specific classes of users; l) developing new, interconnected, non-invasive and low-cost monitoring devices; m) developing new energy diagnosis tools aimed at reducing the gap between real and calculated behaviour.
- Advanced technological solutions for the optimisation of the energy and environmental performance of the building, evaluating its integration and contribution to the achievement of ZEB objectives, with particular reference to the saving of resources, wellbeing and safety of end users. A building-laboratory will be analysed in its parts (envelope, plant system and systems for the management of energy, water and data flows in order to identify its relations and the possibilities of interaction, to provide a model in which each individual element contributes to achieve the different requirements imposed by the ZEB concept.
- As far as the efficient and reliable use of electricity is concerned, advanced technological solutions will be investigated that will allow intervention at different levels from the single building to the microgrid. Furthermore, with reference to both hardware and software aspects, the following topics will be investigated: optimization of operation electric loads (powered by electronic power converters), testing of new electricity distribution patterns within the building, optimal management of energy flows including storage, use of electricity by buildings' occupants, e.g. gamification), electrical interaction between different buildings and between groups of buildings in the microgrid, supply of ancillary services to the operator of the public electricity grid.
- New infrastructures aimed at: verifying the functional-seismic resistance of facades; characterizing the growing media of green roofs defining standardization and certification procedures for regional, national and international producers; verify the performance of new technological solutions for the efficient and reliable use of electricity in the building; verify the user's engagement with respect to the conscious use of electricity and/or his interaction with automatic energy management systems.
- Construction of a family of mass production ready (TRL 7) micro-generators (named with the acronym of CogIM) from 2 kW to 30 kW of electric power, with the specific aim of integrating synergies of low-cost technologies in order to improve electric and thermal performance, to get higher reliability and reduce

sound pressure (<52 dBA). A very high electric efficiency (η_{el} up to 32%) together with a reduced final market price if compared with the state of art (lower than 1000 €/kW of electric power for the bigger plants) permit a very rapid Break Even Point of the investment. The activities considered both the design of very small plants (based on new concept internal combustion engines with a power up to 3 kW) and the transformation of automotive engines in the case of larger plants (up to 30 kWe). For small plants innovative schemes characterized by high efficiency despite of a small unit displacement and very low vibration architectures have been proposed. In case of bigger plants, small Heavy-Duty units capable of ensuring high reliability even in case of severe load factors were obtained, transforming rugged Diesel automotive engines into spark-ignition, natural gas engines (with Ultra Low Emissions). The latter are equipped with high efficient water-cooled asynchronous generators, always designed and assembled at IM together with other elements (heat exchangers, thermal/acoustic cases, etc).

- designing and implementing systems able to manage renewable energy production plants distributed on the national territory. Many buildings are nowadays more and more autonomous and can be viewed as small producers and at the same time consumer of energy. In this respect, within the PA activities it will be really useful the implementation of an innovative system for real-time prediction of the energy needs. It will exploit the latest big data technologies to manage data coming from heterogeneous sources both from a consumer and producer viewpoint. Indeed, the model and the energy source will be decoupled in order to make the system flexible and scalable thus it will be compliant to the requirements for smart cities and intelligent grids.

Due to the heterogeneity and the high volume of data, big data analysis techniques will be leveraged in order to perform a quick and secure access to data that cannot be managed with the traditional approaches of data management.

The following topics are considered:

- **Topic 1: Sustainable Constructions (ITC and ITAE)**
 - Subtopic 1.1: Energy performance certification scheme for existing residential buildings
 - Subtopic 1.2: Definition of methodologies and development of instrumentation aimed at assessing the conditions of indoor Thermohygrometric and Lighting comfort
 - Subtopic 1.3: Definition of an evaluation path for the hydraulic, thermal and energy performance of growing media of green roofs, with the aim of testing laboratory for international guidelines in the UEAtc context
 - Subtopic 1.4: Analysis and characterization of high performance buildings according to Zero Energy Building concept
 - Subtopic 1.5: Environmental retrofit of buildings according to European method "Cost optimal"
 - Subtopic 1.6: Development and characterization of innovative sustainable materials for the acoustic requalification of buildings and urban areas
 - Subtopic 1.7: Definition of special materials for sustainable constructions: development of solution with application of photocatalytic materials
 - Subtopic 1.8: Definition of load match and grid interaction indicators in Net Zero Energy Buildings
- **Topic 2: Smart Cities (ITC)**
 - Subtopic 2.1: Widespread analysis of buildings energy consumption on a large-scale (district) with "smart metering" method in order to identify the best solutions for urban regeneration
 - Subtopic 2.2: Efficient management systems of air conditioning systems at urban scale
- **Topic 3: Advanced Electrical Systems for Sustainable Buildings (INM and ITAE)**
 - Subtopic 3.1: Power electronics for building applications
 - Subtopic 3.2: Energy efficiency of electrical drives for building applications
 - Subtopic 3.3: AC and DC nanogrids/microgrids for building applications
 - Subtopic 3.4: Intelligent management of electrical energy in buildings
- **Topic 4: Hybrid systems integrating generation and storage enabling the Smart Building (ITAE and INM)**
 - Subtopic 4.1: Electrical storage enabling the Smart Building

- Subtopic 4.2: Advanced thermal storage enabling the Smart Building
- Subtopic 4.3: Development of high-efficiency generators for Smart Building
- Subtopic 4.4: Development of adsorption heat pumps for heating/cooling
- Subtopic 4.5: Development of hybrid system integrating high-efficiency generators and storages (electrical and/or thermal)
- **Topic 5: LCA, ecodesign and carbon footprint of building elements and innovative technologies enabling smart building (ITAE)**
 - Subtopic 5.1: LCA, ecodesign and carbon footprint of building elements and innovative technologies enabling smart building
 - Subtopic 5.2: Early-design tool, based on LCA and LCC, used in the field of refurbishment of buildings towards the NZEB target in a multi-disciplinary approach

3. IMPACT

The PA's research results will have direct application in industrial and regulatory fields, both at national and international levels, since active collaborations with the major technical-scientific and research organizations in the construction sector are planned. One of the PA's activities will be the development of technological solutions for design and construction of ZEB buildings. The major potentials of ZEB buildings are the reduction of energy consumption and environmental pollution, and the possibility to implement design, construction and refurbishment techniques of buildings, according to the interests of public administrations and private property owners in terms of technological innovation and sustainability. Incentive tools and energy efficiency measures are envisaged in this context. The realization of a joint laboratory for testing ZEB buildings will provide a tangible example of energy efficiency measures implementation, thus clarifying the concept of zero energy buildings, still little perceived, in spite of information and dissemination campaigns. Many long-term advantages deriving from the PA's activities can be envisaged in terms of reduction of the environmental impact of the buildings, operation costs, maintenance costs and costs related to safety and comfort enhancement. The PA aims to promote and implement the smart city paradigm. Furthermore its activities will contribute to trigger a virtuous circle that allows the creation of new markets and services; this could happen starting from the relaunch of investments, creating synergies between research institutes and the business sector. For example, the goal of creating a platform of multi-functional materials complementary to graphene and carbon nanotubes will have a strong impact on the Lombard technological fabric. The activities envisaged by the PA can therefore produce significant effects on the territorial economic development in several aspects: on the one hand the competitiveness of local businesses will increase, benefiting from the possibility of taking advantage of materials testing results and the opportunity to access a database enriched by the information gathered from the experimental campaign; on the other hand, state-of-the-art laboratories will be solidly integrated into a network of CNR institutes. The properties of the materials developed in the design are enabling to create synergies between research institutes that aim to devise models and innovative systems for reducing the energy consumption of buildings. Within the PA various collaborations are expected, mainly within the laboratory for validation and optimization of the energy-environmental performance of materials, components and casing and plant systems. Furthermore, the PA will respect the objectives of the LE2C cluster, of which ITC, ICMATE, IFN, IMATI, IRSA, ISMAC, ISTM are members. Such CNR Institutes also coordinate operational missions and working groups, providing the opportunity to create contacts with companies operating in the field of energy saving. Lastly, employment growth will be promoted, in which the impact of new high-profile professional figures and of young researchers and technicians, appears to be significant. The PA's research outcomes in the field of advanced electrical power systems for building applications are expected to be of immediate interest for electrical power system designers, and for industrial manufacturers of renewable generators, power electronics, storage systems and ICT systems. On a wider scale, a widespread adoption of nanogrid/microgrid concept is expected to produce significant social and economic benefits. They derive from the energy efficiency achievements that are inherent in the proposed power system paradigm. Such efficiency is capable of turning into cost reductions for the end-users, but also in a lower carbon footprint of the buildings and in the increase of the medium voltage grid hosting capacity. The latter, in turn, determines less need for further

conventional, carbon-based power plants. It is worth considering that the PA's activities on advanced electrical systems for buildings are located in the general strategy of the expansion of smart grids, which is largely considered a major issue in the architecture of future efficient and reliable power grids. As a matter of fact, such developments are widely supported by central agencies not only of the European Union (e.g. in the programs of Horizon 2020), but also in other countries such as the United States, Japan, China and South Korea.

In particular the research result will provide:

- *Scientific impact*, since they will produce advances in knowledge and skills in the PA sector integrating thermal, electric, economic models and increasingly advanced human behaviors. It will be possible to improve existing legislation and/or to draft new rules; in addition, collaboration between CNR, universities and national and international research institutions will be strengthened. Collaboration between CNR and industrial companies will foster new contracts for industrial research and technology transfer; finally, new laboratories will be built and pilot projects launched for field studies;
- *Social impact*, since the research and dissemination activities aim to raise awareness on both the building users with respect to sustainable purchasing and behavioral choices (reduction of consumption and GHG emissions), and on companies with respect to the compliance of present and future commercial solutions; moreover, the proposed technologies will allow an improved usability of the building by elderly or disabled persons;
- *Economic impact*, as the end user of the building will achieve significant savings while maintaining or increasing comfort levels, and, on the other hand, the impact of buildings on the public electricity grid will be reduced and consequently network operators will be able to implement simpler and more affordable procedures for the grid management; moreover, the number of national consulting and energy management companies (facility management, building management) is expected to increase significantly, with a lower involvement of international companies;
- *Industrial impact*, since the use of the proposed technological solutions implies either the need to design and manufacture new devices (e.g. the EMSs) or to redesign and manufacture existing devices (e.g. more efficient HVAC systems); moreover, the attention to user experience and to the management of significant amounts of data will always be increasing; for the aforementioned reasons, as well as in the civil-construction sector, new opportunities will also be created for companies in the electronic and IT sector;
- *Politic impact*, with reference to energy use policies (e.g. new pricing schemes, increase in the number of users participating in demand response programs), and to regional and national energy plans (e.g., increase in the share of renewable generation).

4. EMERGING RESEARCH CHALLENGES

The PA is planning to address the emerging challenges of the relevant scientific area by involving in its key activities both high-level, skilled and experienced researchers as well as new recruited young people. Participation to national and international research projects and initiatives with leading research institutions, industries and Universities is considered the main instrument for the achievement of the PA's goals. Some examples of mainly participations and collaborations of PA Institutes are as follows: European Construction Technology Platform, Cluster Tecnologici Nazionali: Fabbrica Intelligente e Tecnologie per gli Ambienti di Vita, Distretto Produttivo EDA Ecodomus, JP Smart Cities, Energy in Buildings and Communities Programme (EBC) "Energy Flexible Buildings" Annex 67, Distretto ad alta tecnologia per le costruzioni sostenibili, Rete Italiana LCA. National and international collaboration with Institutions, Universities, Ministries and companies

5. CONCLUSIONS

By contributing to about 40% of total final energy consumption and to 36% of CO₂ emissions, the construction sector is one of the most important in Europe as regards energy efficiency-related technologies and policies. The sector of buildings is one of the most complex since it encompasses several different crosscutting fields of competence (e.g., engineering, economics, societal sciences, etc.). Moreover, it is closely related to many other strategic sectors such as smart mobility, smart cities, smart appliances, etc.. Today buildings have the potential to gain a central role in the transition of EU citizens from energy consumers to energy prosumers, with growing possibilities of integrating energy savings, energy production

and energy storage technologies. For this reasons the energy efficiency achievements in the building sector are widely supported by central agencies both in European Union (e.g. in the programs of Horizon 2020) and in other countries worldwide. On such a basis, thanks to the expertise and the resources of the involved CNR Institutes (ITC, INM, ICAR, ITAE, IM), the PA will provide its contribution to meet current and future scientific and technological challenges in the field of buildings with the aim of enhancing the buildings stock in terms of both energy efficiency and renewable energy production. Specifically the PA will develop the following main topics over the next ten-year time horizon: 1. Sustainable Constructions, 2. Smart Cities, 3. Advanced Electrical Systems for Sustainable Buildings, 4. Electrical storage enabling the Smart Building, 5. LCA, ecodesign and carbon footprint of building elements and innovative technologies enabling smart building. Beneficial impacts of the PA's work are expected in terms of scientific, societal, economic, industrial and politic outcomes.

PROJECT AREA 15: SUSTAINABLE CONSTRUCTION

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