RESOURCE- AND COST-EFFECTIVE INTEGRATION OF RENEWABLES IN EXISTING HIGH-RISE BUILDINGS

Theoni Karlessi*[1], Mat Santamouris*[1], Tilmann Kuhn[2]

[1]*National and Kapodestrian University of Athens, Building of Physics - 5, University Campus, 157 84 Athens, Greece*

[2]*Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstraße 2. 79110 Freiburg, Germany*

**Corresponding author: karlessith@phys.uoa.gr*

ABSTRACT

In 2009 the regulatory framework and the business environment for the construction sector has changed significantly in order to reduce the CO2-emissions of existing and new buildings. New buildings have to be net-zero after 2020, some public buildings already after 2018. Several national Governments try to achieve a net-zero primary energy balance for the complete building stock until 2050 which is truly a grand challenge. In order to reach these goals two things have to be done:

- increase the efficiency, especially in case of existing buildings
- cover the remaining energy demand with renewable sources.

The two most challenging aspects resulting from these goals are:

- the number of buildings which have to renovated is really huge, which means that a lot of investments have to be done and which also means that much more labour for construction works is needed than currently available.
- in many cases, current processes and building components are not ready for a widespread and cost-effective implementation of energy-harvesting functionalities in the building skin.

Therefore a fundamental transformation of the construction sector is necessary in order to streamline the fragmented responsibilities and to develop business models which are attractive for third-party financing.

The main objective of the EU Cost Effective project is to convert facades of existing high-rise buildings into multifunctional, energy gaining components. This target includes new façade components, business models, technical concepts and the demonstration in two pilot buildings.

KEYWORDS

high-rise buildings, multifunctional façade components, integrated concepts

1 INTRODUCTION

The use of renewable energy in the building sector is nowadays dominated by the application of solar domestic hot water and PV systems in single-family houses. In order to significantly increase the use of renewable energy in the building sector, concepts have to be developed for large buildings. In these buildings high fractions of the energy demand can only be met with renewable energy sources, when the façade is used for energy conversion in addition to the roof. This is especially true for buildings with a small roof area compared to the floor area ("high-rise buildings") and for existing buildings which generally have a higher energy demand than new buildings. Therefore the main focus is to convert facades of existing "high-rise buildings" into multifunctional, energy gaining components. This goal can be achieved through the development of new multi-functional façade components which combine standard features and the use of renewable energy resources and the development of new business and cost models which consider the whole life cycle of a building and which incorporate the benefits from reduced running costs and greenhouse-gas emissions. The new components will in particular profit from the application of nano-structured coatings and films which will enhance their performance and durability due to antireflective, anti-soiling and seasonal shading functionality. In order to achieve a successful development and implementation of these new technologies and concepts European key actors from construction industry and energy research have been involved.

The main purpose of the actions is to reach the goals of the EC set forth for 2020 and 2050 to address climate change issues and to contribute to improve EU energy independence. In 2009 the regulatory framework and the business environment for the construction sector has changed significantly in order to reduce the CO_2-emissions of existing and new buildings. It is now officially agreed within Europe that Net-Zero-Energy buildings are the goal for the future. New buildings have to be net-zero after 2020, some public buildings already after 2018. Several national governments try to achieve a net-zero primary energy balance for the complete building stock until 2050 which is truly a grand challenge. In order to reach these goals two things have to be done: increase the efficiency, especially in case of existing buildings and cover the remaining energy demand with renewable sources. The challenges resulting from these goals are:

- the number of buildings which have to renovated is really huge, which means that a lot of investments are to be done and which also means that much more labour for construction works is needed than currently available.
- in many cases, current processes and building components are not ready for a widespread and cost-effective implementation of energy-harvesting functionalities in the building skin.

Therefore a fundamental transformation of the construction sector is necessary in order to streamline the fragmented responsibilities and to develop business models which are attractive for third-party financing (Tilmann et al.,2011) .

The main objectives include new façade components, business models, technical concepts and the demonstration in two pilot buildings. In more detail, the following items have been reached:

- a set of 5 of new façade components and systems:
  - a glazing integrated transparent solar thermal collector
  - air-heating vacuum tube collectors for façade application
  - an angle-selective transmittance BIPV-component
  - a facade integrated natural ventilation system with heat recovery
  - a solar assisted decentralized heat pump system using unglazed solar thermal collectors with plaster covering.
- developed integrated (techno-economic) concepts consisting of technical concepts and corresponding business-models for the most important categories of existing high-rise buildings in Europe (EU25). This includes also the identification of the most important categories of existing high-rise buildings.
- demonstrated the practical feasibility in two pilot buildings in Spain and Slovenia.

2 STATE OF THE ART ANALYSIS AND PROBLEM IDENTIFICATION

2.1 Statistical evaluation of high-rise buildings

Statistical information on existing and new high-rise buildings has been collected in order to determine the geographical distribution and the corresponding characteristics of high-rise buildings.

The data acquisition for the different countries is done using a variety of different sources. Where applicable, direct data from the building owners or building maintenance is included. In addition to such direct information, databases with information, e.g. from different EU research projects is used to mainly provide specific values for specific groups of buildings. National statistical and meteorological (for climatic data) organizations and EUROSTAT are evaluated. Additionally, a literature research is conducted, trying to identify relevant literature-values and a significant share of information on single buildings is taken from the "EMPORIS" database, which is commercially available from Emporis Corp. For single buildings, a total of 18.402 datasets are provided. For economic data, a total of 133 different datasets are given, for energy data, the total number of datasets amounts to 409 and for climatic data, a total of 500 datasets is listed in the database. The statistical evaluation includes the following topics:

- overall building situation and general historic trends
- technical and constructional building data including building use
- façade related building data
- energy related building data
- economic building data
- climate related building data

The majority of the investigated buildings are office use buildings. In terms of used facade material, glass facades (usually post-mullion-structures) dominate the distribution, followed by natural stone facades and concrete based facades. Metal facades and other materials are of reduced significance for high-rise buildings.
Figure , which presents the average construction costs in € / m² GFA[1], shows a clear trend of increasing construction costs for the USA and no clear patterns for Europe and China, presumably due to the limited number of data.

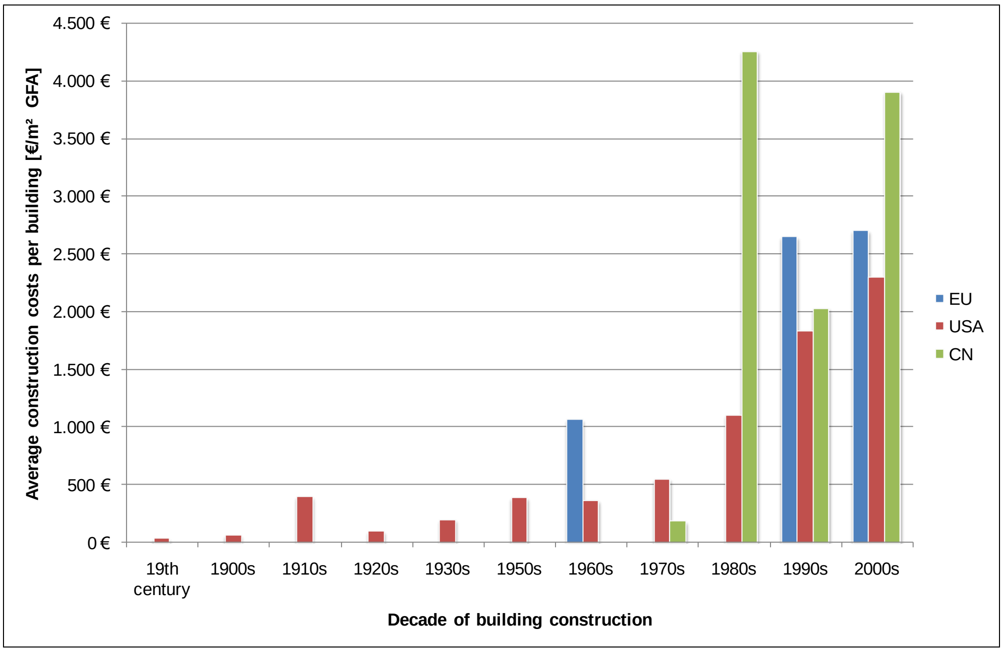

Figure 1: Average construction costs in € per m² gross floor area per decades of construction – separately given for the EU, the USA and China[2].

1 GFA = Gross Floor Area

2.2 Problems and opportunities related to the installation of low energy and renewable energy systems in high-rise buildings

The main focus of the project is to convert façades of existing "high-rise buildings" into multifunctional, energy-gaining components. The implementation of this goal requires the determination and classification of the building characteristics in order to investigate the application of innovative systems in existing high-rise buildings. The first step for the development of new multifunctional components which combine conventional and innovative low energy features is the identification of the problems and opportunities related to their installation (Synnefa et al., 2009).

Twenty two high-rise buildings with different architectural, constructive, systems and energy characteristics from Greece, Germany, Austria, Slovenia, Switzerland, France and Spain were selected for data acquisition. Figure 2 presents the transparent share of the total facade area of the investigated buildings.

Building analysis related to the installation of innovative energy systems require the consideration of building characteristics and the occupant's perception of the building conditions and controls. For this reason data acquisition from high-rise buildings was performed by the completion of two questionnaires, an extended one to be fill in by the building manager concerning building information (General Information, Building Description -Envelope-Interior Surroundings, Heating- Cooling- Ventilation System, Lighting System, Other Equipment, Building Energy Management, Indoor Conditions, Environmental Performance) and a short questionnaire for the occupants with information for indoor conditions and system controls.

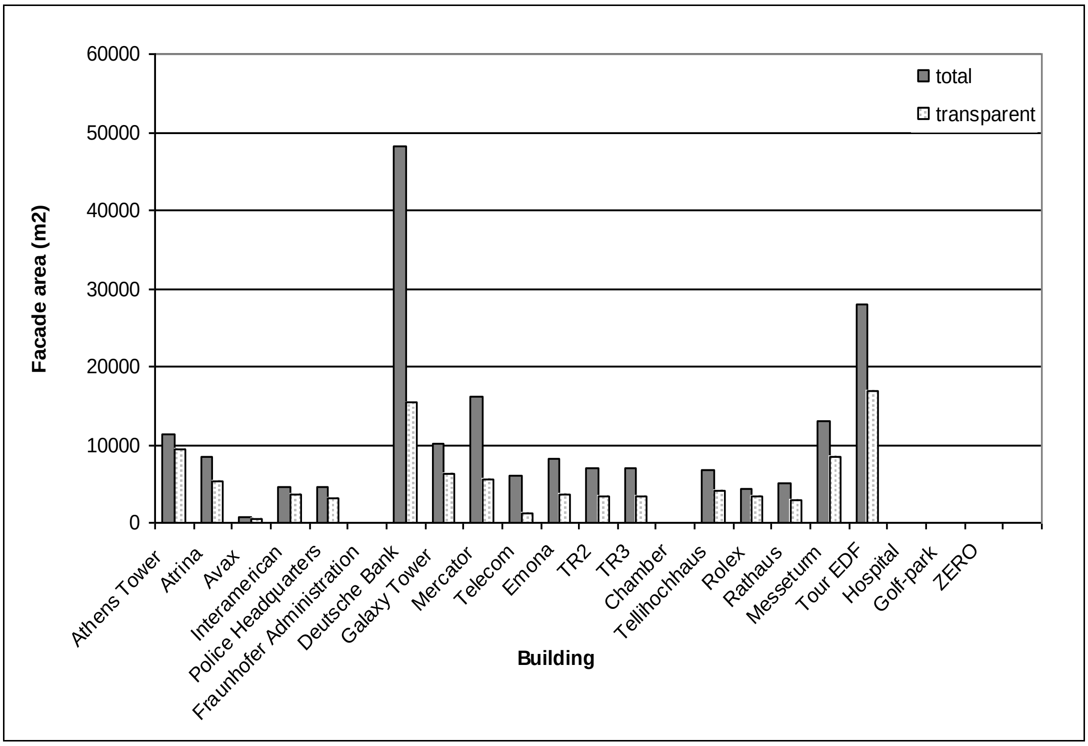

Figure 2: Façade area of the buildings and the non-opaque share

3 BUILDING PERFORMANCE CRITERIA, SPECIFICATIONS FOR INTEGRATED CONCEPTS AND CLASSIFICATION

The specifications of the various building components with regard to energy consumption reduction goals and user comfort have been defined. In addition to that various new technical concepts for whole buildings have been developed and the potential performance of the new concepts has been assessed. Finally high-rise building categories together with typical buildings for each category have been established. The categorization is essential for the development of the facade components which is the core of this assessment (Koene, F. et al., 2009).

The five main building categories identified as predominant for the existing high-rise buildings are:

- Category 1, 1945-1960 Post-war, massive facade in reinforced concrete structure
- Category 2, 1960-1980 Reinforced concrete with perforated façade
- Category 3, 1975-1990 Skeleton construction with precast concrete
- Category 4, 1975-1995 Skeleton construction with curtain-wall façade
- Category 5, 1980-2005 Tall buildings, Skeleton construction with all-glazed facade, air-conditioned.

The main constructive and facade characteristics are presented in Figure 3.

Building categories	Post-war, reinforced concrete structure with massive facade	Reinforced concrete with (precast) concrete façade	Skeleton construction with precast concrete panels (strip windows)	Skeleton construction with curtain-wall façade	Tall buildings, Skeleton construction with curtain-wall facade, air-conditioned
Image					
category	1	2	3	4	5
time line	1945-1965	1960-1980	1975-1990	1975-1995	1980-2005
main construction	reinforced concrete	reinforced concrete	reinforced concrete	reinforced concrete	reinforced concrete / steel
precast	no	possible	possible	no	no
facade	load bearing	load bearing	non bearing	non bearing	non bearing
stability	facade	facade/core	core	core	core
material facade	massive brick, brick cavity wall	brick, natural stone, stucco, ceramic tiles, glass cladding	concrete, metal cladding	metal profiles, metal cladding	metal profiles, meta cladding
glazing	single	single/double	double	double	double coated
windows	openable	openable	openable	openable/closed	closed
floor plan	lineair cell structure	lineair cell structure	core cell structure	cell/open structure	cell/open structure
air-conditioning	no	no	no	no	yes

Figure 3: Building categories and their characteristics

The five building categories are further presented with the identification of representative buildings in each category. Cost-effective partners were asked for collaboration by sending detailed information on selected high-rise buildings representing building categories. The description of the building included general information of the building size, insulation, heating/cooling and ventilation supply systems and controls, energy consumption, indoor environment quality and user satisfaction. The information gives broader insight into building categories and their relating building problems through real building examples.

4 DEVELOPMENT OF NEW MULTIFUNCTIONAL COMPONENTS

Based on the experience of the previous work which included detailed specifications and overall information on high-rise buildings, prototype multifunctional facade components have been developed (Tilmann, K.,2013).

4.1 Transparent solar thermal façade collector

Two generations of prototypes of new transparent solar thermal façade collectors (TSTC) have been developed (Fig.4). The first generation is integrated in a sealed glazing unit, the second generation is integrated in a closed cavity façade. They have been characterised with detailed measurements and concepts for their integration in whole high-rise building heating, ventilation and cooling (HVAC) concepts have been developed.

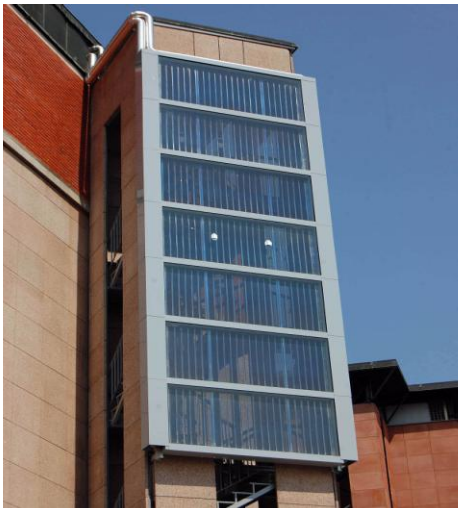

Figure 4: Prototype transparent solar thermal façade collectors, installed at the pilot building in Slovenia

4.2 Solar thermal vacuum tube collector

Prototypes of façade-integrated solar-thermal vacuum tube collectors are used to heat air directly and have been developed successfully (Fig.5). The heated air can be used directly for room heating in winter or in combination with solar heating and cooling systems. Because air is used as the heat transfer medium (simple handling of stagnation situations), easy façade integration is possible.

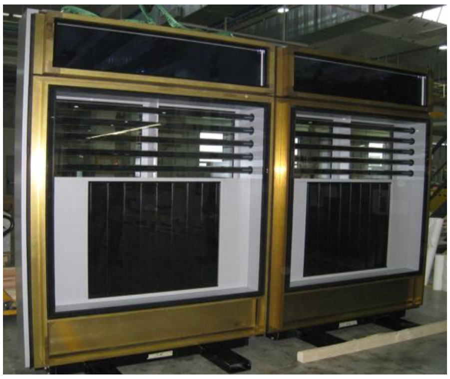

Figure 5: Air-heating vacuum tube collectors (tubes in the middle) at the international trade fair Bau 2011 in Munich.

4.3 Building integrated PV component

Prototypes of a glazing unit with integrated PV, which generates electricity and simultaneously provides solar control and glare protection have been developed successfully (Fig.6). The solar control functionality significantly reduces the energy consumption of buildings because of lower cooling loads. The generated electricity helps to cover the primary energy demand of the building itself.

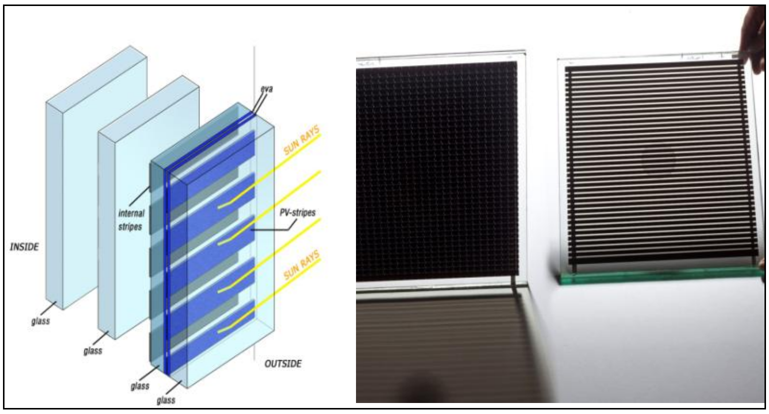

Figure 6: PVShade®

4.4 Facade integrated natural ventilation system with heat recovery

A façade-integrated natural ventilation concept with heat recovery has been developed and demonstrated successfully (Fig.7). The cost effectiveness has been improved by eliminating the supply air ducting by using decentralized supply. The concept consists of local HVAC units placed in the façade which, without air ducting or fans (no noise!), supply preheated or cooled outside air to users. The unit can be driven by low-temperature energy sources, e.g. originating from exhaust air (twin coil) or from renewable energy sources.

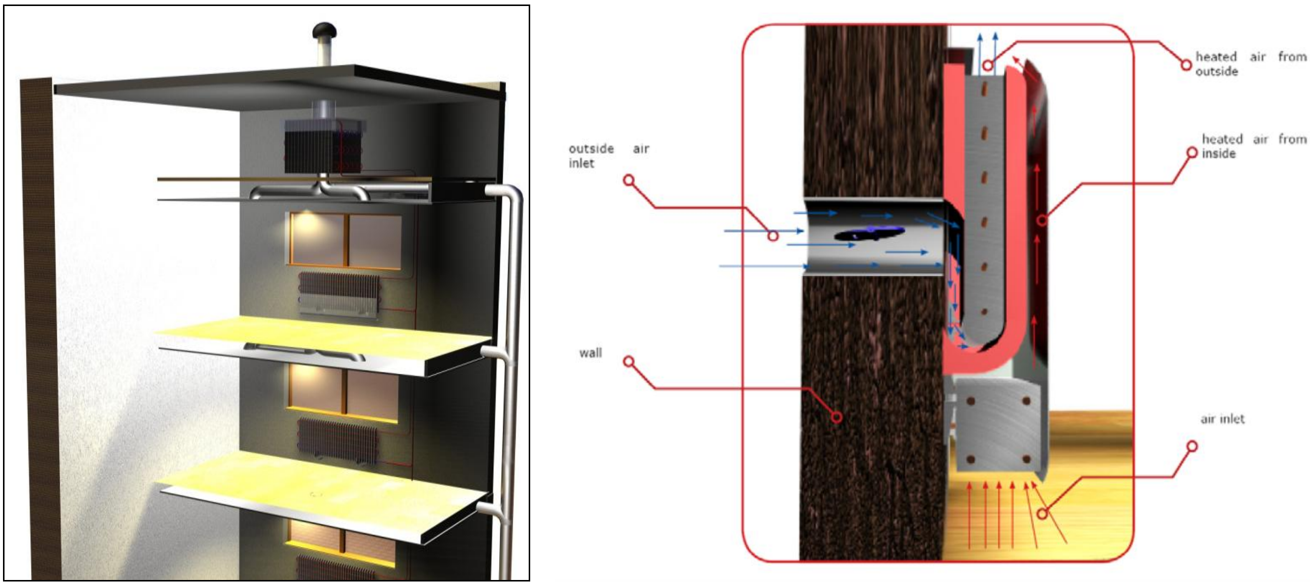

Figure 7: Natural ventilation with heat recovery. The right side shows a sill area integrated device. On the left hand side the device is integrated in the suspended floor.

4.5 Solar assisted decentralised heat pump system

A heating/cooling system for high-rise buildings using active solar façade elements to take advantage of the available unglazed vertical surface was successfully developed. The system is composed of an active solar façade coupled to a reversible heat pump. The active façade works as a low temperature solar collector as well as an atmospheric heat exchanger and a nighttime heat-dissipater in order to boost the heating/cooling efficiency of the system. The first exchanges have pointed out the technical issues and limitation such as condensation or frost formation on the façade and the need for heat storage means. Following, a number of concepts have been proposed, analysed and discussed, sometimes with the help of simulations. The concept of the active solar façade system is presented in Figure 8.

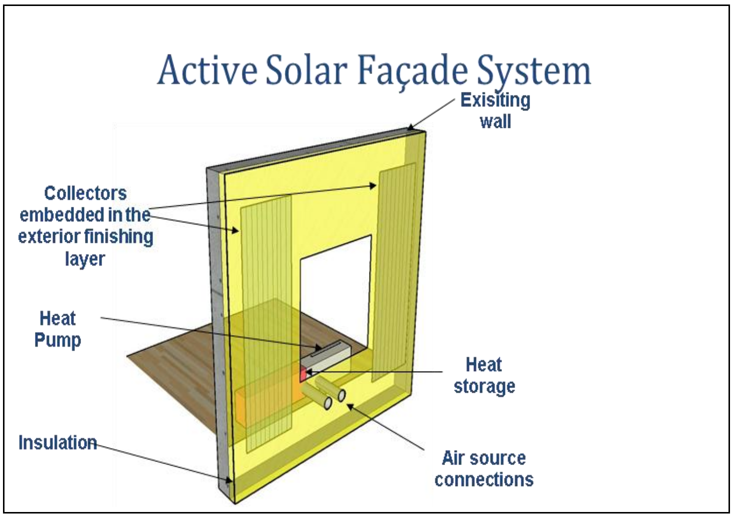

Figure 8: Unglazed collector & heat-pump

5 INTEGRATED CONCEPTS OF RENEWABLES

A number of technical renovation concepts were developed to address the high energy consumption of high rise buildings as well as address challenges in comfort and user satisfaction that are commonly encountered in these buildings. In the concepts, conventional components, such as high quality glazing, as well as novel components analyzed in the previous section are used. The economic feasibility of these concepts is also a crucial topic of the present study. The problem to be adressed is how to make it financially attractive to renovate a building in an energy efficient way, which generally is more expensive than a 'business as usual' renovation. The technical renovation concepts are taken as the starting point for a techno-economic analysis. Energy data, calculated with the building simulation software TRNSYS, and cost data of components are fed into a business model which was developed in this project (Koene, F. et al. 2012).
For each of the technical concepts, dynamic TRNSYS simulations were carried out to calculate the thermal behaviour of the building, the energy demand for heating, cooling, electricity consumption (for lighting and installation) and, when applicable, the electricity generated by photo voltaic panels.In addition, TRNSYS modules were developed to represent the novel components, such as the Active Solar Façade (ASF), the vacuum tube collector, the Transparent Solar Thermal Collector (TSTC) and the semi-transparent PV-shade modules.In addition, cost data were supplied for both conventional and novel components in the concepts. The business model developed calculates the NPV (Net Present Value) of a number of costs and revenues over a period of 15 years. The business model identifies three stakeholders: 1)

building owner, 2) building user or tenant and (optionally) 3) a third party called ESCO (Energy Service Company).

5.1 Construction aspects

A catalogue of solutions and ideas has been produced that helps the planners to integrate the new components (Pfenninger, E.,2012). In general the visual aspects are proposed by the Building Owner/Building Developer and the Architect to achieve the overall investment and maintenance cost as well as the user requirements. The technical requirements of the building envelope are driven by the optimal implementation of the architectural requirements, considering the following aspects:

- Agreed budget (investment and maintenance costs)
- User requirements (natural ventilation, glare-, darkening-, privacy-, energy aspects)
- Physical requirements (thermal-, shading-, glare-, privacy-, acoustic-, structural-, seismic-, wind load-, day light-, weather/air/vapour tightness aspects)
- Local codes/statutory requirements
- Sustainability certificates and labels such as "Leed,"Breeam" etc.
- Technical guidance and recommendations
- Industrial Standards/Quality requirements
- Safety, security and fire rating requirements
- Cleaning access
- Gain energy from the building envelope

In order to meet and comply with all the above requirements a highly successful functional and efficient building envelope shall be designed, which becomes a more and more complex task, thus requires additional input and assistance from a specialised Facade Engineer/Consultant.

5.2 Environmental aspects

This task focuses on the assessment of the environmental impacts of different integrated concepts taking into account retrofit activities for high-rise buildings of all categories and the adequate integration of new developed components. For the assessment, the whole life cycle of the concepts will be considered by taking into account:

- the manufacturing of the components,
- the building construction and retrofit measures,
- maintenance activities for components and buildings,
- the operation of the component and the building where the concepts are applied
- the End-of-Life for building and components.

Parameterized, generic LCA models are built up to assess the whole life cycle of the multifunctional components including the production, the use phase (maintenance and operation) as well as the End-of-Life phase (Lenz, K. et al. 2012). The software provides a graphical user interface where life cycle phases, production steps, maintenance activities or End-of-Life scenarios are represented by so called "plans" and "processes" which are connected by flows (e.g. material flows and energy flows) for modelling purpose.

The LCA model built up is hierarchically structured (meaning plans may consist of processes and other sub-plans), having an overall life cycle plan on the top level and detailed sub-plans for different life cycle phases on sub levels.

5.3 Architectural and aesthetical integration

The aesthetic aspects are based on slightly different façade typologies than the construction aspects. Architects might choose for the feeling or the color of a material like brick, natural stone, metal cladding, glass or wood. In general the material for high-rise are limited. The wind pressure and the difficulty in the maintenance on the higher levels ask for materials that can withstand the climate influence with less maintenance (Reijenga, T.,2012). Main typologies are:

1. Massive or cavity wall with or without openings
2. Precast element wall
3. Curtain wall

Beside this there are many hybrid façade solutions. Mainly based on additional elements like a second layer for the façade and with both aesthetic and quality improving reasons. These are:

1. Integrated systems
2. Climate façade or box windows
3. Second skin (double façade)
4. Second layers (louvers, shading)

5.4 Socio-economic aspects

Under this field, case studies have been chosen as a research tool in order to measure in detail the socio-economic aspects of the integrated concepts for cost-effective integration of renewables (Kowalska, A. et al. 2011). In order to achieve this, context and perception of Most Important Customers (MIC) (investor/owner and tenant/occupant) were investigated in terms of investing in building integrated solutions. What is more, willingness and policy of ESCO financing/co-financing of such projects was explored. The new approach to investment (elaborated within Cost-Effective) was presented to the respondents and their opinion on this issue was gathered and analysed in a further step. To explain further the rationale how the barriers of implementing building integrated renewables have been overcome, non-residential high-rise buildings in which renewables (solar/PV) are already implemented (or there is an ongoing project of implementing) were also investigated. In relation to the previous, societal acceptance of applied technology and stakeholder involvement were investigated as well as the involvement of ESCO, as an important key stakeholder for the Cost-Effective project Under the case studies the following type of respondents were interviewed:

1. Investors/owners
2. Tenant/occupant
3. ESCO (Energy Service Companies) in relevant country

5.5 Integration in building management systems

A holistic strategy has been implemented for each component, facilitating the integration procedure. This strategy includes initially an analysis of the BMS concepts, introducing the main features and functionalities of BMS system including control level, management level, service level and backbone network (Maseda, J., 2011). Independence and autonomy of management and optimization of the energy and maintenance processes are two important features of BMS design. Main commercial implementations in PLC platforms, bluetooth platforms, ZigBee platforms, PLC media and wireless media are stated. The methodology designed and implemented to interface with the technology developers is described and in parallel fundamental questions related to decision making, control and data reporting are answered through a questionnaire, highlighting the importance of the BMS integration of the components developed in the Cost-Effective project. Main topics are technology characteristics, building and BMS integrations considerations and hardware characteristics. The core contribution of the report is an in-depth analysis of the integration of the different components in a BMS. The analysis has been done as an independent process for every component as the characteristics and functionality provided is different for each one.

5.6 Development of a Decision Support Tool

This DST is a tool, containing simple guidelines to give information on energy-efficient and sustainable renovation of high rise buildings focusing on decision makers like architects and building owners (Fig.9). The tool is designed for use in the initial phase, and should inspire decision makers to implement energy efficient renovation measures (Karlessi, T., 2012). Main decisions in relation to ambitions in energy-efficiency, sustainability, economic feasibility and occupants' participation take place in the first, or the initiative phase of building renovation projects.

The DST tool provides practical and in-depth information of relevance by:

- case studies with examples and pictures of virtual and real buildings
- support for planners on how to integrate the new concepts in BMS
- best practice catalogues
- examples of business models
- test results for components
- support for design and commissioning of BMS

The tool works by defining the renovation case selecting:

- Location: Western or Southern Europe
- Building type, according to year of construction, type of building
- Preference for mainly thermal (heat) or photovoltaic (PV, electricity) energy

This will result in:

1) Example of a Cost Effective concept for each situation
2) More detailed information, to support your decisions, on:

- Economic support
- Case Studies
- Components & costs
- Other support

Figure 9: The Decision Support Tool

6 CONCLUSIONS

The main task achieved in the framework of the Cost-Effective project is the development and implementation of new and highly advanced integrated cost-effective façade concepts, based on new multifunctional components and/or new combinations of (improved) existing high-rise building envelope technologies in order to improve the primary energy balance of the building.

This goal is achieved through the development of new multi-functional façade components which combine standard features and the use of renewable energy resources and the -development of new business and cost models which consider the whole life cycle of a building and which incorporate the benefits from reduced running costs and greenhouse-gas emissions. All relevant aspects (construction, environmental, architectural and aesthetical, socio-economic) have been considered. The practical feasibility was tested in two pilot buildings in Spain and Slovenia

Thus the project contributes (1) to convert renewable energy into useful forms for specific applications and (2) to significantly improve the building energy performance through cladding and ventilation technologies and utilisation of embedded renewable energy sources. All outcomes are available at the project site http://www.cost-effective-renewables.eu

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