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PERFORMANCE MONITORING OF MULTIFUNCTIONAL FAÇADE SYSTEM FOR BUILDING RETROFITTING

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ABSTRACT

Retrofitting of external walls and building façades of residential buildings is often considered as the most energy efficient renovation measure. This paper presents a web-based tool for remote monitoring of energetical performance of a multifunctional façade system for apartment building retrofitting, the "MeeFS" system (www.meefsretrofitting.eu/). MeeFS System is an energy efficient non-intrusive concept based on multi-module pre-fabricated components that will allow integrating both active and passive technologies for façade retrofitting. The retrofitting process is based on a combination of innovative composite façade structure materials, multifunctional and easy to install panels, technological modules as well as an efficient energy management system. Every module integrated in the façade is based on particular technologies that will allow the reduction of the primary energy either by reducing energy demand of the building or by supplying energy by means of RES (Renewable Energy Sources).

Key words: Building Retrofitting, Multifunctional Façade, Energy Management, Performance Monitoring

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Introduction

Retrofitting of external walls and building facades of residential buildings is often considered as the most energy efficient renovation measure. This paper presents a web-based tool for remote monitoring of energetical performance of a multifunctional façade system for apartment building retrofitting, the "MeeFS" system [1]. MeeFS System is an energy efficient non-intrusive concept based on multi-module pre-fabricated components that will allow integrating both active and passive technologies for façade retrofitting. The retrofitting process is based on a combination of innovative composite façade structure materials, multifunctional and easy to install panels, technological modules as well as an efficient energy management system. Every module integrated in the façade is based on particular technologies that will allow the reduction of the primary energy either by reducing energy demand of the building or by supplying energy by means of RES (Renewable Energy Sources).

Multifunctional Façade System

The "MeeFS" system, energy efficient façade system for multi-family apartment building retrofitting, is being developed in the course of the MeeFS project [1], granted by EC FP7. The goal of this project [1] is the development and demonstration of an innovative solution of building façade construction providing savings in energy consumption. Studies show that the extent of such savings can reach as much as ca. 50% [2].

The proposed retrofitting façade is based on a combination of advanced active solutions with efficient passive designs and materials as well as an efficient energy management system. Every module will represent different energy efficient innovative solutions packaged into easy to install panels [3]. The system aims at industrialized production of easy to be assembled standardized panels composed of diversified technological modules, allowing personalized configurations for each façade typology, orientation and local climate conditions. Figure 1 shows the main components of the façade system:

- Lightweight and cost-effective **structural panels and an anchorage system** for fixing the structural panels to the existing façade.
- **Technological modules**, each consisting of a structural module and a technological unit (TU). Thermal insulation is incorporated in all opaque modules. All the modules integrated in the façade will implement a particular technology or flexible combinations of technologies allowing the reduction of the primary energy, or reduction of energy demand of the building, or for supplying energy by means of renewable energy sources (RES). Within the MeeFS project two innovative modules are under development: Advanced Passive Solar Protector and Energy Absorption Unit [4], and Advanced Passive Solar Collector and Ventilation Unit [4].

- **Electronic Energy Management System**: the façade integrates an electronic control system for energy management and control of all the functional components. This energy management system is the focus of this paper and is described and discussed in the following sections.

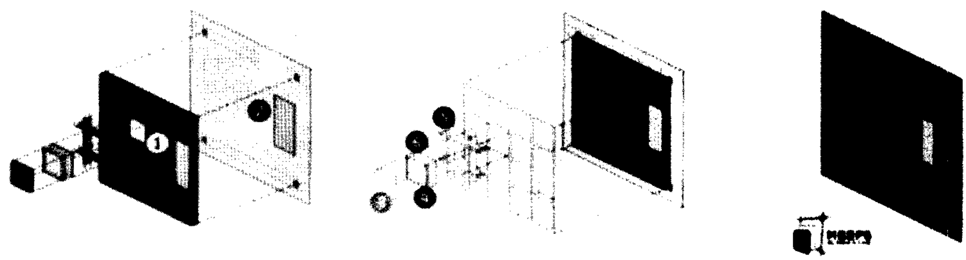

Figure 1 : MeeFS Façade System Constructive Process. 1)Multifuntional panel, 2) Exisiting façade 3) Technological unit 4) Structural module 5) Structural panel 6) Thermal insulation 2+4) Technological module 3+4+5) Multifuntional panel

Façade Energy Management System

The new façade system is intended to improve the energy efficiency of existing buildings. Accordingly, the functionalities of the technological units in the façade system are focused on reduction of energy consumption in a building for heating, cooling and domestic hot water production, as well as generation of electric energy. The façade system incorporates a versatile energy management system for the control of operation performed by the functional elements. Such composed façade system will be integrated with the building's energy system comprising various energy installations, such as HVAC, illumination, and the energy supply installations, such as BIPV or solar thermal collectors, in order to achieve optimal building energy performance balance.

The general logic structure of the façade and the architecture of the control systems are unified, although implementation of the façade will be case-specific for each building, depending on the chosen retrofitting strategies and consequent optimized combination of the different technological modules to be integrated. The system's architecture is based on several subsystems' controls that communicate to control the whole building energy system. In this approach, modularity is pursued in order to allow the control of very different buildings, both in size and type of energy system. Figure 2 shows an example of a possible general architecture for the façade control system.

The façade control system might receive inputs from;

- Module and Panel System,

- Interior sensors from target buildings, when the conditions inside the building can influence a module's operation,
- Existing Control System in the building, providing that is able to supply the appropriate data.

The façade control system might transmit outputs to:

- Control Module and Panel System,
- User Interface, if needed, as e.g. for monitoring parameters or alarms, etc.

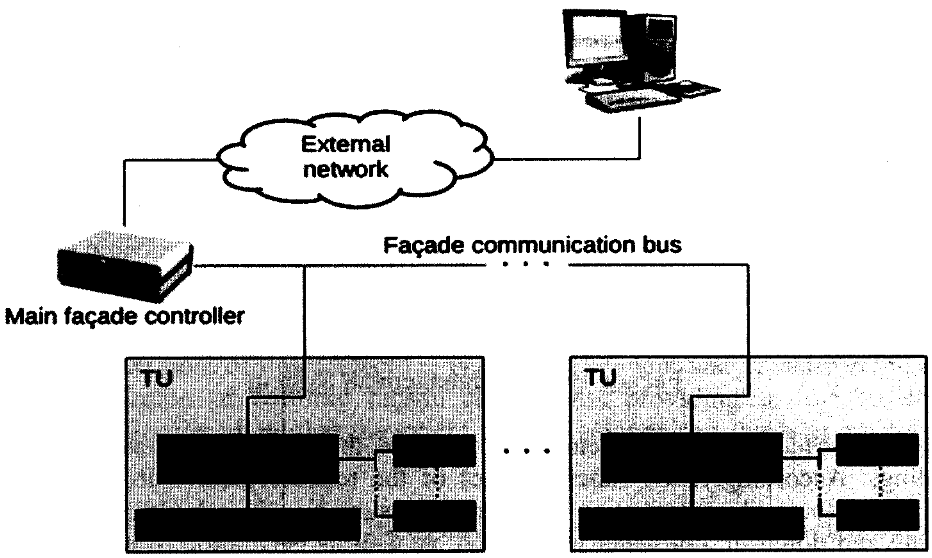

Figure 2 : Simplified schematic view of the proposed façade system monitored externally.

The Energy Management System of a façade is a network of electronic devices including: a main façade controller (responsible for generating, gathering and providing control and status data), individual TU control modules (located within TUs requiring control or providing data e.g. for other TUs or for overall monitoring) and supplementary devices (e.g. a weather station). A simple example of such system is presented schematically in Figure 2. The main façade controller can be a relatively simple industrial computer, e.g. with ARM processor, running Linux or similar operation system, provided with a common mass storage medium, e.g. SDHC card. Functionalities of TU control modules can be performed by properly designed embedded microcontroller devices. Communication within the façade can be conveniently realized by means of a robust differential communication bus, like CAN bus, which is commonly used in automotive solutions, but also e.g. in particularly demanding military applications [5]. The system can be accessed externally by a host running a specialized tool for the monitoring of the whole façade. The latter is the subject of the next sections.

Web Monitoring Tool

The web monitoring tool remotely monitors the façade energy performance and related measurement values by calculating the energy saving potentials. The tool calculates and visualizes the energy performance of the installed technological units through energy balance equations using constant indoor temperature assumption.

The tool reads MeeFS façade system measurement values using façade system's main controller's REST based web service API and calculates and visualizes the energy performance of the installed technological units. It has both façade and TU level functions.

The available functions at façade level are:

- Show façade configuration (TUs colored by type),
- Show façade energy saving (TUs colored by energy saving value), x Show weather data,
- Select TU for TU level monitoring (monitoring of all TU sensors supported).

Then TU level monitoring can be started by clicking the TU in façade level user interface (Figure 3). The exact MeeFS façade system energy performance evaluation requires additional information like measured indoor temperature and measured temperature values between old façade and new retrofitting façade. These measurements are not supported by the MeeFS façade system's main controller neither web monitoring tool. For that reason, an additional extensive data acquisition system is installed in this building which continuously measures temperatures, humilities, heat transfers, internal comfort and energy consumption in several respective points as well as local weather conditions. This data will be used for validation of the web monitoring tools in terms of accuracy of its energetic performance assessments and to evaluate the performance of the façade system as a whole by comparing obtained performance to period from before the retrofitting.

U-Value Estimation

As it was already mentioned the monitoring system gathers data from respective sensors installed inside and outside the residential building. The main purpose of these measurements is to determine the change in overall building energy performance after intelligent Façade installation. Apart of this, the other point of interest is to assess how the energy performance varies locally regarding to the heterogeneous façade structure, i.e. how different types of TUs influence the local wall-façade heat transfer properties.

The heat-transfer properties are most significant in this case as they are strictly related with local heat losses, most heavily affecting local energy performance.

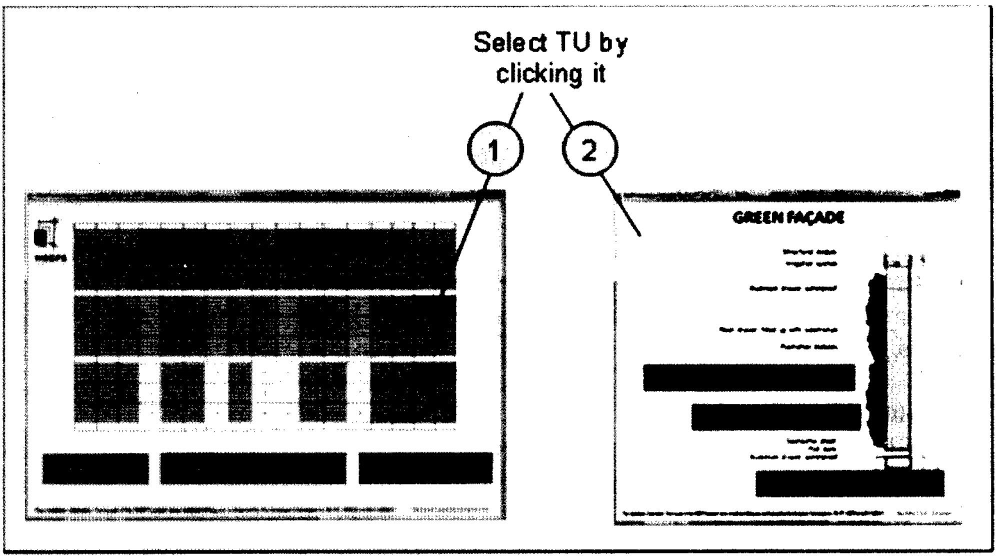

Figure 3 : Selecting the TU from Façade level user interface of the MEEFS façade web monitoring tool.

Wall-façade conductive heat-transfer properties may be represented by a single factor, i.e. the so-called *U-value* coefficient. The definition of this coefficient comes directly from the transformation of one-dimensional Fourier (conduction) heat transfer equation (1).

$$U = \frac{q}{\Delta T}\left[\frac{W}{m^2 K}\right] \quad (1)$$

From the above, the *U-value* is the ratio of the heat flux q [W] flowing through the thermal barrier in steady-state conditions when 1 [K] of temperature difference ΔT [K] is held on barrier external surfaces.

U-value may be also expressed in terms of other thermal parameters, for example the thermal resistance coefficient R or material thermal conductivity λ. Following formula (2) presents the relationship between all mentioned parameters:

$$U = \frac{1}{R} = \frac{\lambda}{L} \quad (2)$$

where L is material thickness.

For a type of thermal barrier which is composed of more than one kind of materials the *Uvalue* coefficient typically denotes the total heat transfer coefficient through that barrier. In such case the *U-value* coefficient may be calculated as the inverse of sum of the particular material thermal resistances, according to the following formula (3):

$$\mathrm{U} = \frac{1}{\sum_{i=1}^{n} R_i} \tag{3}$$

To estimate the *U-value* of a real wall (also a kind of thermal barrier) *in situ*, the long-lasting measurement of heat flux q and $\mathring{a}T$ must be taken. The long period of measurement time is necessary considering that in a real environment the temperature difference across the wall will vary with time and therefore the heat transfer steady-state will not be reached in most cases. Long-lasting measurements introduces the opportunity to average sensor readouts in time and therefore eliminate the influence of non-steady state effects. The procedure of estimating the *U-value* is normalised and may be found in ISO 9869 norm. According to this procedure the *U-value* coefficient time evolution may be computed with the following formula (4):

$$\mathrm{U}_t = \frac{\sum_0^{i=t} q_i}{\sum_0^{i=t} T_i - \sum_0^{i=t} Te_i} \tag{4}$$

where q_i, T_i, Te_i are respectively the wall (thermal barrier) heat flux, wall surface temperature on the internal and external side, all measured at the i-th time instance. The final *U-value* can be red directly from the above function *U(t)* considering that value of interest should change no more than +/- 5% for at least 3 consecutive days. From the practical point of view, the measurements should be done in conditions such that the daily average temperature differences reach at least ~10 degrees of Celsius. Also the time interval between subsequent time instants should be not greater than 1 hour and a whole observation period should be not less than 14 days. Otherwise the estimate may be inaccurate.

Following the ISO 9869 procedure, the early *U-value* estimations were made for five locations on the existing façade of the residential building. The results have been summarized in Figure 4.

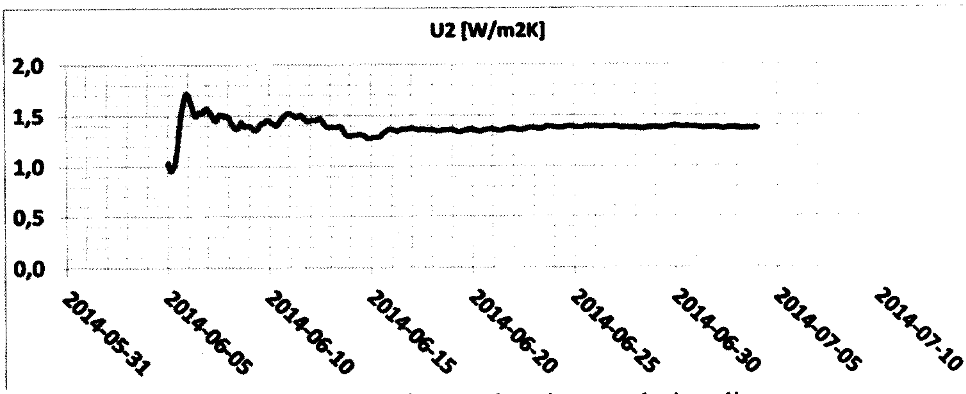

Figure 4 : The sample U-value time evolution diagram.

Conclusion

The MeeFS energy management system is well adapted for a modular facade and provides flexibility allowing to develop control modules for newly emerging TUs, as well as computing power high enough to make the system capable of handling virtually any technological solution employed in the facade, by combination of the ability to read outputs of various sensors, and process the obtained data to produce control signals for functional components of TUs. The system has been constructed in a defined way, so that further development of modules expanding its capabilities is possible while keeping compatibility with the already existing modules.

The MeeFS Façade energy management system includes web monitoring tool which make it possible to remote on-line monitoring of the façade energy performance and especially TUs related sensor values. On the other hand, the official validation of the MeeFS energy management system will be done based on the additional apartments related data acquisition system when enough data is available.

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