INTEGRATION OF AN INFRARED-BASED MONITORING SYSTEM WITH AN EIIP (ENERGY INFORMATION INTEGRATION PLATFORM) FOR INNOVATIVE EFFICIENT INDOOR ENVIRONMENT CONTROL

Enrico Sabbatini[a], PhD Candidate, e.sabbatini@univpm.it
Gian Marco Revel[a], Assistant Professor, PhD, gm.revel@univpm.it
Alvaro Sicilia[b], Eng, asicilia@salle.url.edu
Michel Böhms[c], PhD, michel.bohms@tno.nl
[a]*Università Politecnica delle Marche, Mechanical Department, Ancona, Italy.*
[b]*Universitat Ramon Llull, Escola Tècnica i Superior d'Arquitectura La Salle, Barcelona, Spain.*
[c]*Netherlands Organisation for Applied Scientific Research TNO, The Netherlands.*

ABSTRACT

An innovative thermography based measurement system for real-time estimation of thermal behaviour of a room is already developed as part of the FP7 project IntUBE. The applied approach is based on indoor measurements by an infrared (IR) camera and image post-processing to derive mean surface temperatures, thermal comfort indices, air temperature, number of occupants with the relative heat gains generated and presence of other heat sources (e.g. computers). The purpose is to provide spatially distributed room energy information in order to obtain instantaneous feedback displayed for the users or eventually for automatic HVAC control. Lumped parameter model of the room receives data from IR camera to compute exchanged heat rate and air temperature. A low-cost IR sensor, commercially available as surveillance system with automatic movement control that can provide qualitative data output, has been upgraded with a new interface to achieve quantitative data. The paper describes the integration of energy information related to the developed monitoring device (e.g. *PMV* - Predictive Mean Vote, *PPD* - Predicted Percentage Dissatisfied, room air temperature as output, humidity value from external sensor as input) within the IntUBE Energy Information Integration Platform (EIIP). The key aspect of the platform is smartness or "semantics": ICT applications will communicate via this integration platform on the basis of semantic building objects. Performance Information Model (PIM) server stores data regarding the actual monitored performances of a building (energy, temperature, humidity, *PMV* etc.). These operational data together with the actual weather data can be used e.g. to compare actual performances with simulated performances and can lead to corrective actions. The paper demonstrates that an advanced monitoring/control system (as the IR-based one) can benefit from retrieving data from the EIIP through SPARQL queries, thus activating new functionalities with interoperability guaranteed by the Platform semantics.

Keywords: Thermography, Thermal comfort, Integration Platform, Interoperability, Semantics.

1. INTRODUCTION

A number of Intelligent Building Management Systems (IBMS) suited for residential and office buildings already exists in the market (Dounis et al. 2009). In most cases, typical BMS can allow dedicated remote monitoring and control via a web interface through a particular central unit ready to be remotely controlled or with a supplementary device communicating with sensors and actuators on the local dedicated networks (Grindvoll et al, to be published). Integration of third party and custom applications with diverse system architectures and networks is very difficult at this moment. Remote energy management, electrical, mechanical and automation services, in the case of multi site, multi building solutions, implies, for companies involved in providing these types of services, specific knowledge of different BMS using different web services. Therefore, additional software tools able to read, store and process operational data in neutral format to be available to the users are needed.

Beside this issue, at the state of the art the lack of interoperability often involves the different stages of the building lifecycle (design, energy simulation, operational, retrofit): integration of energy simulation tools and BIM (Building Information Model) tools and these applications with BMS still remain an open issue (Crosbie et al. 2010). In some cases real-time data capturing systems have been integrated with simulation model in order to optimize building control. Packham et al. (2008) have used near real-time dynamic simulation to find optimal stop and start times for HVAC and other equipment. Authors claim that applying their algorithms the energy savings achieved in a Dublin commercial building (1600m^2) was 13.7% and a similar building in London in 8.7% reduction.

The IntUBE project have developed new tools of integrating the information and communication technologies (ICTs) used in the design and operation of buildings with the aim of facilitating improvements in the energy performance of buildings, organisations and neighbourhoods.

In the IntUBE system, non-proprietary and proprietary services provide the information stored in the repositories of the Energy Information Integration Platform (EIIP) that represents the missed link between data obtained from different buildings or devices, at different stages of their life cycle.

The key aspect of EIIP is smartness or “semantics”: ICT applications communicates via this integration platform on the basis of semantic building objects (see W3C web reference), their properties and their relationships directly or indirectly (i.e. via the design stage) relevant to the energy management view in the operational stage of (existing) buildings, and their energy-related installations. The services provided by the platform support the interaction of the processes and methods required by clients. The EIIP ensures homogeneity and compatibility of the data acquired from heterogeneous sources through which the services can be performed asynchronously by different stakeholders, using a variety of tools which are external to the platform (Böhms et al. 2010).

The Energy Information Integration Platform proposed consists of three server types each one storing a different type of information: BIM (building information model), SIM (simulation data: building usage and estimated performance), PIM (actual performance data). Real-time data from sensors collected in proper ontology in the PIM server allows to capture the building dynamic behavior and use this information to improve building design, control, maintenance, and retrofit strategies. The building design models (in BIM) and their simulated performances (in SIM) can be accessed by many different types of users (e.g. designers, software developers, researchers, etc.). Comparing simulations of expected building performance with the actual building performance, measured by sensors, and presenting the data to the building occupant/manager allows to optimize building energy consumption while maintaining the thermal comfort of the buildings occupants.

As a parallel development in IntUBE project an innovative infrared thermography based measurement system for real-time estimation of human thermal comfort and heat rate exchange in a room has been conceived and developed, as preliminarily described in Revel et al. 2010. The system is based on a low-cost IR camera and a local processing unit managing image acquisition/processing and hosting a lumped parameter model for room performance estimation.

In this paper it is shown that such an application can provide benefits and generate new functionalities if integrated with an advanced repository as the EIIP. Therefore the integration of energy information related to the IR monitoring device (e.g. *PMV*, room air temperature, heat rate as output, humidity value from external sensor as input) with the EIIP is developed and described (see figure 1). Performance Information Model (PIM) server stores data regarding the actual monitored/measured performances of a building (energy, temperature, humidity, *PMV*, etc.). This operational data together with the actual weather data can be used e.g. to compare actual performances with simulated performances thus leading to corrective actions.

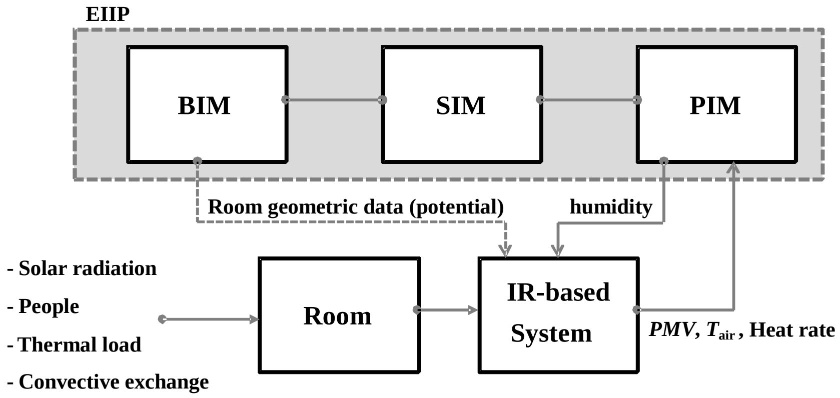

Figure 1: IR-based system data flow integrated with the EIIP architecture.

2. CONCEPT OF THE DEVELOPED THERMOGRAPHIC SYSTEM

The schematic concept of the innovative monitoring system based on infrared thermovision technique is shown in figure 2. The measurement unit consists of an uncooled Vanadium Oxide (VOx) 320 x 240 pixels focal plane array (FPA) detector from FLIR, an infrared transparent lens of 19 mm allowing 36° (H) x 27° (V) field of view, a 360° horizontal and 0° to 90° tilt rotary scanning mechanism. A lumped parameter model of the room (Fraisse et al. 2002), developed in Matlab/Simulink environment, receives in input the information extracted from image processing to compute room exchanged heat rate, air temperature and thermal comfort indices (*PMV*, *PPD*). The aim is to provide the room thermal balance information in an efficient and accurate way for energy saving purposes. Instantaneous information can be displayed for the users or eventually used for automatic or modular HVAC control, moreover thermal bridges can be detected and evaluated.

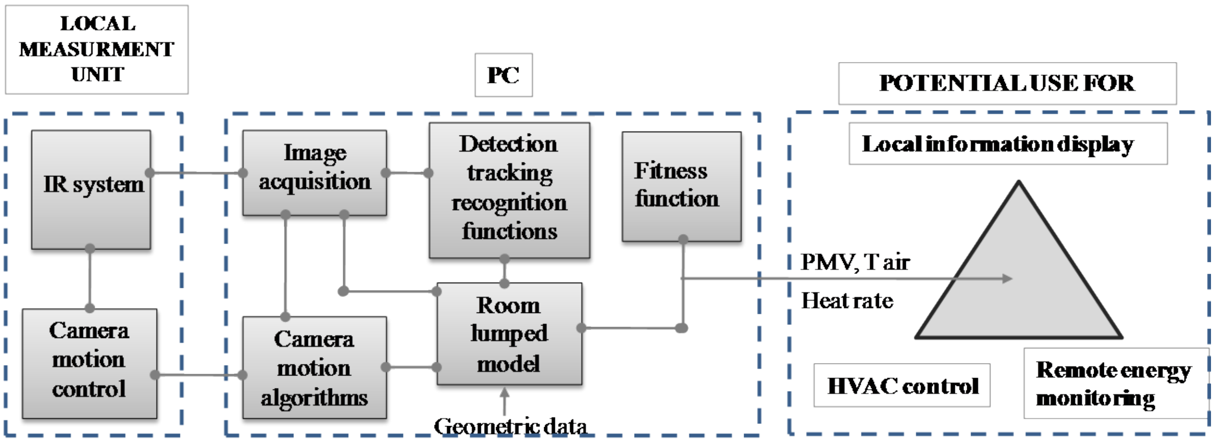

Figure 2: System components and functionalities of the IR-based system

The low-cost IR sensor here used, commercially available as surveillance system, has been upgraded by a new hardware interface: a wireless connection (to avoid cable twist in 360° pan) together with the standard calibration procedure has allowed directional radiometric measurement (Maldague 2001). The developed system has been installed in real working conditions in order to monitor an instrumented office room at Università Politecnica delle Marche in Italy (as shown in figure 3).

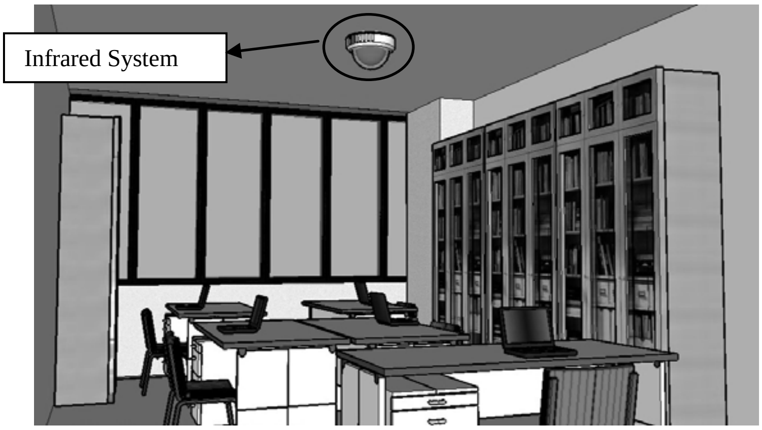

Figure 3: IR-based system installed in the office room.

The calculation is based on “near real-time” simulation developed in Simulink environment. During each time step, the lumped parameter model reads the inputs from the image processing unit, calculates the simulation results for the next time step, and writes the outputs.
The room lumped parameter model includes 5 modules: the convective heat exchange, heater, solar radiation, internal gain (PC and people), and room air volume, as Revel et al. (2010) presented in a previous work. The mathematical function of *PMV* (Predictive Mean Vote) used to evaluate comfort indices and to maintain comfortable environment is then implemented according to Standard ISO 7730:

$$PMV = f(T_{air}, RH, v, MRT, clo, met) \quad (1)$$

where T_{air} is the room air temperature, *RH* is the air relative humidity, *v* is the air velocity, *MRT* is the Mean Radiant Temperature, *clo* is the clothing value, and *met* is the metabolic rate. Based on processing infrared thermal images, T_{air} and *MRT* are estimated in the lumped parameter model and used as input to Equation (1) in which surface temperatures and view factors are dependent respectively on thermal condition of internal envelope and person position. *PMV* as well as *PPD* evaluation (as function of *PMV*, according to ISO 7730) can be achieved for one or more occupants present in the room (in this paper one human position is taken into account), considering as constant the following parameters: air velocity (0.5 m/s), clothing level (1 clo = 0.155 m^2K/W) and physical activity (1.2 met = 69.6 W/m^2). The heat generated from occupant (H_{occ}) is calculated from the heat balance between human body and the environment according with Standard ISO 7730. In order to compute accurate comfort parameters, also *RH* values are needed, which are here measured by another independent sensor and stored in the PIM of the EIIP. From the EIIP this and other information can be retrieved by SPARQL queries (see W3C web reference), as shown in the following paragraphs.

3. INTUBE ENERGY MODEL

One of the key components of the IntUBE Energy Information Integration Platform is the “IntUBE Energy Model” the set of information structures used by the different servers earlier defined and widely described in Böhms et al. 2010: BIM server, SIM server and PIM server.

At the platform level, there are two separate sides as shown on figure below: one side for the clients, another side for the servers.

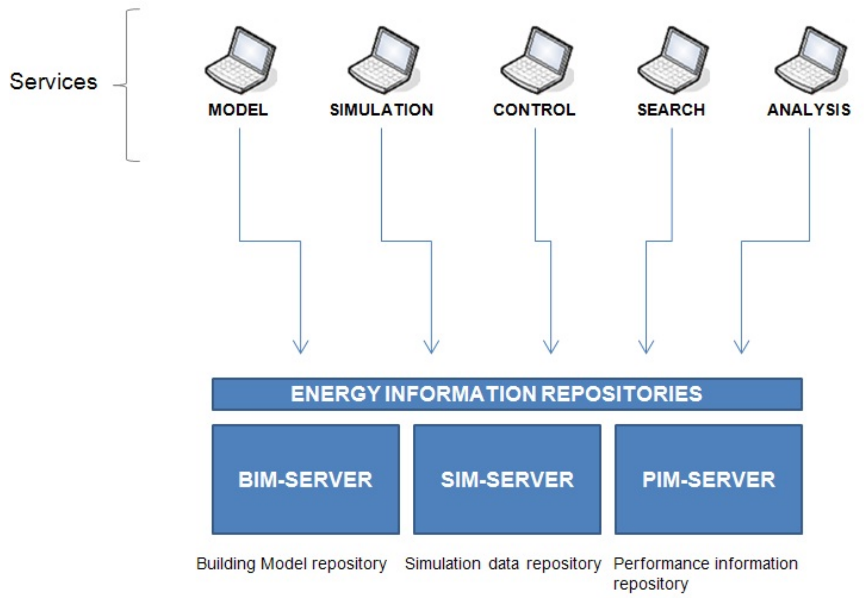

Figure 4: Energy Information Integration Platform (EIIP) concept.

The three severs of the Energy Information Integration Platform supports the following data models.

- **Building Information Model (BIM)**
  The goal of a BIM-Server is to store the building models. Construction data (materials, geometry, glazing details, HVAC components, system types, capacities etc.) are an example of “static” data that can be retrieved by a repository service.
- **Simulation Information Model (SIM)**
  The simulated building performance information is related to a specific BIM model extended with its actual usage. The results for the various analysis parameters are modelled in harmony with the PIM (so that measurements can be easily compared with the simulation results).
- **Performance Information Model (PIM)**
  Performance Information Model (PIM) server stores data regarding the actual monitored/measured performances of a building (energy, temperature, humidity, *PMV*, etc.). The PIM is in a sense the real-life counterpart of both BIM and SIM.

Following a typical three-level protocol stack as depicted in figure 5, a common semantic data structure is defined where all relevant CAD and energy-related software applications (for design, energy profiling, building automation etc.) exchange and/or share their common data. The syntax/format for both this information structure and the actual valid information instantiations has been defined using open standards. This make it possible for software applications to import and export information valid against the data structure. Furthermore, access methods is defined again in an open standards way to directly access the common information (abstracting from the actual data format decided). Finally, the Internet/WWW medium is used over which the common data can be transferred.

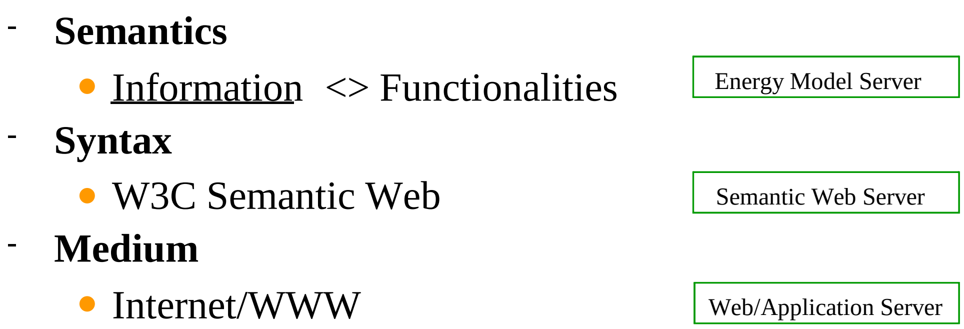

Figure 5: Three abstraction levels relevant for the Energy Model

4. SEMANTIC DATA INSTANTIATION

The three elaborated servers will share common underlying technology and respective implementations: the open and smart technology standards provided by the W3C Semantic Web Activity like RDF(S), OWL and the query language SPARQL.
In IntUBE, an interface between the commercial tool Autodesk Revit Architecture 2010 and the platform has been developed to create the BIM model. The designer application exports their BIM data to a gbXML file, then the file is mapped to an OWL format, and finally it is loaded into the BIM Joseki RDF server. This way, different designer tools with the ability to export to the gbXML format can be used in this process. The mapping process makes use of complex SPARQL queries to transform a gbOWL file into an OWL file in RDF/XML format. Static building data like geometry and construction data are retrieved from the BIM server by means of SPARQL queries and transformed into input files for the simulation engine. Furthemore, the actual actual dynamic usage (e.g. energy consumptions, air temperature, PMV) is recorded into the PIM server and are then compared to the previous corresponding simulation (in the SIM server) and can be used to further fine-tune the simulation engines (and therefore the energy efficiency strategies).
PIM Ontology is based on the Standard Network Variable Types (SNVTs) specification of LonWorks adopting properties and types of sensors and extending new ones. The ontology has been designed to allow new classes definitions. Each sensor measurement contains a quality value and a time stamp property in order to have a flexible way of gathering data. This design enables custom timestamps allowing 15minutes interval or even mixed intervals. The interoperability with monitoring platforms like OPC Server is guaranteed. In fact the IntUBE project has connected an OPC server which stores more than 20 sensors monitoring an apartment building to PIM server.
In order to test connectivity between the developed smart sensor and the Energy Information Integration Platform, a simplified PIM ontology instance of the office room monitored at Università Politecnica delle Marche has been implemented with 5 sensors. For this aim, an existing SWOP software tool was adapted (see SWOP web reference), the PMO Configurator, to make instantiation easier. This tool can read any PMO-based ontology (like the IntUBE BIM, SIM or PIM ontology or any application-specific ontology that is mapped to them) and shows to total decomposition hierarchy relevant.
The room BIM reference and the relative sensors information (location, description, measurement characteristics) are included in the ontology. The stored data (i.e. the 5 sensors, as shown figure 6) are those estimated by the lumped parameter model (T_{air}, *PMV*, *PPD*, H_{occ}) and the *RH* value.

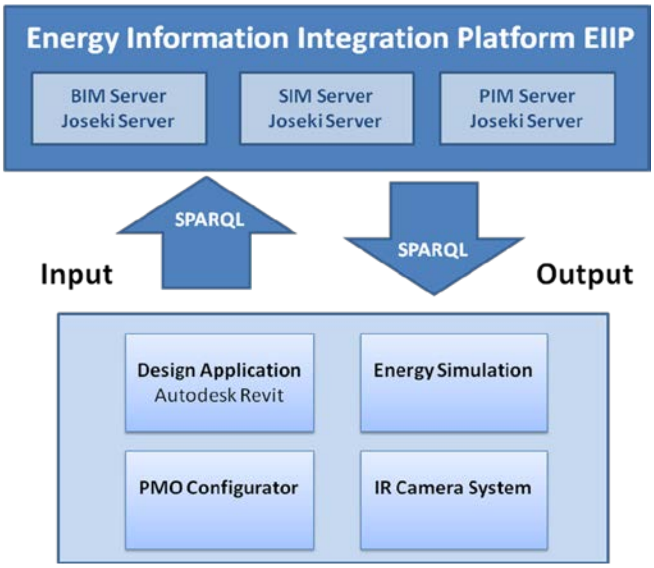

Figure 6: Energy Information Integration Platform (EIIP) data flow.

5. RESULTS

Interface between the IR system and PIM server has been carried out implementing a stand-alone application in Microsoft Visual Studio (in C# language). Measures performed through the IR system and the connected Matlab-Simulink algorithms are up-dated via available DDE (Dynamic Data Exchange) Simulink library from model of room to the PIM server using SPARQL queries. Each measurement is represented by: value, time stamp and quality. In the same time-step another SPARQL query is devoted to retrieve the last humidity value available in PIM server on a proper ontology. The relative humidity (value in %) is in fact necessary for the model to compute accurate comfort parameters *PMV* and PPD. Retrieving and storing operations, that involve bi-directional PIM server connection, are performed with a frequency of 15 minutes.

Figure 7: IR system parameters in implemented ontology instance

In order to test the server connection and validate the implemented code, remote server has been monitored by a visual interface (figure 8) implemented by the research group of “Ramon Llull University” in Barcelona, responsible of demonstration step of the IntUBE project, where real-time data flow can be retrieved.

The application in an instrumented office room at Università Politecnica delle Marche allowed accuracy estimation and functionalities improvement. Tests were carried out during typical working days, as shown in figure 9, relative to the afternoon of November 4th 2010. Transient air temperature cooling is represented and good quantitative agreement between calculated (from the lumped parameter model of the IR-based system) and measured (through thermocouple) values has been achieved. Maximum average discrepancies are in the order of 0.2°C.
Finally, it is worth noting that benefits can be achieved also from the potential connection between the IR-based monitoring system and BIM server. In fact, the room lumped parameter thermal model needs some static parameters such as geometry, material, convective heat exchange coefficients, that can be potentially retrieved from proper ontology stored in the BIM server, whilst currently they are manually inputted. The link between PIM ontology of the monitored room with the BIM ontology is guaranteed by the EIIP.

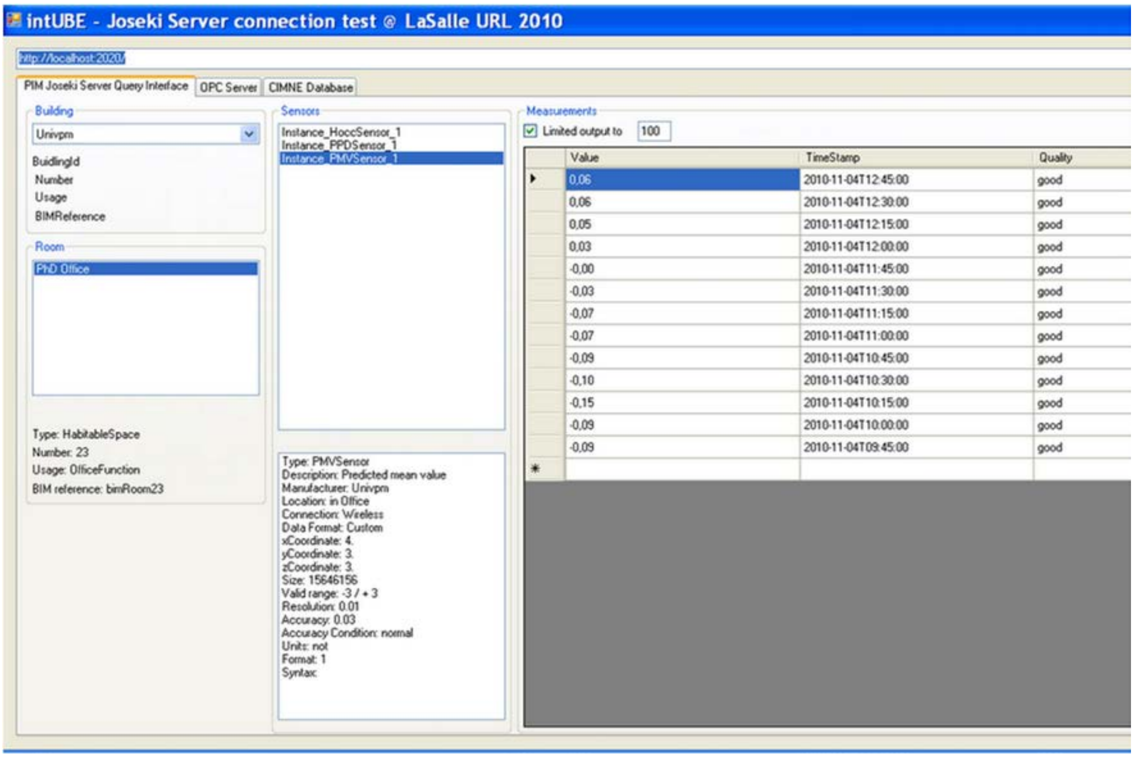

Figure 8: Visual interface for PIM server connection

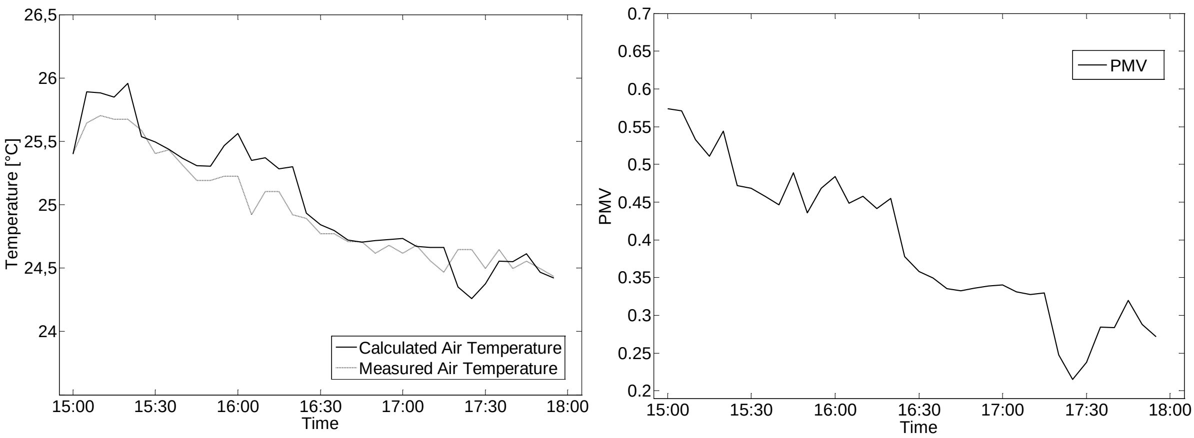

Figure 9: Air temperature comparison (left) and *PMV* of central position inside the room (right) relative to November 4th 2010 evening acquisition.

6. CONCLUSION

In this paper the integration of energy and comfort information, in input and output to the innovative IR-based monitoring device, within the IntUBE EIIP (Energy Information Integration Platform) is developed and described. The obtained results demonstrate that the IR monitoring system can in real-time exchange data from the EIIP through SPARQL queries, such as other sensor data (e.g. humidity) necessary to compute accurate comfort parameter as the *PMV*. To this aim, a PIM (Performance Information Model) ontology has been developed as a PIM operational form. This form records all results from the IR system in a efficient and accurate way.

The developed and tested system, using its advanced measurement functionalities and the communication with the EIIP, allows to measure actual building performance and to present the data to the occupant/manager in order to improve room control, maintenance and thermal comfort for the building occupants.

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