Dynamic System Architecture for Energy Efficient Building Operation: A Case Study of Kiptaş Residential Building

H.U. Gökçe, K.U. Gökçe, Donal Browne, Karsten Menzel
University College Cork, Cork, Ireland

ABSTRACT: Buildings account for almost 40 percent of total energy in Europe. Holistic monitoring and analysis methodologies can reduce this by up to 30%. However, the adoption of monitoring and control systems for building management and control applications is hampered by the unavailability of appropriate tool environments. In this paper an integrated model-driven approach that automates the design from component to application level will be presented to provide optimized building operations. The aim is to create a holistic environment for wireless embedded monitoring and control systems to increase the efficiency of the overall system development process and to exploit their potential for reduction of building energy consumption. To reach this objective, new methods, tools and equipments were researched and integration methods covering integrated design, energy simulation models and data warehouse technologies were developed. The findings were applied to a residential building of Kiptaş in Istanbul, Turkey and possible energy saving improvements were suggested.

1 INTRODUCTION

The emerging EU directives relating to energy (EU EPBD and the EU Directive on Emissions Trading) now places demands on building owners to rate the energy performance of their buildings. Each EU member state is committed to implement this directive.

Currently, energy performance rating of buildings is at best sporadic often consisting of an ad-hoc combination of off-shelf building management components distributed data metering equipment "glued together by several monitoring and targeting (M&T) software tools (Menzel et al. 2008) This ad-hoc combination presents many difficulties to building owners in the management and upgrade of these systems as the Building Management Systems (BMS) and Energy Management Systems (EMS) can consist of a number of components utilising various information exchange protocols.

The absence of BMS standardization coupled with competition for market share results in independent and non-compatible system development. BACnetTM was developed to provide an open, non-proprietary protocol specification that allows building automation controllers of different manufacturers to communicate with each other (ASHRAE 2003). However BMS / EMS still uses non-standardized proprietary interfaces.

Consequently BMS / EMS are becoming more complex over time and are difficult for the average operator to understand given the educational and experience previously outlined (Lowry 2002, Hyvrinen & Krki 1996). Additional training overhead is required for each new system or system update (Agarwal et al. 1996). In conjunction with traditional procurement policy it is conceivable that numerous systems can appear on one site (Ahern 2006), for example (Cylon 2009, Honeywell 2009, Siemens 2009). Hatley et al. (2005) states that in the absence of compatible hardware and communication protocols maintenance can become extremely problematic as seamlessly integrating these systems is an inefficient overhead.

In this regard, the prospective consequence of the building behaviour and occupant/operator needs which would manage energy consumption efficiently would not be predictable with a single combined information and communication platform. A promising approach to overcome these shortcomings is the implementation of a holistic, modular information structure.

On that basis, the integration concepts, holistic monitoring and analysis methodologies, life-cycle oriented decision support and Information and Communication Technologies (ICT) will be described in this paper. The domain specific goal is to develop an anticipating smart building approach that operates on an energy-efficient and user-friendly basis while reducing its maintenance costs.

The proposed concept is developed based on the outputs of ITOBO Research Cluster (ITOBO 2009). The ITOBO, the SFI (Science Foundation Ireland) Strategic Research Cluster for Sustainable and Optimized Building Operation, undertakes research in Information and Communication Technology that will enable us to develop a holistic, methodological framework for lifecycle oriented information management and decision support in the construction and energy management sectors.

This concept was deployed on a demonstrator building of Kiptaş in Turkey.

Kiptaş which is serving as the important company of the building sector since 1995 continues to serve for Istanbul / Turkey as being conscious of the mission it has. With the catchword of “50.000 residence to Istanbul” started to the construction with “BASAK-HILAL Collective Housing Project” on 17 May 1995 (Kiptaş 2009).

2 SYSTEM ARCHITECTURE

The objective of the proposed system is to integrate multiple dimensions of building information, such as performance data (e.g. energy consumption, temprature, light), system data (e.g. status, switch settings) and process data (e.g. inspection, maintenance, repair). This model will be implemented as an extension to international standards (e.g. IFC 2x2 ISO/PAS 16739, ISO-STEP 10303).

The system architecture depicted in figure 1 is constructed based on five scenarios. The result of the decomposition is specified in the form of UML-package diagrams. In this paper *Data Representation and Aggregation* scenario will be presented in detail and applied to a residential building block in Istanbul, Turkey. Building is recently constructed and owned by Kiptaş Company.

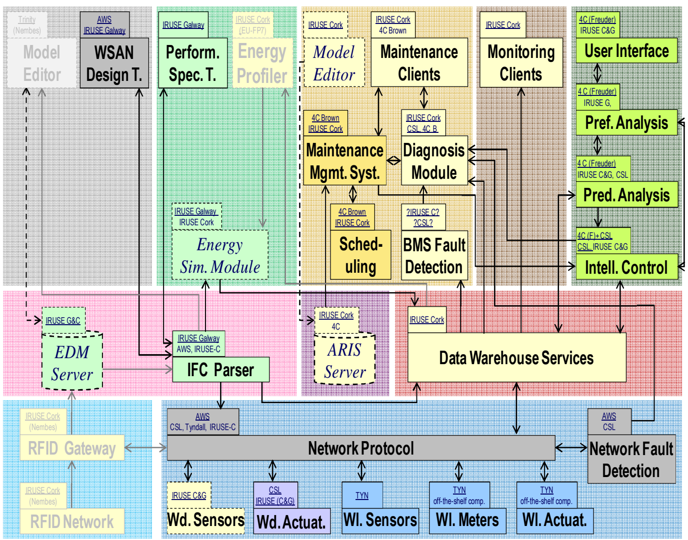

Figure 1. Proposed ITOBO Platform

2.1 *Data Representation and Aggregation*

This scenario addresses the representation of different data streams to various stakeholders (e.g. owner, operator, user/tenant) to provide useful information relating to the energy performance of their buildings. This provides improved alterations of the current conditions and lead to an intelligent control of the buildings. Data acquisition is based on the wired and wireless sensor and meter network. Compiled performance data includes (1) Energy Consumption Data (conventional and renewable sources) (2) User Comfort Data (Temperature, CO2-level, Humidity, Lux-Level), (3) Environmental Impact Data (CO2 - Footprint). Figure 2 depicts UML package diagram for Data Representation and Aggregation scenario.

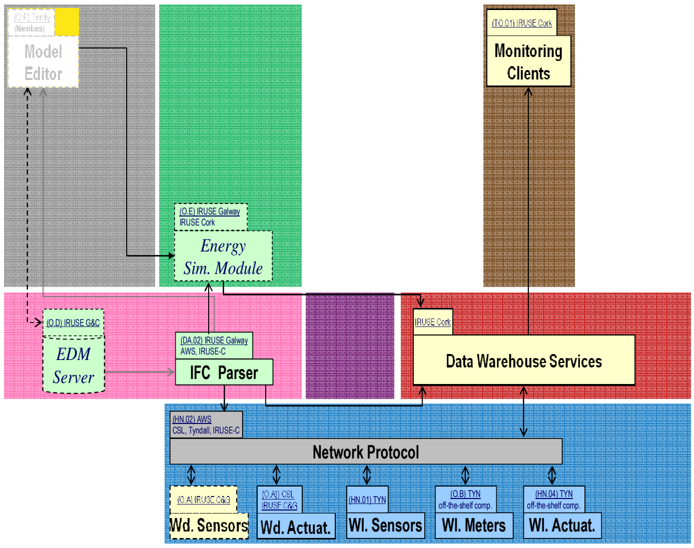

Figure 2. UML Package Diagram for Data Representation and Aggregation

There are three use cases have been defined for this scenario such as network, data warehouse operator and monitoring client use cases.

Use case 1 shows the extraction of raw data from the wireless network as depicted in Figure 3, UML sequence diagram.

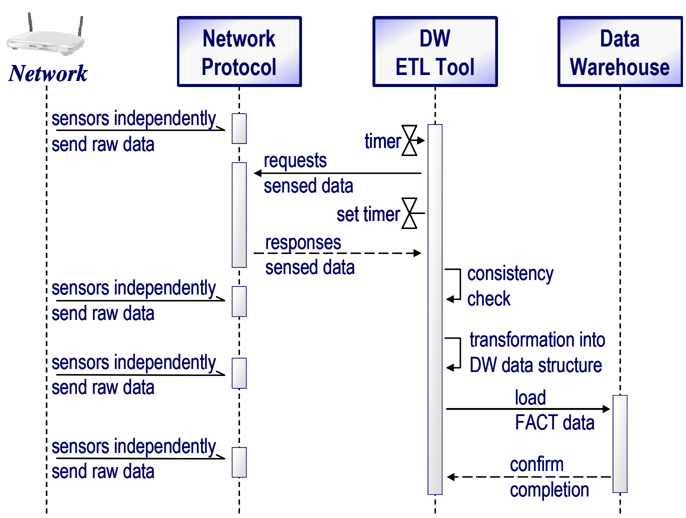

Figure 3. UML Sequence Diagram for Scenario 1: Use Case 1

Use case 2 represents the data warehouse and the BIM interaction. Data warehouse dimensional data (e.g. room information) needs to be updated on regular intervals with the data extracted from the BIM as depicted in Figure 4.

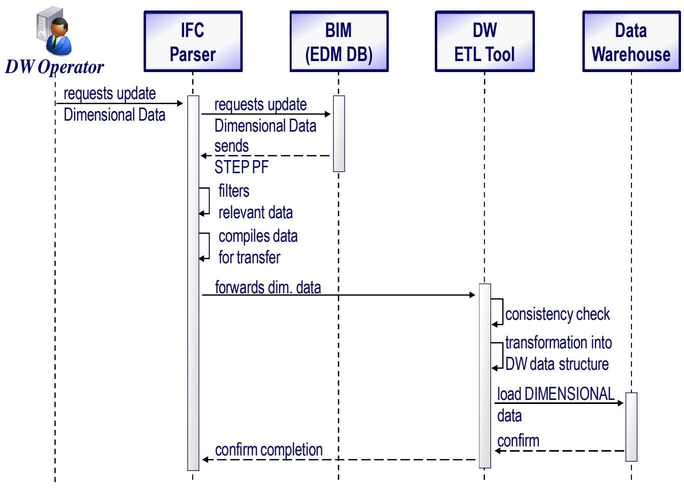

Figure 4. UML Sequence Diagram for Scenario 1: Use Case 2

Use Case 3 shown in Figure 5 addresses the owner requests for energy consumption; the interest of the building owner is to oversee the energy consumption of the overall building, as well as of individual tenants to specifically control cost and create bills. On the other hand the tenant and occupants are primarily interested in their own user comfort at their location (room/zone) and less in the energy consumption. Simultaneously, building operator compares energy consumption & user comfort as his interest is to provide a steady high level user comfort at a minimal energy consumption to increase profit.

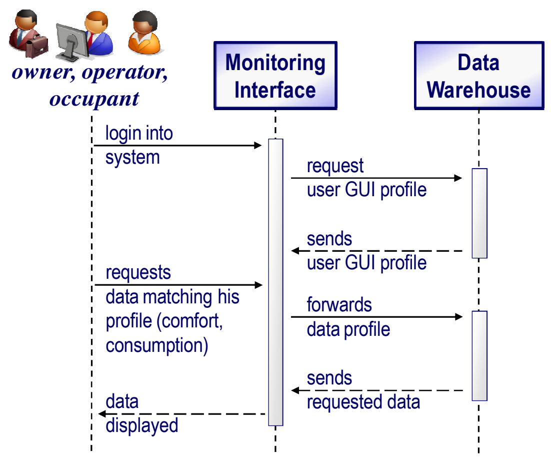

Figure 5. UML Sequence Diagram for Scenario 1: Use Case 3

2.2 *The System Components*

The complexity of the proposed platform requires different systems integration related with the scenarios and envisioned use cases. In this section, data representation and aggregation scenario components will be explained in detail.

These components are:

- Model editors
- Energy simulation models
- Data warehouse services
- Wireless systems

2.2.1 *Model Editors*

Model editor provides required information for the energy simulation module and for the data warehouse as depicted in system architecture (see figure 1) and in use case, UML sequence diagram 2 (see figure 4).

We tested different Computer Aided Design (CAD) systems and analyzed their capabilities. For this process we examined four different CAD systems namely, Autodesk Revit, Microstation, ArchiCAD and DDS-CAD. We looked at the latest offering from these four software vendors. We were not only considering the modelling of the Kiptaş building but we were also investigating the interoperability of these systems and in particular the investigation of the Industry Foundation Classes (IFC) compatibility with a view to finding a system which offers a true standard for cooperative model-based working process in our proposed platform.

As part of the proposed concept we are required to explore the Express Data Manager (EDM) server and explore its uses from a BIM perspective. In terms of IFC all CAD systems are compatible with the latest version of IFC 2x3, but DDS-CAD actively involved in the development of the latest version IFC 2x4. From interoperability perspective all CAD systems claim to offer some form of import/ export functions between systems.

In this regard, we decided to use Autodesk Revit because of its IFC compatible import/export functions. Autodesk Revit Architecture (Autodesk) is a 3-D drawing tool which can encompass all the information aspects necessary to cover the life cycle of a building. This allows for intelligent, 3D and parametric object-based design. In this way, Revit provides full bi-directional associatively. A change anywhere is a change everywhere, instantly, with no user interaction to manually update any view.

A strong point of its design is bi-directional associatively where any change made is updated automatically throughout the model. Revit MEP (Mechanical Electrical and Plumbing) is specifically for design and documentation of building services (Autodesk 2009). It combines all of the tools and capabilities of Revit Architecture with realistic and detailed building services equipment. An important feature of Revit MEP is the availability of product libraries which contain families of accurate parts and equipment, used for construction.

Five Key features of Revit MEP are as follows: (1) Building Information Modelling for MEP Engineers, (2) Sustainable Building Design and Analysis by making informed decisions earlier in the design process supported by gbXML (3) Heating and Cooling Load Analysis through IES (4) Mechanical Systems and Duct Layout Modelling with automatic sizing (5) Electrical Lighting, Wire Path Layout, and Power Circuit Layout.

2.2.2 *Energy Simulation Model*

Energy simulation model will provide measures to predict building energy performance. Also, it will enable the building operator to perform comparisons between design intent and actual performance data.

In order to perform an energy simulation on the Revit MEP model we used the provided IES plug-in.

Integrated Environmental Solutions is an energy simulation software package (IES 2009). It is broken into a number of separate tools which are purchased and licensed separately. Some of the most relevant tools are detailed below.

Model IT is the IES tool used to create the geometry for a building model. AutoCAD *.dfx drawings can be used as a template or models can be constructed from scratch using known dimensions. Alternatively a model can be imported from compatible software programmes, e.g. Google SketchUp. When importing models into IES it is necessary that the model has been constructed correctly or it will not function. Building orientation, location and weather files can also be specified with the Model IT tool.

Once a building model is created and located, the second step is usually running a *Suncast* simulation. This performs solar geometry studies both for thermal heat gains analysis and daylight analysis which is used for site orientation and solar thermal heat gains which provides useful information for glazing/shading specification. Graphical images are very useful for shaping the building geometry.

MacroFlo is a tool used where natural ventilation or mixed mode ventilation is a strategy employed in a building. It is a bulk air flow analysis tool which considers building geometry, wind patterns and internal conditions. Results can be outputted to ApacheSim for total energy analysis.

ApacheSim is the central thermal analysis tool which brings together data from other tools to compute the energy consumption of a building and a wide variety of other energy related loads. Very detailed results are produced which can shape the design of a building and the MEP services.

IES's Revit plug-in Toolbar allows Revit Architecture and MEP to import a 3D BIM model into IES's software and undertake energy and thermal analysis (IES 2009).

No model rebuild is required within IES, an interface 'Setting Model Properties' guides the user. Information is required regarding building type, construction materials, and heating and cooling system types. This information can be entered for the whole building as one set of data or at room (space) level depending on stage of design or results required. For example scheme design may allow whole building data; detailed design would likely require detailed room by room data. Once the model is established, all IES performance analysis products are accessible for the model. While the drafting and 3D modelling properties of Revit are excellent, it currently does not perform its own energy simulation. Rather it relies entirely on IES. Therefore solely from an energy simulation point of view, the use of Revit MEP cannot be justified. Its only function is to create the building geometry and properties before exporting to IES. However it is the building information properties and being the central core of a project which Revit earns it keep.

2.2.3 *Data Warehouse Services*

The objective of the project specific data warehouse core development is to provide a holistic information management system to store integrate and analyse complex data sets from multiple information sources such as model editors, energy simulation tools and performance framework specification tools as well as data streams collected from wired and wireless sensors and meters in order to analyse building performance data and to support decision making process of the stakeholders (Gökçe et al. 2009).

Figure 6 shows holistic N-dimensional information management architecture which is structured under Data Warehouse Services.

System consists of three integrated main components

- Data warehouse core
- Extraction, Transformation, Loading (ETL) Tool
- Information representation tools

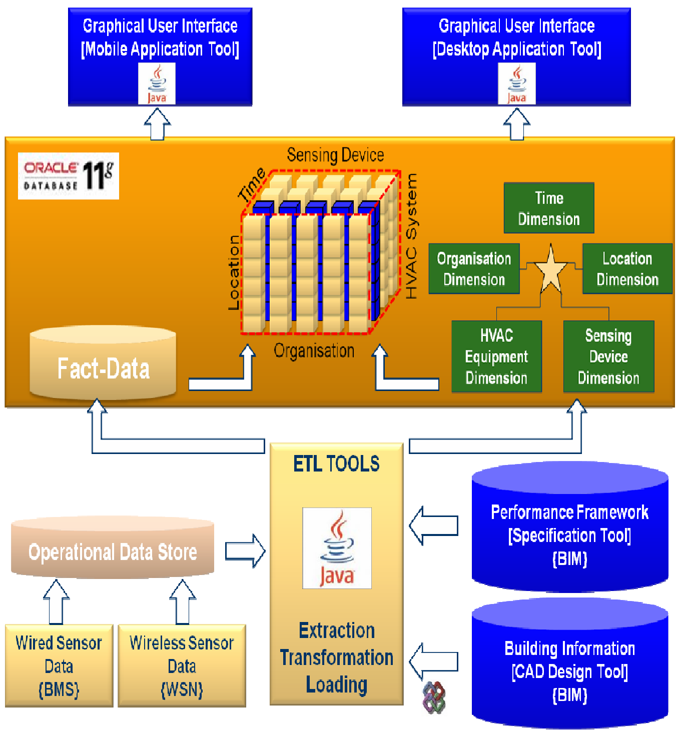

Figure 6. Holistic N-Dimensional Information Management System Architecture

Data warehouse core consist of three subcomponents. These are:

1. *Operational Data Store:* ODS is a database designed to integrate current valued subject oriented, volatile and real time data from multiple sources such as building management system, wireless sensor network and energy unit prices (Gökçe et.al. 2009).
2. *Fact Data and Dimensional Data:* This is the main repository for long term storage of dynamic data. Data collected and temporally stored in the ODS populates the fact data table.
3. *Aggregated Data:* This is the decision support level of the multi-dimensional data warehouse. Fact data become meaningful when it is associated with the dimensional data and provides the end user the means to "slice and dice" data.

Proposed system extracts wired sensor data from building management system and wireless sensor network. Collected sensor data is stored in the operational data store for data cleansing and redundancy check processes.

These pre-processed data is loaded to the fact data section of the data warehouse system via ETL (Extraction, Transformation and Loading) tool. Simultaneously, data gathered from BIM (from model editors and building simulation models) is loaded to the dimensional data section of the data warehouse. Populated fact data and dimensional data is aggregated with regards to different stakeholder requirements in the data warehouse core and presented through specific Graphical User Interfaces (GUI).

2.2.4 *Wireless System*

Wireless systems consist of wireless sensors, meters, actuators and top of them a wireless network platform. Wireless System is designed by Cylon Controls Limited (Cylon 2009). Cylon is one of the industrial partners of the ITOBO Project acting on the hardware development side for our particular hardware needs located in Dublin, Ireland.

For the Kiptaş building various Cylon wireless sensors, control units, receivers (i.e. temperature, light, presence detector sensors, wireless receivers, fan control units) are developed and deployed. The control of artificial light in building automation has a direct impact on energy saving; Light sensors can be used along with the presence detector sensors to improve the energy management, by capturing indoor/outdoor light. They can help to make decisions on if the level of natural light is sufficient to provide the full indoor illumination level required, or if an artificial light is needed (and how much artificial light is needed in case you can regulate it).

Also, appropriate levels of light measured in lux units are important in many areas of human activity such as close field work, general reading, and relaxation which can have important psychological effects.

In this case, Cylon sensor SR04P and Sensor SR04PT are deployed.

SR04P is a space temperature sensor with set point adjustment for use in bedrooms. Sensor SR04PT (see Figure 7) is a temperature sensor with set point adjustment and presence detector for use in living rooms, kitchens and circulation areas. The presence detector can be linked into the lighting system to save power when rooms are not occupied. This system is not suitable in bedrooms as lights may need to be off when spaces are occupied.

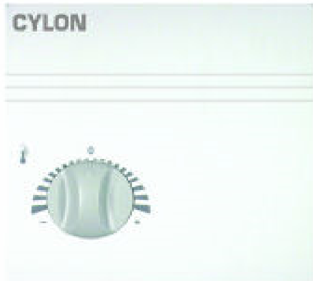

Figure 7. SR04PT Wireless Temperature Sensor with Setpoint Adjustment and Presence Detection

The sensors are battery free and gain power from an integrated solar cell. However it is possible to include a battery if ambient light conditions are not sufficient. This is likely to be necessary in the circulation space and bathrooms where there is no source of natural light and artificial lights will only be lit when rooms are occupied. Battery operating lifespan is 5 to 10 years depending on operating conditions. Sensors are best located on internal walls to minimise external influences, cold draughts in cavities, etc. The range of these sensors is certified to be 20m through 3 Brick or concrete walls.

One Wireless Receiver (Model SRCRS 485 MODBUS) is required per home. This uses MODBUD open protocol to communicate with our Data Ware-house. This facilitates future expansion of the wireless network up to a maximum 1024 no. devices without need for additional BMS outstations. This links directly to an UC32.24 controller which will process and send control signals. This controller can also control the fans to minimise its usage.

3 CASE STUDY: KIPTAŞ RESIDENTIAL BUILDING

Data representation and aggregation scenario is implemented to a residential building located in Istanbul, Turkey. The building is a social housing tower block. The same building design is to be repeated on different construction sites of Kiptaş. The building has 14 storeys including a double basement.

In order to implement the scenario following steps have been accomplished; (1) Building has been modeled with the model editor. (2) Building systems has been modeled. (3) Building energy performance has been simulated with the energy simulation tool. (4) Wireless system has been deployed. (5) Data warehouse services have been implemented. These steps will be explained in the next sections.

3.1 *Modelling the Building*

The building is modelled with Autodesk Revit Architecture (Autodesk 2009) by using the buildings drawings provided by Kiptaş (Figure 8).

Figure 8. Revit Architecture Model created from Kiptaş drawings

3D model developed with Revit Architecture is saved to the RVT file format. The building model can be exported using the IFC format to an IFC-certified application that does not use the RVT file format. The drawing can be opened and worked on in the non-native application. Similarly, in Revit Architecture you can import an IFC file, create a RVT file, and work on the building model in Revit Architecture which is essential for our structure.

3.1.1 *Modeling the Building Systems*

A completed 3D BIM model which was created using Autodesk Revit was the starting point for addition of MEP systems. The systems modelled in Revit MEP are:

- Heating
- Ventilation
- Hot and Cold mains water services
- Soils and Waste
- Gas

Although very detailed and capable of producing excellent 3D and 2D drafting drawings and produces intelligent 3D object based building models, the level of detail in Revit Architecture and Revit MEP does not contribute to the energy simulation which is done through IES.

In this case 3D model was combined with IES for a dynamic thermal simulation. This thermal simulation analyses the following properties:

- Location (for weather conditions)
- Orientation
- Building Construction including:
  (1) Structure (Slabs, exterior and interior walls)
  (2) Glazing (Exterior, interior and roof lights)

Before running any simulation a number of alterations are needed on the Revit Architecture model as detailed in the illustrations and descriptions below (see Figure 9 - 10).

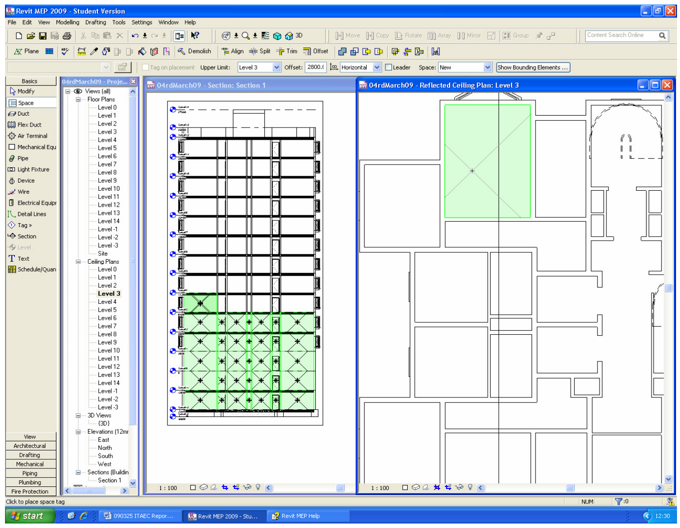

Figure 9. Creating Spaces

Although the model has been created with separate spaces visible, it is necessary to individually pin point and separate each of these spaces.

This procedure is done graphically using simultaneous windows of plan and section.

Once created, each individual volume can be renamed for location and use.

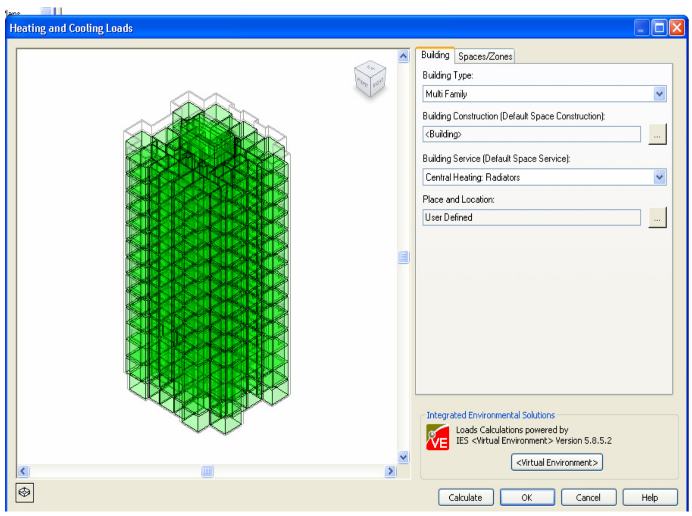

Figure 10. Setting Heating and Cooling Loads

Heating and cooling loads allows 4 variables to be altered. For this project these were set as follows:

1. Building Type set as Multi Family for separate families homes within a single building structure.
2. Building Construction opens separate window shown below (see Figure 11).
3. Building Services set as “Central Heating Radiators”.
4. Place and Location opens separate window as shown below (see Figure 11).

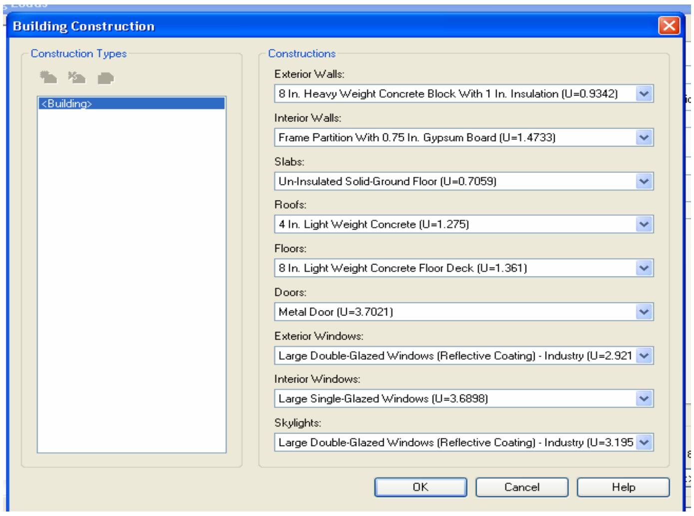

Figure 11. Setting Building Construction Settings

The Revit MEP allows 9 no. construction variables to be altered. These were chosen as follows:

1. Exterior walls were set as Heavy Weight Concrete,
2. Interior Walls set as Frame Partition with Gypsum Board,
3. Slabs set as Concrete,
4. Roofs as Light Weight Concrete,
5. Floors as Light Weight Concrete Deck,
6. Doors as Metal Doors,
7. Exterior Windows varied for different simulations see Section 3.1.2,
8. Interior windows left as default as they are not contained in this building,
9. Skylights left as default as they are not contained in this building.

The simulation and calculations for the building took approximately 4 to 5minutes.

3.1.2 *Simulation Results*

A number of simulations were performed altering different building façade properties for comparisons For example; a simulation was performed with poor quality single glazed windows with a u-value of 5.5475w/m^{2}ºC. This resulted in a total heating load of 134kW for the building or 72 w/m^2 which is a reasonable result. The second simulation performed replaced the poor quality single glazed windows with large Double Glazed Reflective windows having a u-value of 2.921 w/m^{2}ºC. This resulted in an improved total heating load of 116kW for the building or 63 w/m^2. For the building type and climate this can be considered to be a reasonable result. This also proves that the Revit/IES programme responded correctly to the improved construction.

3.1.3 *Revit/IES Simulation Conclusions*

All results provided can be considered to be reasonable and accurate. When the entire design process is taken into account, the benefits of Revit Architecture and Revit MEP are clear to see. The drafting quality and properties exceed current 3D AutoCAD software on the market; the BIM properties have huge potential to save design and construction time and the software has the potential to become the central hub of any future complex design. Moreover this integration supports a holistic framework for information management and decision support.

3.2 *Wireless System Deployment*

Wireless sensors are not currently widely utilised because of their supply cost, for example in Ireland a traditional wired sensor can be supplied and programmed for approximately €70 per point whereas a similar wireless sensor may cost approximately €100 per point. However as the technology improves and scale of manufacture increases their use will become more economical, furthermore wireless sensors reduce labour costs with less on site wiring which will add to their value. The two primary advantages of wireless sensors is ease of installation, commissioning and their easy mobility. Moreover *Wireless Embedded Monitoring and Control Systems* may easily be added to old and new buildings and enable the reduction of the energy-consumption by 5 to 30 percent (Salsbury et al. 2000, Jagemar et al. 2007, VDMA 2008).

3.2.1 *Wireless Scheme Design for Kiptaş Building*

Figure 12 shows an architectural layout for a typical floor level.

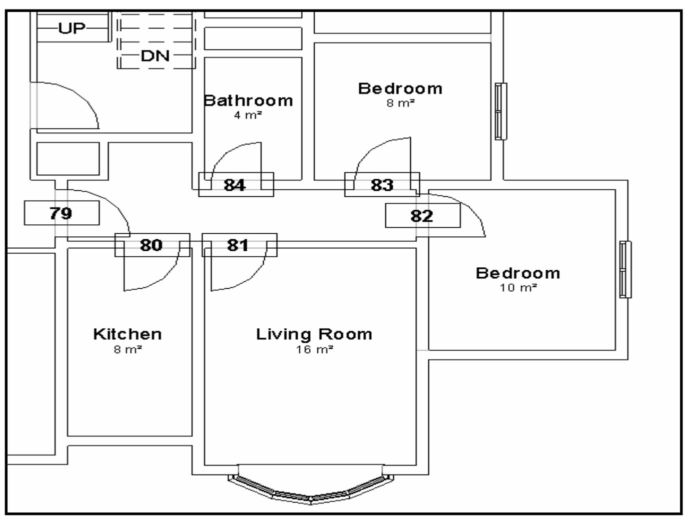

Figure 12. Typical Kiptaş Building Layout

The layout is symmetrical and each home consists of 6 no. rooms. These are circulation hallway, kitchen, living room, two bedrooms and bathroom.

Because of the repetitiveness this scheme, design has concentrated on one home only which can be repeated throughout the building.

The specific products (see Table 1) used here are manufactured by Cylon which also support Kiptaş Building requirements.

Table 1. Sensor Types and Models

Type	Model
Temperature Sensor	SR04P
Temperature Sensor	SR04PT
Wireless Receiver	SRCRS485MODBUS
Controller	UC32.24

3.2.2 *Budget Costs*

The likely installation costs for a single apartment were determined using a number of assumptions as given in Table 2.

Table 2. Wireless System Cost Allocation

Assumptions	Wireless System
Controls Supply and Commissioning	€ 4,200.00
Electrician Wiring and Installation	€ 60.00
Main Contractor Builders Works	€ 100.00
Total Cost	€ 4,360.00

This rough estimation has been made using the following assumptions;

- Irish supply of controls equipment
- Typical EU electrician labour cost of €60 for electrician & apprentice
- Builders works assuming minimal concrete disturbance

This estimation gives very general cost estimation for a single independent apartment.

Costs would be further reduced if the building was taken as a whole and controlled centrally. This would be achieved for both systems by requiring less controllers and wireless receivers.

3.2.3 *Wireless System Deployment Summary*

The wireless scheme design above provides a self contained and practical wireless control system for heating, ventilation and lighting within a residential unit.

For efficient energy management, the monitoring of buildings current energy consumption is of central importance, to identify and eliminate energy wasting processes. In extension, the implementation of an appropriate Building Control Systems permits energy saving up to 30 percent (Salsbury et al. 2000, Jagemar et al. 2007, VDMA 2008). However, this requires inexpensive, flexible and easy to handle monitoring and control technologies (Jagemar et al. 2007, Itard et al. 2008).

Wireless devices support this approach. As they communicate wirelessly and run on batteries or harvest energy from their environment (Enocean 2007), they can be easily installed without wiring, saving effort and cost (Kintner et al. 2002). This makes them a potential replacement of wired technologies as they can sense building performance data with high precision and accuracy requiring less installation cost. This flexibility makes them especially attractive for energy management in residential buildings, as they allow an easy scaling of the monitoring system size from small size system which is a necessity for residential units.

3.3 Data Warehouse Services

A data warehouse is a subject oriented, integrated, time varying, non-volatile collection of data that is used primarily in organisational decision making (Inmon, 1996).

The aim of the data warehouse services of the system is to (Gökçe et al. 2009):

1. Collect dynamic data from different sources such as wired/wireless sensors and meters.
2. Map the dynamic data with data extracted from CAD tools, energy simulation tools and performance specification tools.
3. Perform N-Dimensional data aggregation to support decision making process.
4. Provide information for building users (e.g. building owners, occupants and facility managers) to monitor their current energy consumption.
5. Provide information for preference analysis, predictive analysis and diagnosis to lead to an intelligent building control.

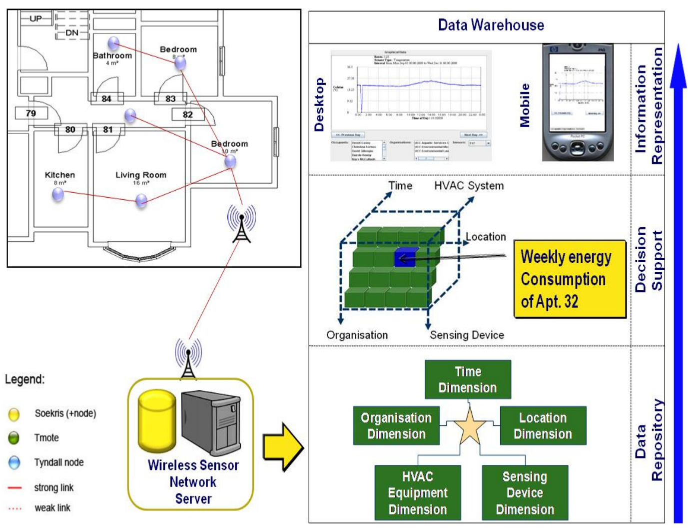

Figure 13. Implementation of Data Warehouse for Kiptaş Apartment Blocks

Figure 13 depicts the implementation scenario of Wireless Sensor Network (WSN) and data warehouse system. Data collected by the WSN server is aggregated within the data warehouse and results represented through graphical user interfaces developed for both mobile and desktop PC applications.

Figure 14 depicts a possible business scenario for monitoring and certification of the energy performance of specific apartment blocks. In this scenario data collected by the WSN and aggregated by the data warehouse system. Results are represented via touch screen monitors installed within the flats. Simultaneously, this aggregated information can be used to issue BER (Building Energy Rating) certificate.

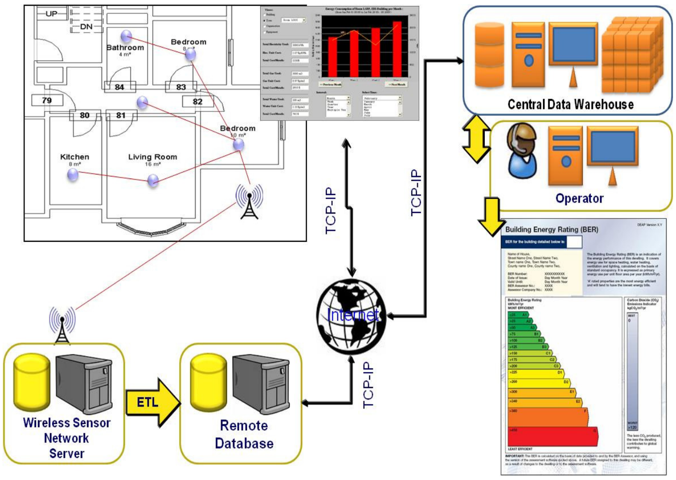

Figure 14. Kiptaş Business Scenario

4 POSSIBLE ENERGY SAVING IMPROVEMENTS

Aside from the alternative facades detailed above, the following MEP alterations could also be made to the existing design for this project with the aim of improving energy efficiency.

4.1 *Centralised Heating Plant*

The first consideration to save energy on site is implementation of district heating system with the possible inclusion of combined heat and power plant. On large mixed use developments the diversity which can be applied to heating is as low as 12-15%. For example if one home required a maximum load of 10kw heating, then 100 homes would only require 120 to 150Kw of central plant, not 1 MW. Centralised heating plant could also be implemented if there was a steady heat load, ideally this would require inclusion of a nearby hotel, swimming pool or hospital.

4.2 *Centralised Ventilation*

Centralised ventilation for building ventilation could be implemented but would likely demand too much vertical ventilation space. Ownership and maintenance issues would also become more complex in this situation unlike the self contained set-up currently designed.

4.3 *Heat recovery*

Heat recovery fans could be utilised for heating savings in winter. Air to air heat recovery devices can retain up to 75% of heat. Theses devices are not as efficient in summer because of the lower temperature difference between internal and external air.

4.4 *Rainwater Harvesting*

Implement water harvesting system, will require an additional water system and may only be feasible for upper floors due to the height to floor area ratio of the building.

4.5 *Night Purge*

The very heavy thermal mass of the building can be utilised for free cooling of buildings in summer. Night purging works by allowing cooler night air to naturally enter a space and remove heat from the building. The construction of the building is already suited to this. The system could be automated or with occupant education a free and simple method could be utilised depending on weather conditions.

4.6 *Atrium/stack effect.*

Atria are often used to take advantage of the stack effect. The stack effect takes advantage of natural convection of warm air rising but is limited to certain heights. There is no atria designed in this project and would not be economically viable in a municipality sponsored residential project. Staircases in the building could be used as natural stacks to allow heat to rise throughout the building. However this would make the upper floors too hot for comfort and is likely to cause fire separation problems.

4.7 *Solar thermal heating*

On roof and as shades on south facing facades could provide a sizable amount of hot water requirements for domestic washing and cleaning. These panels are economically viable in Ireland in the right circumstances so should also prove useful in Turkey.

4.8 *Photovoltaic*

PV could be utilised for electricity generation however these systems are very expensive and produce little useful electricity. In Ireland the capital cost of installation exceeds the useful electricity generated by the panels over their useful lifespan (Approx 20 years). However in Turkey with greater sunshine these may be feasible.

5 CONCLUSION

The European directive EPBD (Energy Performance Building Directive 2002/91/EC-2006/32/EC) and the Turkish directive ENVER (Energy Efficiency Directive 5627 18/04/2007) requires a dramatic change in the way buildings are analysed. Current building performance analysis focuses on assessment at earlier stages of building life cycle (BLC) with a deficiency in analysis at the later stages of operation and maintenance. Dynamic System Architecture for Energy Efficient Building Operation described in this research enables continuous assessment process throughout the BLC by combining the data from different sources and phases in a single data repository.

A single data warehouse processing geometrical, material, simulated and real time data provides enhanced decision making capabilities to the stakeholders.

Model editors and simulation tools with industry standardised interoperability capabilities provides a dynamic information flow for efficient building operation.

The Kiptaş case study demonstrates the potential of the proposed system. Based on initial results, it enabled continuous building energy analysis from design through building operation. Also, results lead to possible energy saving improvements.

Finally, the system maintains the basis for: improving building performance; developing intelligent control routines and implementing fault diagnosis measures.

6 REFERENCES

Agarwal, R., Prasad, J. & Zanino, M. C. 1996. Training experiences and usage intentions: a field study of a graphical user interface, *International Journal of Human-Computer Studies* 45 (2)(45), 215–241.

Ahern, M. 2006. Energy management in UCC, *Personal Communication*.

ASHRAE 2003. HVAC Systems and Equipment, *ASRAE Publications*, ASHRAE.

Autodesk 2009. www.autodesk.com. Last accessed 01/06/2009.

Cylon 2009. www.cylon.com. Last accessed on 01/06/2009

Gökçe H.U., Wang Y., Gökçe K.U., Menzel K. 2009. A DataWareHouse Architecture supporting Energy Management of Buildings, *CIB-W78 Conference Proceedings*, Istanbul, Turkey.

Hatley, D., Meador, R., Katipamula, S., Brambley, M. & LtCol. Carl Wouden, USAF, R. 2005. Energy management and control system: Desired capabilities and functionality, *Prepared for HQ Air Mobility Command (AMC/CEO) PNNL-15074, PNNL-15074*, Richland, Washington 99352.

Honeywell 2007. 'Honeywell building management systems', http://content.honeywell.com/UK/building_management_systems.html.

Hyvrinen, J. & Krki, S., eds 1996. Building Optimisation and Fault Diagnosis, System *Source Book, IEA Annex, Real Time Simulation of HVAC systems for Building Optimization, Fault detection and Diagnosis, 25.*

IES 2009. www.iesve.com. Last accessed on 15/05/2009.

Inmon, W. 1996. Building the Data Warehouse. *Second Edition, John Wiley & Sons.*

ITOBO 2009. http://zuse.ucc.ie. Last accessed 01/06/2009.

Kiptaş 2009. www.Kiptaş.com.tr. Last accessed on 15/05/2009.

Lowry, G. 2002. Modelling user acceptance of building management systems, *Automation and Construction,* 11 (6), 695–705.

Menzel K., Kean M., Keller M., O'Mathuna C., Pesch D. 2008. Toward a Wireless Sensor Platform for Energy Efficient Building Operation, *Tsinghua Science & Technology*, Volume 8, Number 1.

Siemens - APOGEE 2008. www.us.sbt.siemens.com. Last accessed on 15/05/2008.

Tyndall 2009. www.tyndall.ie. Last accessed on 01/06/2009.

Soekris board, http://www.soekris.com/, last accessed on 15/05/2009

Salsbury, T. & Diamond, R. 2000. Performance validation and energy analysis of HVAC systems using simulation. *Energy and Buildings*, vol. 32, no. 1, pp. 5 - 17

Jagemar L., Olsson D., Schmidt F. 2007. The EPBD and Continuous Commissioning, *Project Report, Building EQ, EIE/06/038/SI2 .448300*

VDMA (German Engineering Federation) 2008 Energy-efficiency of Buildings

Itard L., Meijer F., Vrins E., Hoiting H. 2008. Building Renovation and Mod-ernisation in Europe: State of the art review. Jan. 2008

EnOcean Alliance, Energy for free, White paper, 2007.

Kintner-Meyer, M., Brambley, M., Carlon, T. & Bauman, N. 2002. Wireless sensors: technology and cost-savings for commercial buildings. *2002 ACEEE Summer Study on Energy Efficiency in Buildings*