Energy Monitoring Programme for Social Housing in Ireland: Pre- and Post- Retrofitting

Derek Sinnott[1] and Mark Dyer[2]

[1]Department of Construction and Civil Engineering,
Waterford Institute of Technology, Waterford,
Ireland
[2]TrinityHaus,
Trinity College Dublin, Dublin 2,
Ireland

Email: DSinnott@wit.ie; M.Dyer@tcd.ie

Abstract:
There is a scarcity of empirical data to demonstrate the actual benefit of energy efficient retrofitting in the residential sector. The Irish official methodology for calculating the energy rating of dwellings only offers an indication of energy performance. This paper describes the methodology involved in the initial stages of an on-going longitudinal energy monitoring programme to determine actual energy savings brought about by a building retrofitting programme for social housing in Kilkenny, South East Ireland.
The bespoke system was designed to monitor whole building energy use for one year pre- and post- retrofitting. The wireless system installed in nine dwellings regularly logs indoor temperature, humidity, volatile organic compounds, gas and segregated electricity. Raw data is relayed to a data concentrator within the building and via a network to a secure database. Basic cleaning of the data is carried out prior to presentation for analysis on a secure website.
The monitoring system is designed to provide an understanding of energy consumption patterns and energy wastage in social housing. The paper explains and reviews the monitoring system employed and highlights some of the key lessons learnt during the planning and installation of equipment. Gas meters which do not have a pulse output and solid fuel use pose the largest challenge to monitor. The paper makes suggestions to researchers and industry professionals for future domestic energy monitoring systems.

Keywords:
Energy Performance, Monitoring, Longitudinal Study, Existing Dwellings.

1 Introduction

Buildings account for more than 40 % of Europe’s energy consumption, 64% of which is accounted for by the residential sector in Ireland (IEA-ECBCS, 2008; SEI, 2009). With such a large share of total consumption, improving the energy performance of buildings is key to achieving the EU objective of reducing energy consumption and greenhouse gas emissions by 20% by 2020. The EU Action Plan for Energy Efficiency states the most cost-effective means of realising these savings is in the residential sector with a potential to reduce energy use by 27% (CEC, 2006). The Irish Government is investing up to €100 million in programmes to support efficiency upgrades in older homes in an attempt to substantially reduce carbon emissions from dwellings (DCENR, 2009). The technical effects of these upgrading measures such as increasing attic and wall insulation, improving boiler efficiencies and heating controls are well understood. However, empirical evidence supported by some research suggests that observed energy demands are often higher than expected (Cayre *et al.*, 2011; Rogan and Gallachoir, 2011).

In compliance with the European Directive 2002/91/EC, Ireland has adopted the Dwelling Energy Assessment Procedure (DEAP) as the official methodology for calculating the energy performance of buildings. The DEAP calculation framework, based on IS EN 13790, is adapted for Irish conditions. DEAP draws heavily on the calculation procedures and tabulated data of the UK Standard Assessment Procedure (SAP), itself based on the BRE Domestic Energy Model (BREDEM) (BRE, 2009). DEAP calculates a monthly energy balance, but does not take account of geographical location and assumes standard occupancy, duration of heating and usage of appliances (SEI, 2008). Thus, the results are independent of household size and energy use patterns offering only an estimate of real energy use of the building. In reality such procedures are over simplified for the accurate evaluation of energy policies and the undertaking of detailed assessments, such as life cycle analysis. For research purposes there is a dearth of detailed utility and building environmental data, supported by extensive occupant information to demonstrate energy use patterns and actual benefit of energy efficient retrofitting in the residential sector. This necessitates the inclusion of socio-economic variables in addition to technical attributes in energy assessments to realistically evaluate energy policies.

To date a great deal of research use models based on notional buildings to make assertions about the effect of policy implementation on energy efficiency (Uihlein and Eder, 2010; González *et al.*, 2011) and assess various energy performance parameters relating to whole buildings energy use and related cost of upgrading (Pellegrini-Masini *et al.*, 2010; Hamilton *et al.*, 2011; Olesen and de Carli, 2011). The results of such research influences policymakers and guides them when developing targets, but have little practical research as back up. Oreszczn and Lowe (2010) highlight the fact that energy performance in the domestic sector is highly complex and in many cases poorly understood as a result of a dearth in real data on the actual performance housing, which is leading to a ‘progressive widening of the gap between theory and practice’. This supports the findings of Wingfield *et al.* (2008) and the editorial by Lomas (2010) who emphasise the value of detailed testing and monitoring across an number of research disciplines to understand building performance. Recent studies which seek to develop the long term detailed understanding of energy performance, life cycle effects and costing on building energy efficiency and increased thermal efficiency identified the lack of empirical research and real data as an impediment to making useful conclusions and adding to policy debate (Morrissey and Horne, 2011; Rogan and Gallachoir, 2011).

Drawing on the lack of real life data for whole house energy use patterns, a baseline of energy usage must first be established from which improvements and efficiencies can be measured. This paper describes the methodology for the initial stages of an on-going longitudinal energy monitoring programme to determine actual energy savings brought about by a building retrofitting programme for social housing in Kilkenny, South East Ireland. A longitudinal study over two years has been adopted, allowing continuous energy monitoring over two heating seasons, both pre- and post retrofitting works.

2 Dwelling Selection and Typology

2.1 Dwelling Selection

Directly monitoring a statistically significant number of dwellings, representative of all dwelling types, sizes and occupant demographic in Ireland would be prohibitively expensive and logistically very difficult. Kilkenny County Council are typical of many local authorities who provide social housing, which accounts for 8.6% of all housing in Ireland (ICSH, 2006). Government funding is provided to the local authority to retrofit housing up to a C1 BER. There is a two-fold interest for local authorities to upgrade their houses as it increases the life cycle of a physical building which is both a function of the social and economic value (Ravetz, 2008).
Two estates were indentified where upgrading of 90 dwellings is scheduled for summer 2012. Following consultation with the councils tenant relations officer and dwelling tenants, nine houses were selected for the monitoring study. Given that the sample is statistically small, the selection process aimed to keep the dwelling construction type as homogeneous as possible. This uniformity reduces the number of physical variables and will allows occupant behaviour to be assessed, which Brown *et al* (2011) concludes has a large effect on energy consumption.

2.2 Dwelling Typology

The dwellings are occupied single family residential semi-detached and terraced houses, built circa 1980. Combined terrace and semi-detached houses account for the biggest proportion, 44.8%, of dwellings in Ireland (CSO, 2007). The average floor area of the seven two-storey (Figure 1a) and two single storey houses (Figure 1b) is $80m^2$ and $60m^2$ respectively. Each have load bearing external cavity walls and are naturally ventilated. Ground floors are slab-on-grade with suspended timber first floors. The attic space is of typical cold roof construction with insulation between ceiling joists. From previous refurbishment schemes all windows have been upgraded with double glazing and back boiler heating systems replaced with natural gas central heating. The system has simple on/off timer controls, no room thermostats, with temperature controlled by a boiler thermostat. One house did not partake in the scheme and remains heated by a solid fuel cooker.

a) b)

Figure 1. Typical Single and Two Storey Dwellings

3 Methodology

The research seeks to monitor the real energy use patterns of the single family homes and establish the effect on energy use of upgrading to C1 BER. The research will also evaluate the reliability of predicted energy use from the Building Energy Rating (BER).
To isolate the actual effect of physical upgrading from changes in occupant behaviour, minimal contact with the dwelling occupants is vital. To be successful the monitoring programme requires reliable remote data acquisition of gas, electricity for at least one year pre- and one year post- retrofitting. Monitoring of various aspects of energy use has been ongoing for years and there is an assortment of sensors and systems on the market. However, there are a number of limitations. At the time of developing the system an intense review was undertaken to establish the best 'off the shelf' system to remotely monitor all the variables required at a reasonable price. It was found that there were several companies that could supply a number of the requirements but none that could provide an all inclusive system. This was particularly the case when dealing with the in-situ gas meters, which do not have pulse outputs. Many current systems are aimed at the commercial sector and are expensive.
As a result a bespoke system has been developed with VVS Technology Discrete wireless sensors are installed where possible to minimise installation time and aesthetic impact on the tenant's homes. The wireless system installed in the nine dwellings logs indoor temperature, humidity, air quality, gas and segregated electricity every 15 minutes. The system allows for the energy use in the dwelling to be related to the external environment by locally monitoring weather conditions.

3.1 Wireless System

As shown schematically in Figure 2, the essence of the system is to collect data within the house, transfer the data to a hub, which in turn sends the time stamped raw data to a database, where formatting is carried out for presentation on a website.

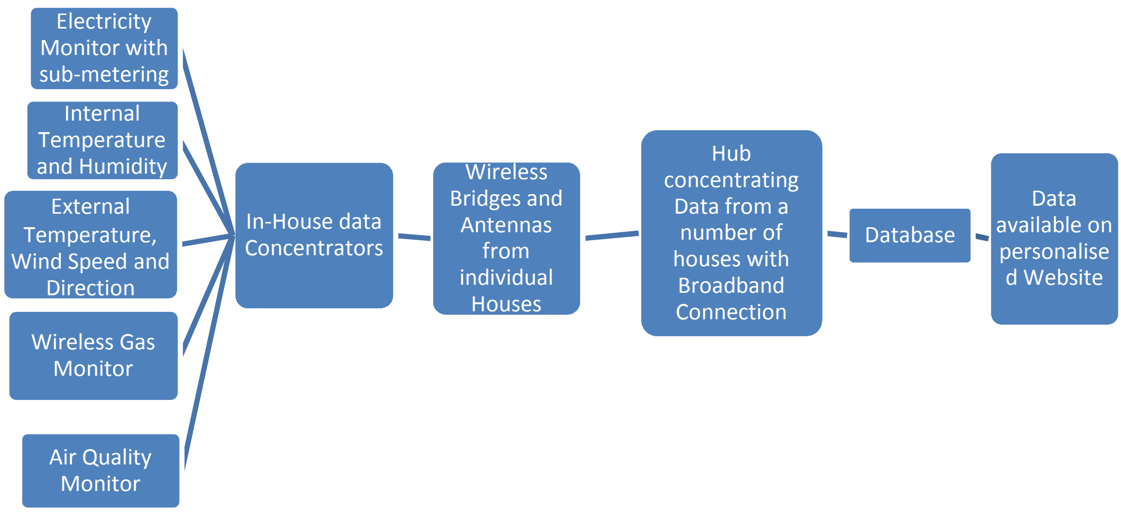


Figure 2. Data Collection and Transfer to Database

3.2 Website

Accessed through a secure login the entire site is 'read only' and is displaced in .php format, as shown in Figure 3. For research purposes the data is presented with as little refinement as possible for post processing by the user. There is potential to develop a user friendly dashboard in the future. In total there are 13000 pieces of data being recorded every day, growing the database at 1.2 megabytes. From such a large data set there is a large potential for errors. However, basic cleaning of the data is performed in SQL prior to presentation on the website. An example of this is that extreme values are removed using an iterative algorithm. Further analysis is performed on individual computers. A cluster of five servers are employed to process the data. In the case of any attack or malfunction on one server back-up servers will act to protect the data.

3.3 Data Transfer

A broadband connection is required to transfer the data from each house to the database. However, none of the nine houses currently have broadband connections. In Ireland, a 1Mb broadband connection costs approximately €250 per annum per connection. A GSM system, where a SIM card is installed as part of the system was also investigated as a less expensive alternative. However, cost and potential reliability issues of the system made this unattractive. Therefore, a bespoke system was designed utilising the proximity of the houses in each estate. Each estate has a hub, being one designated building with broadband connection from where the data is transferred to the database. All other buildings are within a radius of 600m of the hub. A local WiFi was then established whereby the data concentrator (DC) in each house is connected to the hub by secured WAP bridges and Antennas. This significantly reduced the cost of the project, requiring just two broadband connections.

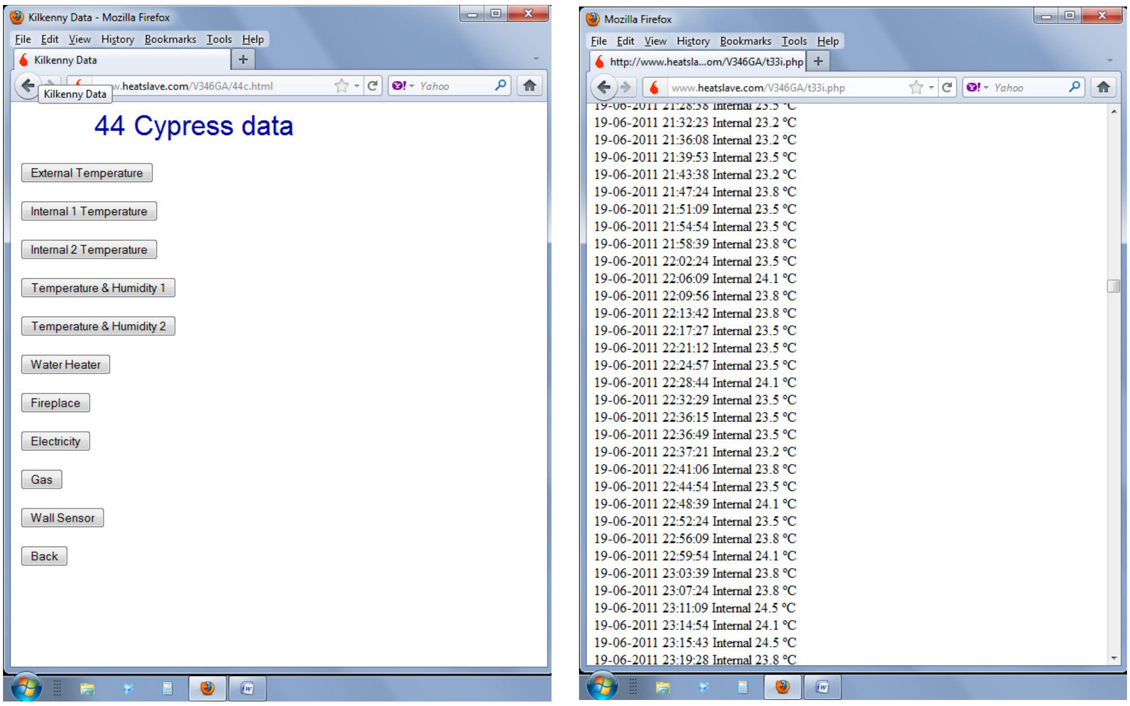


Figure 3. Data website display

3.4 Internal Data Acquisition

The integrated communication of a number of components is critical to data gathering within the dwellings, as the following details.

3.4.1 Data Concentrator (DC)

Located in the attic of each house, these powered units and are key to the collection of data. The DC performs three functions acting as:

- an IP client to the server, making a connection and uploading and downloading the data.
- a data storage unit to store data from the sensors if the data connection to the hub is slow, none existent or unavailable for some reason.
- a coordinator for the wireless network of the sensors.

The DC does no processing of the data other than packaging it up for IP and doing an MD5# encryption. Each raw data packet is stored in a circular buffer, giving around 21 days of data storage. All data is time stamped.

Around each DC there is a wireless network of battery powered sensors. Data from the wireless equipment is transmitted using the wireless ZigBee mesh networking standard. This system offers the project the option of long battery life; necessary for the two year project duration. If a sensor fails to connect with the Data Concentrator (DC) it will try again twice more. If that fails the sensor pushes the reading into a FIFO (First in First out) stack. When the sensor next tries, 15 minutes later, and it connects then it sends the last reading first, with a subtract 15 minutes flag, and then the new reading. Each sensor has a 1 megabit flash card, so as each reading is 100 bytes, the card can store 13 days worth of data at 15 minute intervals.

3.4.2 Electricity monitoring

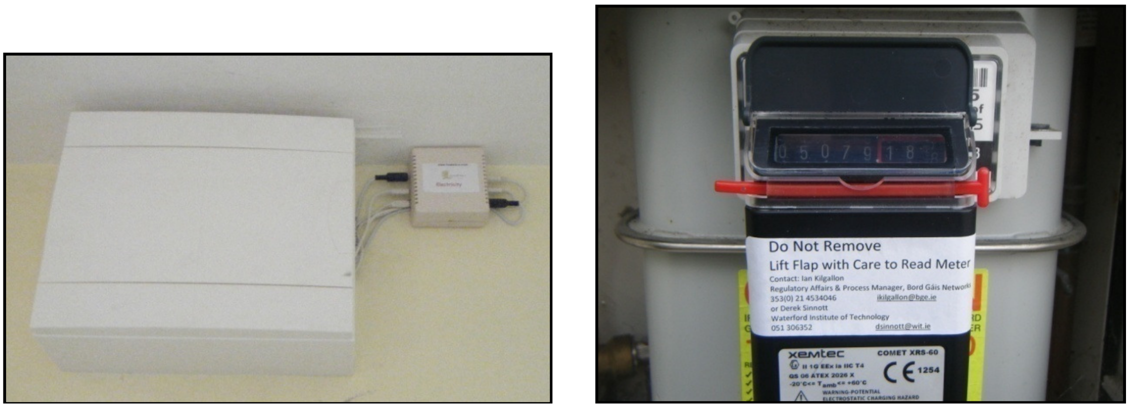
Usage is monitored by a 6 channel electricity meter. This is fitted beside the electrical distribution box electricity, as shown in Figure 4a, and connected using clamp-on current transformers (CT's) to incoming mains and up to five other circuits. This allows for the monitoring of sockets, shower, lights, immersion heater and electric cooker if installed. The units were calibrated and checked against the meter box reading. Data is presented in kilowatt hours (kWh).

3.4.3 Gas metering

The existing Elster BK-G4 meters are fitted with a wireless battery operated Xemtec Comet optical reader, as shown in Figure 4b. This converts the optical meter reading to digital format. Data is presented in m^3.

3.4.4 Temperature and Humidity

Internal temperatures are measured using temperature sensors, similar in size to a light switch. Internal temperature is monitored in three/four locations in each house including, hall, sitting room, kitchen and main bedroom. Condensation is often reported as dampness to KCC housing department. Temperature sensors have integrated humidity sensors in the kitchen and main bedroom to monitor potential increased humidity as a result of fabric upgrading. Temperature sensors report in degrees Celsius



a) b)

Figure 4 a) electricity meter and b) Xemtec Optical Gas Meter

with a reported accuracy of ± 0.5^0C. Percentage relative humidity is measured with a reported accuracy of ± 3%.

3.4.5 Air Quality

Air Quality monitors are installed in four of the nine houses. These monitor part per million (ppm) of carbon monoxide, methane and Iso-butane present in the air. The aim is to establish if upgrading effects indoor air quality.

3.4.6 Water Heating

To separate the proportion of heat energy provided for space and water heating a wireless temperature sensor is fitted on the flow and return pipes of the hot water tank of each house.

3.4.7 External Environment

There are two weather stations gathering temperature, wind speed and direction. These have their own IP address and are connected directly to the broadband routers. They transmit their data every 20 seconds directly to the server.

3.4.8 Solid Fuel

Camilleri *et al* (2007) identified a number of intrinsic barriers to gaining accurate solid fuel usage in dwellings. The study found in situ efficiency calibrations were time consuming, expensive and contained to many uncertainties to be accurate. Also, fuel usage log book accuracy was not as good as hoped. However, the study did develop a model to estimate unmonitored heat loads based on using the whole house as a calorimeter. This study intends to adopt the model as a basis to estimate heat loads from the solid fuel burners. As an aid to verify results a wireless temperature sensor is installed above each fireplace to establish when the fire is being used. Though the temperature will not give an indication of heat load, combined with a fuel diary it should provide an estimate.

3.4.9 Wall Sensor

Two wall temperature sensors have being developed and installed to measure the temperature difference across the wall thickness at two dwellings. These have five sensors placed through the wall to allow heat flux in and out of the wall to be measured. These sensors will also give a guide to the solar radiance intensity hitting the vertical external walls.

4 Limitations and Lessons Learnt

As with any bespoke system there were a number of issues that arose during planning, development and implementation of the project. Some of the key limitations and lessons learnt are presented.

4.1.1 Dwelling Typology and Selection

As recognised by Wingfield *et al.* (2008) it can be difficult to get people to agree to having their energy monitored. An intensive desk study followed by visiting in excess of twenty dwellings yielded nine households that were suitable and willing to partake in the study. There is a large monetary investment in hardware for such a complex monitoring study. As a result, care must be taken to minimise the risk of equipment being damaged or removed from the building.

4.1.2 Electricity Monitoring

Ideally each individual electrical element in the house would be monitored. However, the cost was beyond the scope of the project. An alternative was to monitor individual circuits along with the main incomer at the distribution box. When installing the CT's a number of unplanned distribution boards replacements had to be undertaken due to the poor condition of the existing boxes.

4.1.3 Gas Monitoring

Residential natural gas supply in Ireland is provided by Bord Gáis. Until recently, Bord Gáis installed Elster BK-G4 residential diaphragm meter as standard. These meters do not have a pulse output, which is the simplest method to monitor usage.

Practical options available were:

1. Join the Bord Gáis smart metering programme and receive the monitored data from Bord Gáis;
2. Install a LF pulser, which the gas meter manufacturers offer as an add-on, to the existing meters;
3. Replace the existing meters with a modern meter incorporating a pulser;
4. Break the mains and install an inline meter with pulse output;
5. Install an ultrasonic meter.

At the time of developing this research, the Smart Metering Programme was closed to new entrants. In addition, Bord Gáis expressed concern about sharing information gathered as part of the scheme. Bord Gáis do not allow any modifications to their hardware without their direct supervision. This process is very expensive and would have taken a large proportion of the budget. The options of installing inline or ultrasonic meters were also found to be too expensive and intrusive for the occupants. However, with Bord Gáis permission, the most cost effective solution was to use, the Xemtec Comet XRS-60 meter reader. This galvanically isolated reader clips to the front of the meter and captures the meter data optically, processes it locally and transfers the data wirelessly to the data concentrator.

4.1.4 Temperature and Humidity

Suitable sensor placement is critical to avoid draughts, convective and other heat sources that would distort readings. There is a temperature differential between the floor and ceiling level and where large movements of air from draughts around doors exist or convective currents from the radiators cookers. Placement also had to take account of the occupant's wishes and typically tried to be out of view about 1.7m above ground level. This was not always possible.

4.1.5 Wireless Communication

Three options were explored for the wireless communication within the houses:

1. Self-designed system using all bi-directional wireless transmitters and receivers on a permitted frequency;
2. ZigBee, an international free open standard;
3. Zwave, similar to Zigbee a proprietary system requiring a license to use from Sigma Designs. All Zwave devices work with each other. They work on a lower frequency than ZigBee so have better range for the same power but antennas are physically larger.

The cost of both Zwave and self-designed systems were found to be too expensive to implement; therefore, a Zigbee system was developed. While ZigBee has a lower entry cost, in terms of development and knowledge environments, there is a high probability that ZigBee devices from other manufacturers, while they won't interfere with each other, will be unable to communicate with each other. This posed a problem when introducing hardware like the Xemtec Comet requiring considerable development and testing.

When the Xemtec meter readers were installed in the gas meter boxes, which were attached to the exterior walls of the houses, unexpectedly the wireless signal was lost in all the houses. This required extra work whereby the external wall had to be drilled through and the wireless module installed inside the dwellings. Therefore, though it was expected that the range was good enough with Zigbee, installation proved otherwise.

4.1.6 Air Quality Meters

For a wireless system the air quality meters presented a future challenge. Prior to taking a reading the sensor head needs to warm up for 4 – 5 seconds, consuming 200mW when awake. The solution was to add an extra 4 cell lithium pack to power the sensor during date time. This may not be such a problem with the advent of new technologies such as PV cell powered sensors which are being developed and coming on the market.

5 Conclusions

This paper highlights the shortage of practical and evidence based research assessment of building energy performance parameters. The paper describes the basis for an ongoing detailed two year longitudinal study of energy use in nine dwellings in

Kilkenny. A study of its kind requires the gathering of high resolution, reliable data in tandem with a system to securely handle large datasets.
The approach adopted reflects current technologies being adopted in a novel way. The lessons learnt during the development and implantation of this project should be used drive innovation in design and technologies to refine monitoring of future projects.
Future work will examine the data gathered and analyse the relationship between variables relating to energy use in dwellings. The data will also be used to evaluate the predicted reduction in energy use based on BER's pre- and post- retrofitting. The data gathered in this study gathered will add to the body of knowledge as more research data becomes available and should provoke policy makers to base decisions on evidence based research.

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