
**Development of a Data Acquisition System to Characterise
Sustainable Energy Technologies and to Support Web-Based
Learning (DAQ-WBL)**

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Abstract

Driven by concerns about rising energy costs, security of supply and climate change a new wave of Sustainable Energy Technologies (SET's) have been embraced by the Irish consumer. Such systems as solar collectors, heat pumps and biomass boilers have become common due to government backed financial incentives and revisions of the building regulations. However, there is a deficit of knowledge and understanding of how these technologies operate and perform under Ireland's maritime climate. This DAQ-WBL project was designed to address both these needs by developing a Data Acquisition (DAQ) system to monitor the performance of such technologies and a web-based learning environment to disseminate performance characteristics and supplementary information about these systems.

A DAQ system consisting of 108 sensors was developed as part of Galway-Mayo Institute of Technology's (GMIT's) Centre for the Integration of Sustainable Energy Technologies (CiSET) in an effort to benchmark the performance of solar thermal collectors and Ground Source Heat Pumps (GSHP's) under Irish maritime climate, research new methods of integrating these systems within the built environment and raise awareness of SET's. It has operated reliably for over 2 years and has acquired over 25 million data points.

Raising awareness of these SET's is carried out through the dissemination of the performance data through an online learning environment. A learning environment was created to provide different user groups with a basic understanding of a SET's with the support of performance data, through a novel 5 step learning process and two examples were developed for the solar thermal collectors and the weather station which can be viewed at <http://www.kdp1.aquaculture.ie/index.aspx>.

This online learning environment has been demonstrated to and well received by different groups of GMIT's undergraduate students and plans have been made to develop it further to support education, awareness, research and regional development.

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List of Publications

Burke, N., Greene, M., Lohan, J., and **Clarke, R.**, “*Sensitivity of Heat Pump Performance to Horizontal and Vertical Collector Configuration in a Maritime Climate Region*”, Under review for presentation at the 9th International Energy Agency (IEA) Heat Pump Conference, Zurich, Switzerland, 20th – 22nd May, 2008.

Greene, M., (a) N. Burke, J. Lohan, and **R. Clarke**, “*Ground Temperature Gradients Surrounding Horizontal Heat Pump Collectors in a Maritime Climate Region*”, Energy and Sustainability, WIT Transactions on Ecology and the Environment, Vol. 105, pp. 309-319, 2007.

Greene, M., (b) Burke, N., Lohan, J., and **Clarke, R.**, “*Investigating Temperature and Moisture Gradients in the Ground Surrounding Horizontal Heat Pump Collectors in a Maritime Climate Region*”, Under review for presentation at the 9th International Energy Agency (IEA) Heat Pump Conference, Zurich, Switzerland, 20th – 22nd May, 2008.

Lohan J., Fitzgerald F., McAllen P.J. and **Clarke R.**, “*Development of an International Standard Solar Thermal Characterisation, Demonstration and Research Facility in Ireland*”, presented at the Challenge of Sustainability Conference, Dundalk IT, 19th-20th June, 2008.

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Burke, N., Greene, M., Lohan, J., and **Clarke, R.**, “*Sensitivity of Heat Pump Performance to Horizontal and Vertical Collector Configuration in a Maritime Climate Region*”, presented at the 9th International Energy Agency (IEA) Heat Pump Conference, Zurich, Switzerland, 20th – 22nd May, 2008.

Lohan J., **Clarke R.**, Burke N., Greene, M., and Fitzgerald F., “*Development of Experimental Test Facility for Continuously Monitoring the Performance of Sustainable Energy Technologies in Maritime Climates*”, presented at the Challenge of Sustainability Conference, Dundalk IT, 19th-20th June, 2008.

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Chapter 1 Introduction

As energy costs continue to fluctuate and the concern about security of supply and environmental issues increases in Ireland, the demand grows for alternative energy sources and more energy efficient systems. Growing demand from the Irish consumer is led by Government policy which responds to the cited concerns by promoting the need for increasing awareness of SET's in the recent Energy White paper (Delivering a Sustainable Energy Future for Ireland, 2007-2020) and revisions of the Building Regulations in 2007 which now directs that all new homes include renewable energy systems and the allocation of grants to support the purchase of these systems through the 'Greener Homes Scheme'.

Responding to Government policy commercial and educational institutions are now striving to promote and generate a greater awareness of the SET's such as solar collectors, heat pumps and wind turbines. The commercial sector can achieve this through the promotion and marketing of their systems via press advertising, the internet or any of the many new trade shows like the 'Ideal Home's Exhibition', 'Modern Homes Exhibition' or 'Self Build' shows. The educational and research sectors have responded through the introduction of energy research awards such as the Parsons Awards and new programs with Science Foundation Ireland and Enterprise Ireland, and by offering fulltime and evening courses and seminars. This research based project is an example of some of these initiatives since it was part funded by private industry and public bodies such as Enterprise Ireland (EI), Irish Research Council and Technology (IRCSET) and the Department of Education and Science.

1.1 International Energy Policy

National Energy policies reflect initiatives undertaken by European Union (EU) and world-wide organisations. International Bodies such as United Nations Framework Convention on Climate Change (UNFCCC or FCCC) created policies like the Kyoto protocol (1997) under which industrialised countries are asked to reduce "their collective emissions of greenhouse gases by 5.2% compared to the year 1990". Other international bodies such as the Intergovernmental Panel on Climate Change (IPCC) (1988) were given the task to "provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences". The EU has also introduced legislation to ensure the member states consume less energy, through initiatives such as Energy Performance of Buildings Directive (EPBD) which requires all

EU countries to “enhance their building regulations and to introduce energy certification schemes for buildings”. Consequently this directive has driven the Building Energy Rating (BER) certification in Ireland which was introduced in 2007.

1.2 National Energy Policy

Extracts from the recent Energy White Paper (2007) states that “currently over 90% of Irish energy requirements are imported”. Combined with our peripheral location and small market scale, this leaves Ireland vulnerable to supply disruption and imported price volatility. One of the Energy White Paper’s strategic goals identifies “actions to promote the sustainability of energy supply and use”. Therefore the Irish Government has introduced a number of initiatives to reduce our dependence on imported fuel by stimulating the market for SET’s. Initiatives include;

- The ‘Greener Homes Scheme’ introduced in 2007 provided grant aid to those renovating their home to consider installing SET’s such as solar collectors, heat pumps or biomass boilers.
- Part L of the Building Regulations were reviewed in 2007 and now stipulates that Sustainable Energy Systems (SES’s) must supply a minimum of 10 kWh/m²/annum space and water heating/cooling and 410kWh/m²/annum in electrical energy to a new house (Building Regulations part L, 2007). This dictates that SET’s will be integrated into all new homes in the future.
- These regulations together with the BER certification, driven by the EU, have combined to increase the demand for SET’s significantly since 2005.

The (Irish) Government’s overriding policy objective therefore is to ensure that energy is consistently available at competitive prices with minimal risk of supply disruption. This project also responds to these needs to monitor functional SES’s and make this data available to the wider community so that they can make an informed choice about the selection of SES’s.

1.3 GMIT’s Energy Strategy

Galway Mayo Institute of Technology’s (GMIT’s) Strategic Plan 2004-2009 states that “GMIT’s research strategy will integrate research, teaching and regional development as we develop a critical mass of research capacity in targeted areas”. One of these ‘targeted areas’ is sustainable energy and GMIT’s research Centre for the Integration of Sustainable Energy Technologies (CiSET) is playing an integral role in providing teaching, research

and regional development to undergraduate students, the wider community and regionally based suppliers and manufacturers of SES's.

CiSET has undertaken a number of industry funded collaborative research projects which has enabled it to integrate a number of SES's within GMIT's Dublin Road campus. These systems include two ground source heat pumps and two solar thermal collectors and CiSET undertakes research to;

- benchmark the performance of sustainable energy systems under Irish weather conditions,
- research new methods of integrating these technologies for a range of applications,
- raising awareness of SET's and their performance characteristics, through both on-site and on-line demonstration, publication and seminars,
- inform policy makers of the potential of these systems to supply energy, best practice for their use and means of minimising energy use.

This project was therefore motivated by CiSET's need to conduct on-going system characterisation and optimisation research on these energy systems while recognising the Institutes mission to disseminate research, for the benefit of teaching and regional development. CiSET is committed to "accelerating the growth of sustainable energy sources", targeted as an action in the Energy White Paper (2007), and projects such as this DAQ-WBL project helps deliver on these commitments by;

- increasing awareness of these technologies and their performance characteristics through continuous monitoring,
- building more sophisticated Information Technology (IT) and R&D infrastructure to support the future development of these technologies,
- support the promotion and growth of Irish based green energy technology companies,
- delivering relevant and well structured research, teaching and training programmes that are facilitated by the dissemination of relevant knowledge through a range of modes, such as technical papers and reports, dedicated teaching and training courses as well as on-site and on-line visits.

This shows that GMIT's CiSET is currently well positioned to support the 'actions to promote the sustainability of energy supply and use', as it contributes to each of the following five underpinning strategic goals identified in the Energy White Paper (2007);

1. Accelerating the growth of sustainable energy sources.

2. Accelerating energy research development and innovation programmes in support of sustainable energy goals.
3. Delivering an integrated approach to the sustainable development.
4. Maximising energy efficiency and energy savings across the economy.
5. Addressing climate change by reducing energy related greenhouse gas emissions.

The internet is becoming an invaluable tool for the publishing of information to the wider community. It provides an organisation with a platform to promote and display information around the clock to different stakeholders. Section 1.4 presents some details of CiSET's experimental facility designed to research, develop and promote SET's and its ambition to use the internet to disseminate research findings to a wider audience.

1.4 CiSET's Experimental Facility

This section provides a brief description of the experimental test facility developed by CiSET and the energy systems that required monitoring through this DAQ-WBL project. The site, shown in Figure 1.1, is located on GMIT's Dublin Road campus, Galway and the experimental facility is based within and around a 1200m² office building known as the Innovation and Business Centre (iIBC). This building is heated by both a Ground Source Heat Pump (GSHP) and a solar thermal system. As indicated in Figure 1.1, CiSET's researchers had identified a number of parallel strands of research that demanded different aspects of these systems to be continuously monitored, including both the local weather and the building's internal air temperature. A DAQ system was therefore required to monitor the following systems;

- Weather station.
- 2 x solar thermal collectors.
- 2 x GSHP's.
- iIBC Building's air temperature.

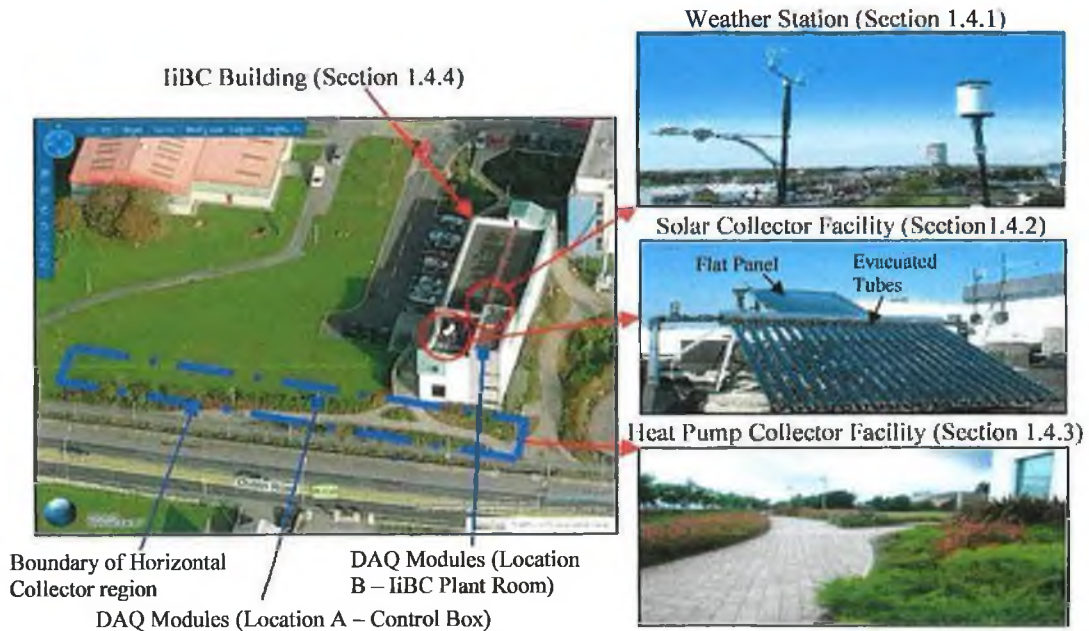


Figure 1.1 Site plan of iIBC building and the sub-systems of the experimental facility to be monitored.

1.4.1 Weather Station

Since the performance of both the GSHP's and solar collectors is dependent on the weather, it was critical to monitor the climate. Hence this project had to deliver a weather station that was capable of continuously monitoring the air temperature, humidity, rainfall, rain temperature, solar variables, barometric pressure, wind speed and wind direction.

1.4.2 Solar Thermal Collectors

This facility also consisted of two solar thermal collectors shown in Figure 1.1. One is at a 2m² flat plate solar thermal collector mounted on a sun tracker. The second thermal collector consisted of 20 evacuated tubes mounted on a fixed stand. The performance of both solar collectors was to be continuously monitored.

1.4.3 Ground Source Heat Pump

Two 15kW Solterra 500 GSHP's were installed in 2004. One heat pump is connected to 3 vertical bore holes that extend to a depth of 100m into the ground and the second to a horizontal collector, buried at a depth of 1m, within a 430m² footprint whose perimeter is identified using a blue dashed line in the aerial photograph in Figure 1.1.

One strand of research required the performance of both heat pumps to be monitored. This required both the electric power consumed by the pump and heat delivered to the building to be monitored.

A second strand of research aimed to establish the impact of heat pump's operation on the ground collector region. This was complicated in the case of the horizontal collector since it was situated under four different ground cover types which include grass, porous paving, non-porous asphalt and shrubbery. It was essential to monitor the condition of the ground in response to the combined influences of both the heat pump's operation and the climate. The impact or influence of different ground covers, ground materials, weather conditions and heat pump operation on both the ground condition and heat pump performance also required monitoring. This necessitated the ground temperature and moisture content be monitored continuously.

1.4.4 IiBC Building Environment

The internal air temperature of the building was continuously monitored in order to quantify the impact of the heat delivered to the building.

1.5 Promoting Sustainable Energy Technologies

Considering the Government's desire to "accelerate the growth of sustainable energy sources" and GMIT's mission "to support regional development", this project identified the internet as an effective medium to disseminate its research findings and to help achieve both these goals.

With the recent advances in Information and Communication Technologies (ICT's), the internet has become an important platform for the effective and efficient dissemination of information. One of its primary advantages is that it provides flexible access to up-to-date information for a wide range of people regardless of their location around the world (Lund, 2001). The internet enables the use of rich media files (pictures, video and audio) and the interactivity of electronic communications like e-mail and discussion forums (Frydenberg, 2002) which provides a platform for commercial and educational institutions to promote their systems or courses. With the increasing demand on the community as they balance work and family commitments and as employers and educators find improved and more efficient teaching methods, it is not surprising that online learning has become so popular. According to Rudestam *et al.*, (2009), the "e-learning market has an annual growth rate of 20% worldwide". Online learning is one of the most rapidly growing fields in education

(Drigas, 2005) which is being used as a resource to support traditional learning and also to run new courses. Online platforms like Moodle™ are used to support traditional learning methods where lecture material and assessments are conducted via Moodle™ and other institutions use online learning to run complete courses which include GMIT, IT Sligo, Dublin City University and University of Ulster. Over 70% of GMIT's academic staff use Moodle™ as part of their teaching. Other methods of using the internet to support learning include virtual or remote labs. Chapter 2 presents details of more complex tools developed to carry out virtual/remote labs (Drigas *et al.*, 2005, Hutzet *et al.*, 2006 and Michaelides *et al.*, 2004) and the monitoring and promotion of SET's (GreenTouchscreen, Fatspaniel, Building Dashboard and Sunviewer).

Commercial institutions also exploit the potential of the internet by using its world wide appeal to promote and create awareness about their sustainable systems and their environmental concerns. The internet can be used to display live performance data of working systems for the public to view and analyse. Companies like WECC, Yahoo and Woods Hole Research Center (WHRC) all use the internet as a tool to generate a greater awareness of sustainable technologies and the environment. They also promote green features like recycling and energy efficient equipment and materials via these web based environments and these will be discussed further in Chapter 2.

Therefore, this project also sought to explore means of using the internet to promote SET's by increasing awareness and supporting online learning.

1.6 On-line Learning Environment (OLE)

This concept of research enabled on-line learning environments was first promoted by GMIT's Research Strategy 2007-2011, which outlined that;

“The concept of establishing Knowledge Discovery Platforms (KDP's) is a key and distinctive element of this Strategy as they will enable the Institute to fulfill the Research Strategy articulated in the Strategic Plan (2004-2009) to ‘integrate research, teaching and regional development’”.

“KDP's aim to encourage the transfer and sharing of knowledge and research outcomes to all learners and end users so as to maximise the returns to education, the economy and society. They will foster the vision of promoting knowledge discovery and innovation which will allow GMIT deliver new learning opportunities for the knowledge society. This dovetails perfectly with GMIT's

teaching and learning remit and facilitates the integration of research, teaching and regional development”.

This KDP concept has evolved and Sustainable Energy On-line Learning Environment (SEOLE) presented in this thesis represents the first example of a KDP that combines both an integrated on-line and on-site research and teaching facility. SEOLE places “research, including the personnel, project or initiative, motivation, methodology and findings on a more accessible platform within the wider community”. This should help to increase awareness of the ongoing research within GMIT’s CiSET’s by promoting the exchange of ideas between the education and the research communities, policy makers and the private sector. SEOLE will provide a platform for the CiSET group to increase their profile through the promotion of SET’s and the dissemination of performance data from SET’s.

1.7 Aims and Objectives

This section outlines the aims and objectives of this project.

The project sought to deliver the following two aims;

- i) Develop a Data Acquisition (DAQ) system to continuously monitor the performance of 2 GSHP’s, 2 solar thermal collectors, a weather station and liBC building. This was to be achieved by executing the following objectives;
 - a) Conducting a literature review of similar research facilities to establish the most appropriate test methodologies and DAQ equipment,
 - b) consult with co-researchers within CiSET to establish the type of measurements required to meet their research goals,
 - c) identify suitable hardware and software to meet these requirements,
 - d) commission a suitable system to provide reliable and accurate data, which was to be stored in a secure and accessible database.

- ii) Develop a flexible on-line learning environment to promote sustainable energy technologies by;
 - a) Conducting a literature review of similar research facilities to establish the most appropriate design, layout and functionality of such a website,
 - b) identifying typical user groups and designing a website structure to accommodate each group,
 - c) develop a suitable website layout and design to support learning across a wide cohort of learners,

- d) build a prototype website and seek feedback to guide future developments.

Since there are two distinct elements to this project, Data Acquisition and Web-Based Learning, this project will be referred to using the DAQ-WBL acronym.

1.6 Summary of the Thesis

This section summarises the content of this thesis by Chapter. Chapter 2 discusses the existing DAQ hardware and software systems used by previous SET's researchers. It also reviews previous applications of the internet for both online learning and the promotion of SET's, to highlight both their strengths and weakness.

With the support of Figure 1.2, the design, installation and operation of the DAQ system is detailed in Chapter 3. This involves defining the sensor locations and specification of the DAQ modules, the control software and finally the logging of data, with each element being described, discussed and justified.

The creation of an on-line learning environment shown in Figure 1.2 is described in Chapter 4. The navigation of the website and the influencing factors behind the design and layout of the SEOLE are discussed in this Chapter.

Chapter 5 discusses the outcomes of the project and evaluations conducted through a questionnaire.

Chapter 6 discusses conclusions and future recommendations.

Appendix A contains details affecting the accuracy and calibration of DAQ systems. Also included in this section are the details of the setup and calibration of the moisture sensors. Photographs showing the DAQ sensors calibration, the building and the DAQ facility are also contained in Appendix A.

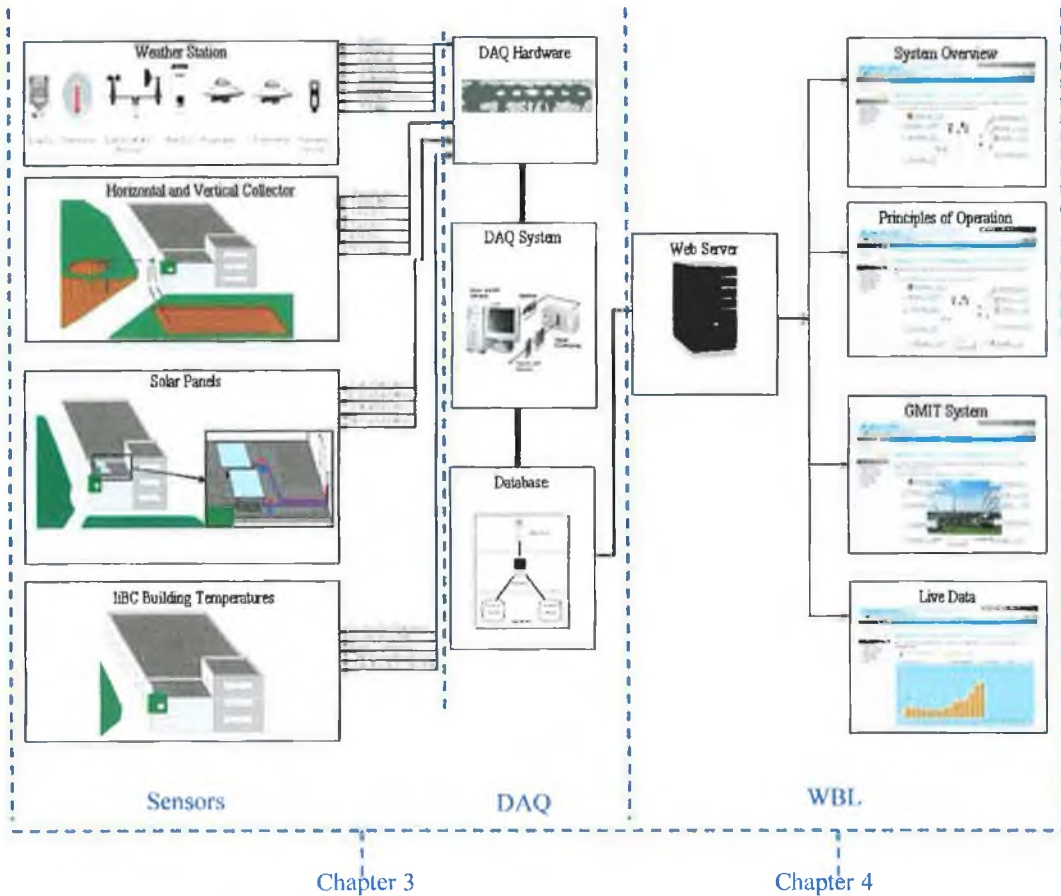


Figure 1.2 Top-level schematic of the data flows through-out this DAQ-WBL project from the sensors to the online learning environment.

Appendix B contains screen shots of the initial designs stages of SEOLE, other online learning environments that influenced the development and the final working live version of SEOLE. Appendix C contains the feedback from GMIT students on their impressions of SEOLE. Appendix D contains extracts from the primary and secondary school curriculum regarding sustainable energy. Appendix E (attached Cd-rom) contains the wiring diagrams and characterisation for the sensors installed in this facility and the calibration results for the temperature sensors and flow meters.

Chapter 2 Literature Review

Introduction

This chapter presents the most pertinent literature reviewed as part of this DAQ-WBL project. It highlights the state-of-the-art Data Acquisition (DAQ) enabled Web-Based Learning (WBL) environments that have been developed to promote both energy awareness and sustainable energy technologies. It also provides an insight into the key features and functionality that can be achieved and many of these concepts are later integrated into the 'learning environment' developed through this project. This review is therefore sub-divided between DAQ systems and WBL environments for energy awareness and SET's systems. The first section however provides a brief overview of similar research facilities to highlight their focus and DAQ infrastructure.

2.1 Sustainable Energy Systems Research Facilities

This section overviews some of the research facilities that have been established to monitor and research the operating performance of SET's. This baseline study was undertaken to establish the test methodology and DAQ equipment employed by earlier researchers and 15 such facilities are summarised in Tables 2.1 and 2.2. These facilities were designed to test SET's in different operating environments to serve both commercial system suppliers and researchers optimising performance. Typical energy systems include Ground-Source Heat Pumps (GSHP), Air-Source Heat Pumps (ASHP), solar thermal collectors, solar Photo-Voltaic (PV) arrays, wind turbines and their operating environments, usually buildings (Inalli *et al.*, 2004; Michopoulos *et al.*, 2006; Rybach *et al.*, 2000; Urchueguia, 2006). The objectives of these studies are to fully understand system performance and to optimise each system for its intended application or operational environment. For instance, Table 2.1 highlights that Urchueguia *et al.*, (2006) installed a total of 68 sensors to monitor the performance of a GSHP, an ASHP and the local weather condition. Other similar facilities were created via user defined hardware and software by Inalli *et al.*, (2004) and Michopoulos *et al.*, (2006).

Table 2.1 List of sustainable energy systems research facilities (1997 – 2006).

| # | Researcher, Institute, Year | Sustainable Energy System | Primary Aim/Objective* | Period of study | Number of sensors | Logging interval | Graphical User Interface |
|----|--|---|---|---------------------------------|-------------------|------------------|--|
| 1 | Forero <i>et al.</i> , National University of Columbia, 2006 | Solar PV collectors and weather station | D/Develop DAQ system to monitor PV solar systems | Continuously | 10+ | Not defined | Yes |
| 2 | Michopoulos <i>et al.</i> , Aristotle University of Thessaloniki, Greece, 2006 | Ground-source heat pump x 7 and weather station | AR/Performance analysis of a GSHP used for heating and cooling | 3 years | Not defined | 10 mins | No |
| 3 | Urchueguia <i>et al.</i> , University of Valencia, Spain, 2006 | Ground-source heat pump x 1, air-source heat pump x 1 and weather station | AR – M/ Performance comparison between a GSHP and an ASHP in heating and cooling modes | 1 year Feb 2005- Feb 2006 | 68 | 5 mins | No |
| 4 | Migoya <i>et al.</i> , University of Madrid, 2006 | Wind Turbine x 24 and weather station x 2 | AR/ Performance comparison between different types of wind turbines | 4 years 2001 - 2005 | 28 | 10 mins | No |
| 5 | Martinez, Miguel Hernández <i>et al.</i> , University, Spain, 2005 | Solar thermal collector x 6 and local weather station | AR/Performance analysis of a Solar thermal collector heating system | 2 years | 32 | 1 min | Yes |
| 6 | Inalli <i>et al.</i> , Firat University, Turkey, 2004 | Ground-source heat pump x 1 | AR/ Performance analysis of a GSHP used for space heating | 6 months Nov' 02 – April '03 | Not defined | 30 mins | Yes |
| 7 | Pecen <i>et al.</i> , University of northern Iowa, USA, 2004 | Solar PV collectors x 4 and Wind Turbine and weather station | E – AR/ Monitor performance of a hybrid sustainable energy system and provide college with a teaching resource for students | Not defined | 5+ | 10 mins | Yes (web-based for use within college network) |
| 8 | BIPV project, USA, 2003 | Solar PV Collectors x 17 | CR – M/ Performance comparison between different types of Solar PV Collectors | Continuously from 2002 | Not defined | 15 mins | Yes |
| 9 | Koutroulis <i>et al.</i> , Technical University of Crete, 2001 | Solar PV collectors, Wind turbines and weather station. | D/Develop DAQ system to monitor PV sustainable energy systems | Continuously | 17+ | 1 min | Yes |
| 10 | Patel <i>et al.</i> , Murdoch University, Australia, 2001 | Solar PV collector x 60 and weather station | AR /Performance analysis of a Solar PV/Diesel hybrid system | 20 Months, Sept '99 – April '01 | 70+ | 10 mins | No |
| 11 | Wichert <i>et al.</i> , Curtin University of technology, Australia, 2001 | Solar PV collector x 16 and weather station | D/Test facility for Solar PV/Diesel hybrid system | Continuously from 2001 | Not defined | 5 mins | Yes |
| 12 | Benghanem <i>et al.</i> , University of Science and Technology, Algeria, 1997 | Solar PV collectors and weather station. | AR/Develop DAQ system to monitor PV solar systems | Not defined | 7+ | 60 mins | Yes |

Note*: AR - Applied Research, E - Educational, D - Development, CR - Commercial Research, M - Marketing

A similar research facility was established by Martinez *et al.*, (2005) to study solar thermal technologies. The aim of this facility was to acquire and analyse the performance data of a residential solar heating system in Murcia, Spain and to compare the recorded data with the performance estimate provided by the F–Chart method used for sizing such systems. The F–Chart is an analysis tool used for the designing and sizing of solar heating systems. A total of 32 sensors were installed through-out the system. The system performance was logged at 1 minute intervals over a two year period. Data from the local weather station in Murcia was used as part of the facility. Other similar facilities were created by Patel *et al.*, (2001) Tiwari *et al.*, (2006), and Wichert *et al.*, (2001).

Table 2.2 Range of DAQ systems used to monitor sustainable energy systems

| # | Researcher, Institute, Year | Research Area | Data acquisition system (Software/Hardware) |
|---|--|---|--|
| 1 | Urchueguia <i>et al.</i> , University of Valencia, Spain, 2006 | Ground-source heat pump system and Air-source heat pump system | User programmed hardware and software |
| 2 | Forero <i>et al.</i> , National University of Columbia, 2006 | Solar Photovoltaic collectors and weather station | NI Labview and NI DAQ card and FieldPoint module |
| 3 | Maheshwari <i>et al.</i> , Indian Institute of Technology, Bombay, 2006 | Solar Photovoltaic collectors and weather station | User programmed and Microcontroller unit, DC and Multiplexer |
| 4 | Michopoulos <i>et al.</i> , Aristotle University of Thessaloniki, Greece, 2006 | Ground-source heat pump system | Campbell Scientific software and data logger |
| 5 | Pecen <i>et al.</i> , University of northern Iowa, USA, 2004 | Solar Photovoltaic collectors and Wind Turbine and weather station | Fluke Software and Hardware |
| 6 | Koutroulis <i>et al.</i> , Technical University of Crete, 2001 | Solar Photovoltaic collectors and Wind turbine and weather station. | NI Labview and NI DAQ cards |
| 7 | Benghanem <i>et al.</i> , University of Science and Technology, Algeria, 1997 | Solar Photovoltaic collectors and weather station. | User programmed and Micro-processor |
| 8 | Migoya <i>et al.</i> , University of Madrid, 2006 | Wind Turbine x 24 and weather station x 2. | User programmed hardware and software |

A closer inspection of the experimental facilities in Tables 2.1 and 2.2 reveals aspects of the experimental procedure and DAQ equipment deployed which helped guide selection of suitable DAQ equipment for this DAQ-WBL project. The following observations were made;

- This type of DAQ application began to become more popular since 2000 and these systems have been used continuously to record data from between 5 and 68 sensors with a sampling interval of between 1 and 60 minutes.
- There is a wide geographical spread with continental climate countries well represented. Conversely, few such facilities have been developed in maritime climate regions, which helps distinguish this DAQ-WBL facility.

- Since all sustainable energy systems absorb energy directly or indirectly from the climate, it is not surprising that the majority of the cited studies employ a weather station, and this was also a feature of this DAQ-WBL study.
- The SET's being studied generally fell within 3 technology types; solar (thermal and PV), heat pumps (ground and air source) and wind turbines, with few studies exceeding to research more than one technology. In addition to climate monitoring, DAQ-WBL focuses on both GSHP's and solar thermal collectors.
- Few embraced a direct educational remit within their brief/scope since this is difficult to achieve and execute. However, education is an integral part of this DAQ-WBL project.
- Table 2.2 identifies that many different types of DAQ systems are deployed including off-the-shelf solutions supplied by Hewlett-Packard, Campbell Scientific and National Instruments as well as custom designs.

The proposed DAQ-WBL test facility therefore was specified to deliver the following relatively novel attributes;

- Its design had to facilitate performance measurement from two different technologies (GSHP's and solar thermal), while also including a weather station and building performance monitoring. However it was to provide a platform for expansion to allow solar PV and wind power to be included in the future, thereby enabling a comprehensive educational and research resource be deployed.
- It will generate performance data under maritime climate conditions, which is less frequently addressed in the literature.
- It was conceived to serve both the research and educational functions equally well, by designing an easy to navigate and intuitive GUI.

2.2 Data Acquisition Systems

In all computer aided industrial or research environments, great effort is placed on both the precision and reliability of instrumentation, DAQ and control technologies, since they have a significant impact on the efficiency of product quality and help reduce the operating costs. They certainly impact on the confidence one places in the result or outcome and it is essential that confidence be preserved in all working environments.

This section identifies the key features of the DAQ system required to monitor the energy system associated with this DAQ-WBL project. Since the performance of a DAQ system not only relies on sensor accuracy, close attention is also given to sensor measurement range, accuracy of the DAQ system, response time, resolution, drift over time and calibration. DAQ concerns the gathering of signals from any measurement source and digitising those signals for storage, analysis and presentation on a Personal Computer (PC) (Bishop, 2007b). Temperature, voltage, speed, moisture content and humidity are just some of the many variables that can be monitored and captured using a DAQ system and these are all employed in this DAQ-WBL project. An overview of a DAQ system that delivers such functionality is presented in Figure 2.1. It consists of measurement sensors, signal conditioning, DAQ hardware and DAQ software/drivers.

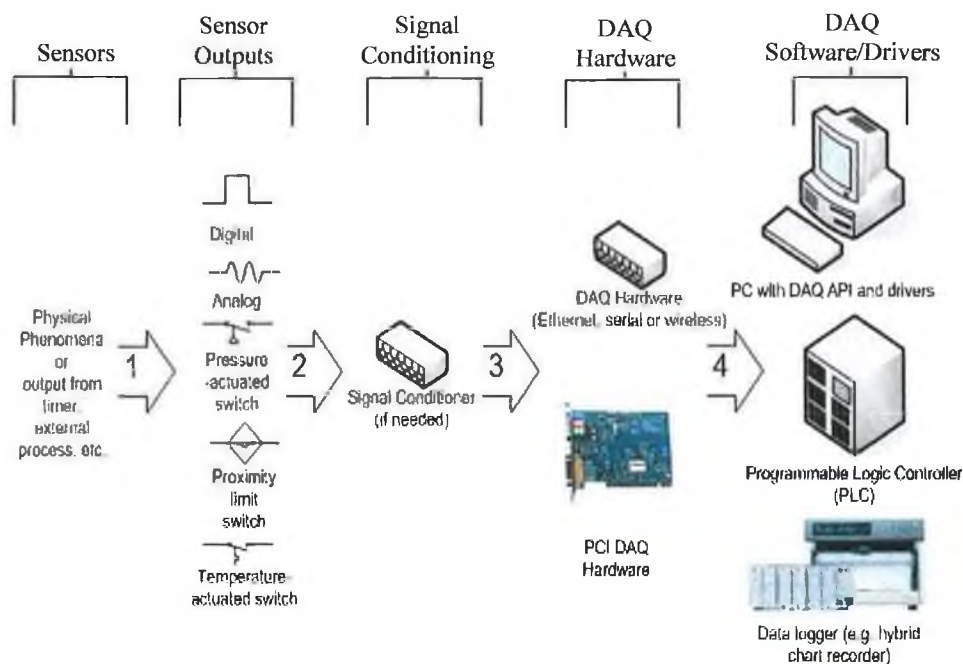


Figure 2.1 Typical configuration of a modern DAQ System [Source: Data Acquisition, 2008].

DAQ systems are used in many different engineering disciplines. They are not only used to collect and process data, but also to monitor and evaluate the performance of devices and systems. Examples of DAQ systems developed to monitor sustainable energy systems and energy efficiency are summarised in Table 2.2, and include Benghanem *et al.*, 1997, Forero *et al.*, 2006, Koutroulis *et al.*, 2001, Maheshwari *et al.*, 2006, Michopoulos *et al.*, 2006 Pecen *et al.*, 2004 and Urchueguía *et al.*, 2006.

At a basic level a DAQ system can include the recording of readings from a multimeter or some other display instrument. However, data recording applications that require a large

number of process variables to be monitored, and also perhaps at high frequency rates, require additional instruments or micro controllers to acquire and record data precisely (Rigby *et al.*, 1995). A microcontroller is a single chip computer that can be used to control processes or events and can upload or run software programs. DAQ systems are not only used to gather data but also to generate output signals. These signals can be used to control mechanical systems or generate an impulse so that the DAQ system can measure the response. However this control aspect was not required in this DAQ-WBL project.

The emergence of the PC in the 1980's revolutionised DAQ systems. The advent of the PC made it possible to connect DAQ devices and instruments to a computer via a serial port, parallel port or some custom interface (Bishop, 2006a). These devices and instruments can now be connected to other instruments via the Universal Serial Bus (USB) or Ethernet ports. The following subsection provides more detail on each of the constituent elements of a modern DAQ system.

2.2.1 Sensors and Transducers

Morris (2001) defined a sensor as “the first element of any measuring system and gives an output that is a function of the measure and or the input applied to it”. A liquid-in-glass thermometer is a very visible example of a sensor that is used to measure temperature. A transducer is slightly different to a sensor in that it gives an output that is a function of the input signal, but where this output is in an inconvenient form and has to be converted to a more convenient form (Morris, 2001). For instance, a strain-gauge has an output in the form of varying resistance. The resistance change cannot be easily measured so it is converted into a change in voltage. This conversion element combined with a sensor is known as a transducer. Transducers and sensors both act to provide the interface between the equipment, process or environment being monitored and the data acquisition system. They operate by converting physical variables into electrical signals that the signal conditioning (Section 2.2.2) and DAQ hardware can accept and interpret (Park *et al.*, 2003). Park *et al.*, (2003) recognised that “transducers can perform almost any physical measurement and provide a corresponding electrical output”. These examples include temperature, humidity, wind speed and pressure sensors that convert the input signal into a voltage or current output signal. Sensors and transducers are however both referred to as sensors from this point onwards.

2.2.2 Signal Conditioning

As indicated in Figure 2.1, signal conditioning takes place between the sensors and the DAQ hardware. Anderson (2007) advised that few, if any, real systems generate perfect signals that are completely free of noise or be guaranteed to be electrically safe. Hence most signals require some conditioning in order to remove unwanted noise or interference from the measured signal which may involve one or more of the following operations; Filtering, amplification, isolation, excitation and multiplexing. These are defined in Section A.1, Appendix A.

2.2.3 Wiring and Cabling

This involves wiring the sensor to the signal conditioning unit (if required) and then to the DAQ hardware and PC. This link between the hardware and PC can be arranged using either an RS232 (Recommended Standard 232), network cabling or even USB. Park *et al.*, (2003) cautioned however that “the correct earthing and shielding of the cabling is extremely important in order to reduce the effects of noise interference”. In certain cases where sensors are positioned at distant or remote locations from the DAQ hardware, the cabling becomes hugely important because the risk of noise degrading the sensor signal output increases with cable length (Section 2.2.8.1). Park *et al.*, (2003) also recognised that this aspect of the DAQ system is often over looked as an important part of the overall infrastructure leading to inaccurate and unreliable measurements.

2.2.4 Data Acquisition Cards/Hardware

DAQ modules or cards are developed at the interface between the computer and the sensors and Figure 2.2 presents a photograph of a typical DAQ card.



Figure 2.2 Typical PCI Data Acquisition Card [Source: National Instruments, 2008].

A wide range of DAQ plug-in cards are used including PCI, PXI, PCMCIA, and ISA. The PCI card has become the most commonly used. In 2003, Austerlitz noted that DAQ hardware modules are often connected to a PC via a USB, serial or parallel port. Johnson also stated that IEEE 1394, which is also known as FireWire (Apple), i.LINK (Sony), and Lynx (Texas Instruments), is commonly used due to its easy plug-and-play functionality (Johnson, 2001).

DAQ hardware devices are sub-divided into the following subsystems;

- a) Analog Input
- b) Analog Output
- c) Digital Input/Output
- d) Counter/timer

Some devices, known as multi-function boards, provide most or all of these features, while others may only support one feature (Austerlitz, 2003). The functionality of these devices are discussed further in Section A.2, Appendix A.

2.2.5 DAQ Software

The software is also a vital part of the DAQ system, enabling the computer and DAQ hardware to simultaneously perform data acquisition, recording, analysis and display. Software is as important to modern DAQ systems as the hardware capabilities, and well written software can be used to maximise less than average hardware (Austerlitz, 2003). The majority of DAQ systems use driver software built on DAQ cards and there are two types of software;

- (i) Driver Software
- (ii) Application/Development software.

(i) Driver Software: Driver software is used to program the DAQ card and co-ordinate communication between the card and the PC. DAQ card drivers can be provided by either the supplier software or custom designed by the user. The first option is very straight forward as the supplier's software driver takes care of all the programming and communication requirements. The second option requires the user to undertake all the programming of the board. The programmer may use programming languages such as C, Basic and C++ to write a series of binary codes to the DAQ board to control its operation (Whitaker, 2005). Whitaker also states that this method offers greater flexibility and levels of customisation, but it is also more time consuming, even for an experienced programmer.

Since such programming skills were not available to this DAQ-WBL project, the use of driver software was not pursued.

(ii) Application/Development Software: The second option for programming the DAQ hardware involves using Application/Development software. The first step is to decide which operating system is suitable for one's needs, with Windows or UNIX being the best options. Development/Application software can be a full screen Graphical User Interface (GUI), a dedicated input/output control program, a data logger, a communication handler or a combination of all these (Park *et al.*, 2003). A modern example of a GUI that is used by Apple for its iPhone™ is presented in Figure 2.3. The user can easily and quickly access specific features (phonebook, calendar or camera) or functions using icons on the main screen without the need for programming.



Figure 2.3 Example of the GUI developed for Apple's iPhone™ [Source: Apple's iPhone™, 2008].

Applying this approach to DAQ the user can program the DAQ hardware and set the system to record the required data via user friendly software that requires little or no knowledge of programming. Bishop (2006a) identifies Labview™, Measurement Studio™, Microsoft Visual Basic™ and Visual C++ as some of the most commonly used software applications. These packages allow the user to customise the Interactive Panel, or GUI, so that a pictorial representation of the physical system can be generated using software images of icons, switches, indicators, knobs and graphs. This degree of flexibility was considered suitable for the user interface envisaged for this DAQ-WBL project and an example, from a similar application, of an Interactive Panel is presented in Figure 2.4.

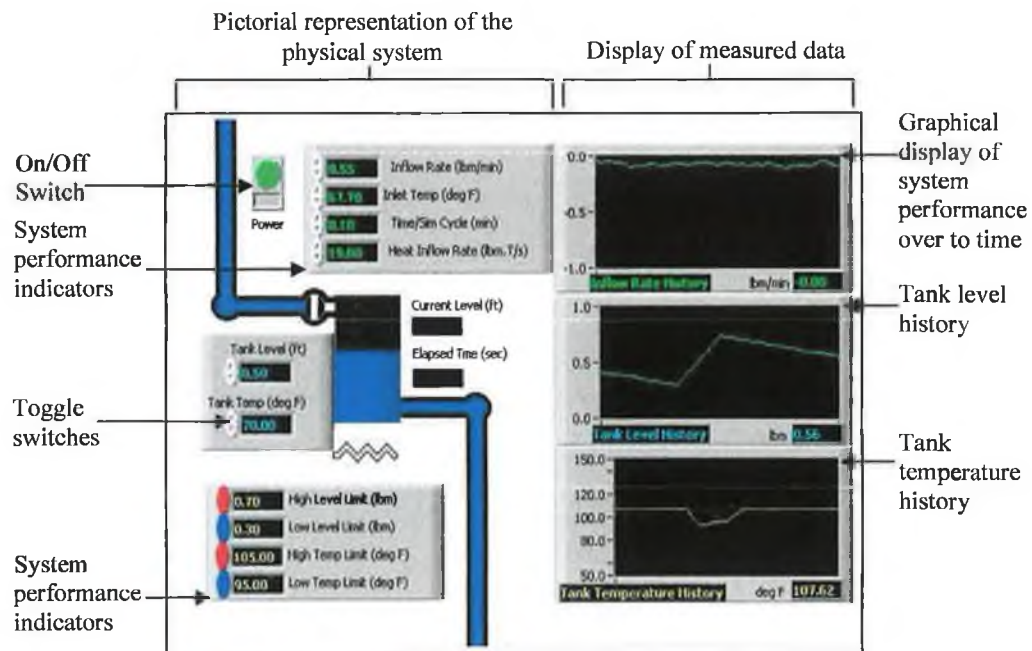


Figure 2.4 Interactive Panel Labview™ Library VT's [Source: NI Labview™, 2008].

Note from Figure 2.4, that it is possible to generate a graphical representation or flow chart of key physical characteristics (tank level and temperature) being monitored and controlled, while simultaneously presenting 'key performance indicators' and a graphical representation that captures changes in these indicators over time.

Some vendors supply add-on applications to provide the user with more advanced options for control and data logging, in addition to DAQ. However, Bishop (2006a) identifies that users need to consider the following aspects when evaluating the suitability of application/development software.

a) Wide Range of GUI Components: As identified in Section 2.2.5, many applications provide a pallet of ready made graphical components like knobs, switches and graphs to reduce programming time. Figure 2.4 represents a GUI where the user has both control (via toggle switches) and a feedback view from the system through the performance indicators and the graphical displays.

b) Integration with Measurement Hardware: Ideally, although this cannot always be assured, all software and hardware should be procured from the one supplier in order to ensure compatibility, reduce development time and generate trustworthy results. When this is not available it is important, where possible, to obtain guarantees from the vendors as to the compatibility and reliability of the software and hardware.

c) Analysis Functions: Besides managing data capture by interacting with the sensors, the development software also controls critically important functions of data logging and storage. It usually provides the user with greater options to cater for all types of user

requirements such as; (i) selecting and identifying individual channels to log, (ii) setting the scan rate or interval between successive scans and (iii) define the DAQ start and stop-times.

d) Network Connectivity: As in the DAQ-WBL, project it is becoming increasingly vital that the DAQ system can be connected to a Local Area network (LAN), so that the data can be accessed and possibly published via the web. The development software should provide the option to use network/web publishing techniques. This was very important for this DAQ-WBL project as it set out to reach a diverse audience within the extended community, education and commercial sectors.

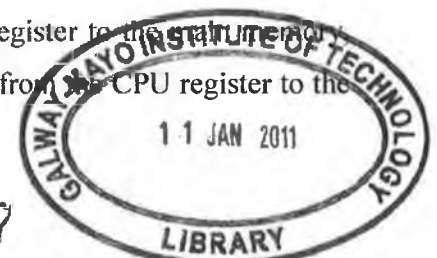
e) Report Generation: In situations where large amounts of data is being processed, it is important that the software has the ability to automatically signal faults, issue parameter limit warnings or control signals, generate progress, update or summary reports on the system being monitored. The user may also require the ability to allow the programming of external report options.

Since GMIT's Department of Mechanical and Industrial Engineering acquired a software licence for Labview™ application/development software, supplied by National Instruments in 2002, this was a major influencing factor that impacted the choice of DAQ software deployed in this DAQ-WBL project.

2.2.6 The Personal Computer (PC)

The emergence of the Personal Computer (PC) has revolutionised the capabilities of the DAQ system. The PC dictates the maximum speed at which data can be acquired. The microprocessor speed, hard disk access time, hard disk capacity and type of data transfer available can all impact on the speed and flexibility at which the PC can continuously acquire data (Park *et al.*, 2003). In some cases the specification of the graphics card can also be a limiting factor. As the application/development software becomes larger in size and more demanding on the PC's RAM, processor and graphics card, it is important that the PC has the capacity to meet these increasing demands. However, standard workstations are now available with at least two or more processors, so the PC is no longer a limiting factor in DAQ applications. The PCI bus and the USB ports are a standard part of modern PC configuration. IEEE 1394 interfaces are also an option to consider when connecting to the PC. For applications where distances of greater than 5m for USB, or 23m for RS232 are involved, standard networking technologies are available such as ethernet or wireless.

Other important elements include the Direct Memory Access (DMA) controller which moves data directly from the Input/Output (I/O) data buffer register to the CPU register rather than the data buffer registers to the CPU registers, then from the CPU register to the



main memory (Bishop, 2007b). Bishop also states that DMA controllers greatly increase achieved transfer band width of I/O operations and have become standard components of today's microprocessors.

Another factor that affects DAQ performance is the storage of data to the hard drive. National Instruments recommends that a separate drive be used for data storage and another drive for the Operating System (OS). A hard drive of 200-300Gb capacity is relatively affordable as most desktops now come with 100Gb drives as standard.

Hard drive access time is also important since the speed at which the system can acquire and stream data to disk will be reduced if the drive is not a high speed drive. Real-time processing is not such a major issue as it once was as PC's are now available with at least one processor with speeds of up to 3.0GHz. Most recent PC's are available as standard with 2 core processors and clock speeds of at least 2.0GHz.

2.2.7 Data Logging and Analysis

Bishop (2007b) identifies the most common applications for modern DAQ systems as data recording and logging which involves a combination of a) online analysis, b) offline analysis, c) display, d) report generation and e) data sharing. A short description of each follows;

a) Online Analysis: consists of any processing done while the data is being acquired. One of these processes is 'channel scaling' where the binary values outputted from the DAQ system are converted into proper scaled measurements with appropriate engineering units (Bishop, 2007b). Online analysis also applies to limit and alarm warnings built into the system in order to respond to certain events like high temperature or pressure.

b) Offline Analysis: describes the manipulation and recalculation of the measured data after it has been acquired in order to maximise its potential. It is important when selecting the DAQ software that these extra functions are built into the package that allows the manipulation of the measured data, otherwise third party software would be required. The analysis may include mathematical or statistical analysis.

c) Report Generation: Most software packages have the capability to automatically generate reports and analyse data. This can be very important where large volumes of data are acquired and therefore enable the efficient monitoring of the system data.

d) Display: The display enables live or historical data to be presented via graphical, numerical or some other form of display. Most DAQ software allows the simultaneous viewing of live data combined with the data logging. Some packages also allow live or

historical data to be viewed on local PC's, intranets or over the web. Figures 2.5(a) and (b) present two examples of data display from energy related applications.

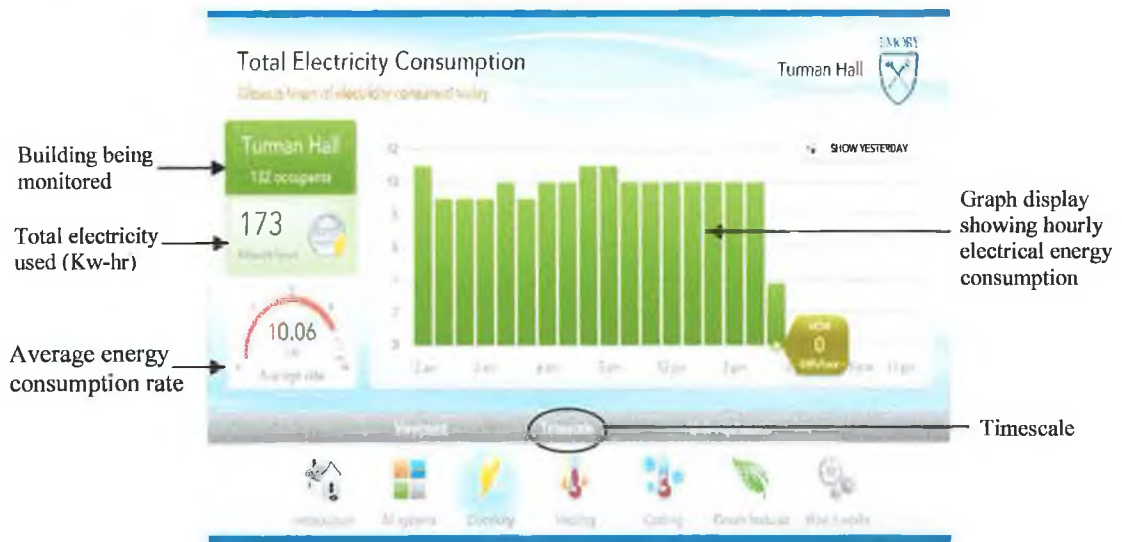


Figure 2.5(a) Graphical data display from an electrical energy monitoring and awareness software deployed by Emory University, USA [Source: Buildingdashboard, 2007].

Both GUI's in Figures 2.5(a) and (b) influenced the design of the GUI developed for this DAQ-WBL project and elements of these designs will be elaborated on in Chapter 4.

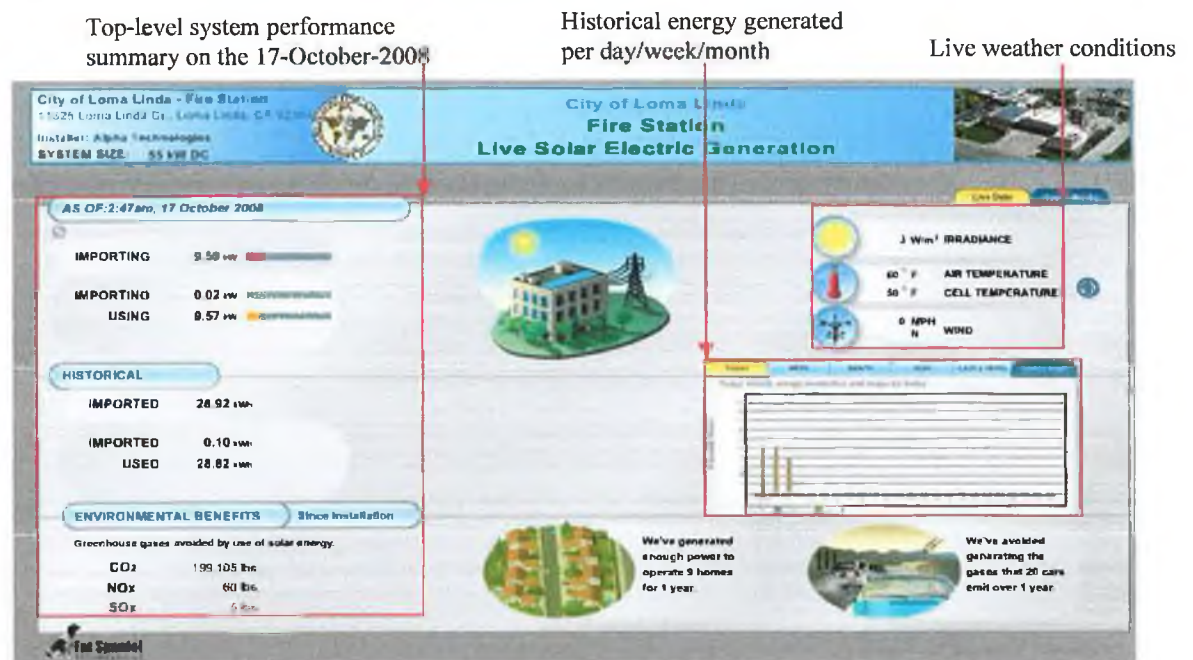


Figure 2.5(b) Graphical display presents electrical energy generated by solar PV array at Loma Linda Fire Station, USA [Source: Loma Linda Fire Station, USA, 2008].

e) Format and Schedule: Other important aspects regarding the logging of data, includes the format and schedule in which data is logged. The format that the data is stored in is very important so that the PC software can interpret it at a later date. The most common format is ASCII text files and types of ASCII text files include *.txt* and *.csv*. Both these formats

can be easily read by word processing applications. The disadvantage of ASCII files is that the conversion of the raw data into these readable files takes extra time and the files tend to be bulky when used to store numerical data (Johnson, 2001). Other types of databases include *.sql*, *.db* and *.xls*. It is also important that each data scan can be stored with the corresponding date and time stamp.

According to Perujo *et al.*, (2003) it is important to set the storing interval to the correct frequency in order to gather meaningful information. If the interval is too short then the data becomes difficult to manipulate and requires extra storage space. If the interval is too long or infrequent the trend can become unclear. "Measurements are usually processed to provide a meaningful average value over a longer time period, usually between minutes and days" (Perujo *et al.*, 2003) as indicated in Table 2.1. Other authors log the average data at periods between 1 and 10 minutes (Berg *et al.*, 1998, Bloem *et al.*, 2004, Koutroulis *et al.*, 2001, Michopoulos *et al.*, 2006, Wichert *et al.*, 2001, Wilshaw *et al.*, 1997).

It is sometimes impossible to assign the same measurement interval to all parameters being measured. For instance, within the DAQ-WBL project both the solar intensity and soil temperature had to be recorded and both had different rates of change. These features will be expanded on in Chapter 3, however the DAQ system needs to be capable of acquiring data at different rates or intervals from different sensor groups.

2.2.8 DAQ Accuracy and Calibration

This section discusses critical features of a DAQ system, such as measurement accuracy and calibration. Josh (2005) defined measurement accuracy as "the closeness with which the reading approaches an accepted standard value or the true value". The reading accuracy is both a function of the sensor and the DAQ system accuracy. The accuracy of a sensor is determined by calibration under certain operating conditions. Sensor accuracy range is depicted as plus or minus a specified value or a percentage, and a particular point or between particular points of range. For example, a thermocouple might display an accuracy of $\pm 1^{\circ}\text{C}$ between 0°C and 100°C .

2.2.8.1 Sensor Accuracy

One of the most crucial parts of the accuracy of the system is the accuracy of the sensors. Careful planning must be undertaken in order to source appropriately accurate sensors. In some cases the accuracy requirements are greater than the standards and increasing the accuracy or resolution of an instrument can only be done at the penalty of

increasing manufacturing cost (Morris, 2001), which may not be realistic. Hence the expectations on accuracy need to be balanced with the available budget.

There are many factors that influence or affect the accuracy or calibrated accuracy of a sensor. These include electrical noise, grounding and shielding, wiring, accuracy of sensors, environment, quality of calibration, temperature, drift, software and hardware, stability and reliability.

2.2.8.2 DAQ Hardware

DAQ hardware accuracy is an important factor for the accuracy and reliability of the DAQ system, as hardware with low accuracy will distort the accuracy of the sensors. Just like sensor accuracy, the hardware can be affected by electrical noise, grounding, wiring, environment, quality of calibration, temperature, drift, software, stability and reliability. Therefore it is important to acquire DAQ hardware that is equal or better than the accuracy of the sensors.

2.2.8.3 Calibration

The second most critical part of the DAQ accuracy relates to calibration. Calibration is important prior to installation as one cannot simply assume that a sensor will perform to the manufacturer's quoted accuracy because faulty values are hard to identify at the data analysis stage (Masheshwari *et al.*, 2006). This applies to the calibration certificate of sensors and equipment on purchasing and also the calibration of the entire DAQ system on installation. Calibration is defined as "the comparison of specific values of the input and output of an instrument with a corresponding standard" (Rangan *et al.*, 1997). There are many different conditions that affect an instruments calibration. These include temperature, time, mechanical wear, dirt, dust, usage and chemicals. A laboratory or calibration area must be set aside for the calibration process in order to control the surrounding environment as much as possible. Morris states that the level of environmental control required during calibration should be considered carefully with due regard to the level of accuracy required in the calibration procedure (Morris, 2001).

The calibration process should range above the maximum and below the minimum values that the instrument will measure and the value recorded. Readings should be taken during the calibration procedure both in the ascending and descending order (Rangan *et al.*, 1997). Depending on the level of accuracy involved, the calibration of the instruments may be required on a regular basis. Where possible calibration should be carried out to a relevant standard such as BS EN ISO/IEC 17025:2005.

Other issues that affect the accuracy of the system are the stability of the output signal and of the voltage input. If the hardware does not provide stable and consistent signals the application software will be unable to produce quality data. Signal conditioning is another method of removing noise from a signal. Noise can also be reduced from an electrical field by placing a grounded wire mesh over the circuit which will effectively kill the electro static or electrical field and reduce the noise effect (Ozkul *et al.*, 1996). This is known as a Faraday Cup.

Other method of reducing noise is to ensure that the wires are positioned as far away from noise sources as possible. Morris states that a “minimum separation of 0.3m is essential but 1m is preferable” (Morris, 2001). It is also recommended that the signal cables are run separately to the power cable. If they are required to run closely ensure that they cross over at right angles to each in order to keep contact to a minimum. A range of these steps were employed in this DAQ-WBL project to prevent the transfer of unwanted noise to the sensor signals.

2.2.9 Data Acquisition Hardware and Software Products

While DAQ equipment supplied by National Instruments had been adopted by GMIT’s Mechanical and Industrial Department in 2002 for educational use, a wide range of products were reviewed at the outset of this research project and the various leading options available are summarised in this section. Most manufactures supply both hardware and software products and will recommend a compatible system that will interact with their product. Hardware and software is an integral part of the DAQ system and requires research and planning before acquisition.

Some of the main suppliers currently on the market are National Instruments, Honeywell, Omega, Keithly Instruments and Data translation (Datx). Siemens, ABB and others are commonly used for larger industrial DAQ and control systems for large industrial plants or production processes.

2.2.10 Summary

Despite the availability of a range of quality products it was decided that the DAQ equipment used in this DAQ-WBL project should be consistent with that used by GMIT’s Mechanical and Industrial Department and hence NI products were deployed.

The next section reviews some of the web based learning initiatives created by a number of institutions and explores the functionality of dedicated learning environments that have emerged.

2.3 Web Based Learning

Electronic Learning (E-learning) supports have been established to promote E-Learning as part of educational and training initiatives coordinated by the National Centre for Technology in Education (NCTE) and e-learningeuropa, organisations in Ireland and in Europe respectively. The NCTE was established in 1998, “to provide advice, support and information on the use of ICT in education”. Elearningeuropa was established in 2000 and was setup by the European Commission to “promote the use of multimedia technologies and the internet at the service of education and training”.

Academic institutions have also embraced Information Technology (IT) to support the development of new approaches to learning, by promoting greater access to knowledge through E-Learning platforms. Institutes like Cork IT, Dublin IT, Galway–Mayo IT, IT Sligo and Waterford IT are each availing of the web to deliver course materials and conduct assessments using software such as Moodle™, a free and open source E-Learning software platform, and Blackboard. Custom designed initiatives such as ‘distance learning courses’ have been pioneered by IT Sligo. This allows students to take courses online with reduced class attendance (4-5 days per academic year) and has gained wide acclaim amongst students and lecturers. While many educational institutes support the provision of course notes, lecture materials and conduct assessments online, a smaller number are making the significant investment to replicate the physical infrastructure of practical laboratory experiments using either remote or virtual representation on the web.

The more expensive virtual/remote laboratory based initiatives developed are discussed in Section 2.4. These enable educators to access a wider audience and provide this audience with a safe and easily repeatable environment to carry out laboratory demonstrations and practical experiments.

The ever advancing capability of ICT has generated these new opportunities for learning providers. Students, industry and the general community are becoming more familiar with, and dependent on computer technology. Learning providers seek new ways to transfer knowledge to learners as they juggle their work and life balance. Therefore, it is not surprising that a flexible method of learning such as E-Learning has become popular and this DAQ-WBL project sought to embrace these practices to support learning associated with sustainable energy systems.

Numerous configurations have been created including remote/virtual labs; Drigas, *et al.*, 2005; Hutzel *et al.*, 2006; Lund *et al.*, 2001 and on-line sustainable energy courses such as those offered by University of Ulster (2008) and Chevron Training (2008).

2.3.1 E-Learning Initiatives

Allen (2003) defined E-Learning as “a structural, purposeful use of an electronic system or computer in support of the learning process”. It is sometimes also referred to as online learning, distance learning and web-based learning. Supported by Table 2.3, this section reviews seven of the leading E-Learning approaches that have been deployed in conjunction with initiatives to promote SET's.

Table 2.3 Summary of E-Learning initiatives deployed by educational institutes to promote SET's.

| # | Researcher/Institute/Url | Technologies | Goals of Site |
|---|---|---|---|
| 1 | Lund <i>et al.</i> , Murdoch University, Australia, 2000, www.risc.org | Live data, sustainable energy systems, energy awareness and promotion, labs | “To test, research, promote, educate and demonstrate RES in order to support Australia’s sustainable energy Industry” |
| 2 | Queens University, Canada, 2006, http://livebuilding.queensu.ca/ | Live data, energy awareness and promotion, sustainable energy systems, green features, labs | “To create a ‘live building’ to be used as a lab and to be made available to researchers, students and the public to further advance engineering theories and ideas” |
| 3 | Willis College, Canada. http://www.williscollege.com/International/Programs/Energy/index.html | Sustainable energy courses | “To offer flexibility to students wishing to study online and for individuals from anywhere in the world. To assist the public to acquire skills to manage sustainable energy projects, combine existing transferable skills or acquire the skills on the latest sustainable energy technologies” |
| 4 | University of Vermont, USA http://buildingdashboard.com/clients/uvm/davis/ | Energy awareness, sustainable energy systems, Live data, green features | “To hold the college community accountable for their environment and to display to the college community and visitors the energy flows, water and materials used to create a more ecological conscious place” |
| 5 | Oberlin College, USA, 2000, http://www.oberlin.edu/ajlc/ajlcHome.html | Energy awareness, sustainable energy systems, Live data, green features, | “To be used as a core area of the students environmental studies and to share this information with other students, educators, activists, architects or other interested parties in creating a sustainable relationship among humans, technology and the natural world” |
| 6 | Blanchard <i>et al.</i> , CREST, Loughborough University, 2006, UK, http://crestdl.lboro.ac.uk/outside/index.php | Biomass, hydro-electric power, Solar PV | “To offer flexible and distance learning for study at home or in your workplace in sustainable energy” |
| 7 | Moreno <i>et al.</i> , Desire - Net Project, 2007, Italy http://www.desire-net.enea.it/e-learn.htm | Sustainable energy courses | “E-Learning in sustainable energies for managers, designers and operators in Central, East and South East European and South Mediterranean countries” |

a) **Murdoch University, Australia:** One such approach has been created by Lund *et al.*, (2001) at Murdoch University, Australia, to inform the community about the cost, performance and reliability of sustainable energy systems by providing them with on-line access to a demonstration of the following three sustainable energy systems;

System 1) 160W solar PV array.

System 2) 300W solar PV array and a 300W micro wind turbine.

System 3) 1.2kW solar PV array and a 1.8kW micro wind turbine.

The University hopes to provide this information to the community so as to promote itself and the application or suitability of sustainable technologies in Australia.

At Murdoch University a DAQ system is connected to System 3, (1.2kW solar array and a 1.8kW wind turbine). A PC and DAQ card perform the data logging and data analysis and the learner/user interface is generated using Labview™ as shown in Figure 2.6. The learner/user interface also provides the locally measured meteorological data as indicated in Figure 2.6.

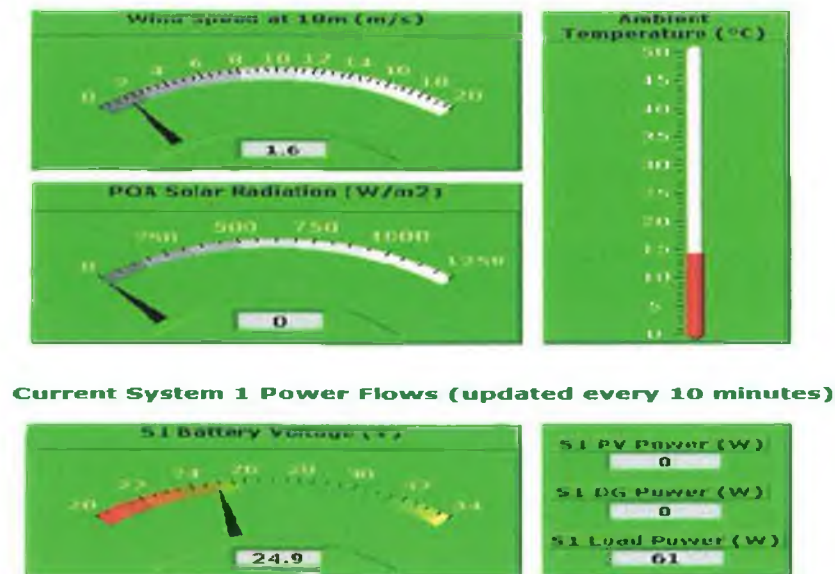


Figure 2.6 User interface from the University of Murdoch's E-Learning environment showing the Meteorological data and the power output from a 160W PV collector [Source: Murdoch University, 2008].

Learning is therefore facilitated by presenting both the weather and the system performance data in the same screen where learners can clearly identify the reaction of the energy system to the energy source, be it wind speed (wind turbine) or solar intensity (solar PV) and then plot the comparisons. Reflective learning is available by providing an option to download historical data. Further changes and improvements have recently been made to this E-learning site by the University who now also provide certified testing, research and development services to industry. The University also provides education, training and other services in the field of sustainable technologies.

Similar facilities have been developed by Blanchard *et al.*, (2006) at Loughborough University, UK and Moreno *et al.*, (2007) through a Bureau for Science and Culture in Europe (BRESCE) funded project entitled “Development and Sustainability with International Sustainable Energies Network” (Desire-Net).

b) Queens University, Canada: Queens University, Canada, has developed the comprehensive and extensive website shown in Figure 2.7(a) for educational purposes. The site uses the campus as a ‘living lab’ to generate detailed and relevant data on both the energy consumption of up to 90 campus buildings and their embedded sustainable energy systems. Viewers can select each campus building from a 3D campus map, shown in Figure 2.7(b), and the daily, weekly, monthly or yearly power consumption for that building is displayed. A more detailed level of information is also presented at the energy system level as the mechanical/electrical systems within the building are instrumented and provide live data as presented in Figures 2.7(b-d).



Figure 2.7(a) Homepage of Queen's University Living Lab showing the six key features of this e-learning environment [Source: Queen's University, 2008].

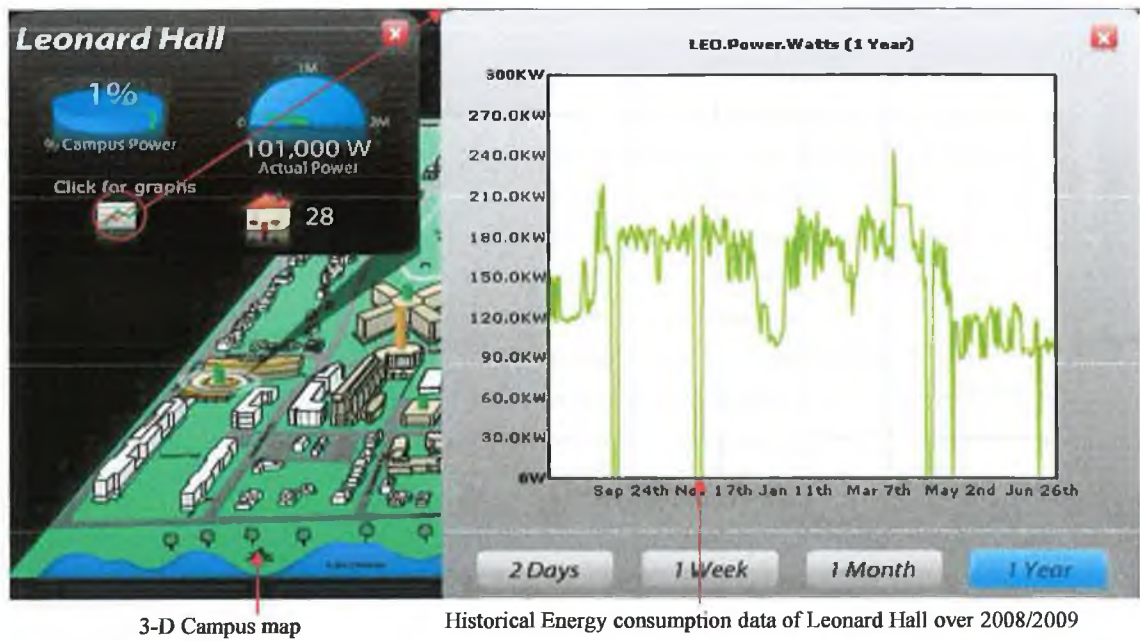


Figure 2.7(b) Detailed breakdown of Campus power consumption by building [Source: Queen's University, 2008].

Some sub-systems such as the air ventilation system in Figures 2.7(c) and (d) are monitored and graphically represented in great detail. Users can view the system in operation and carry out performance analysis on the system, thereby giving students a deeper understanding of the technology.

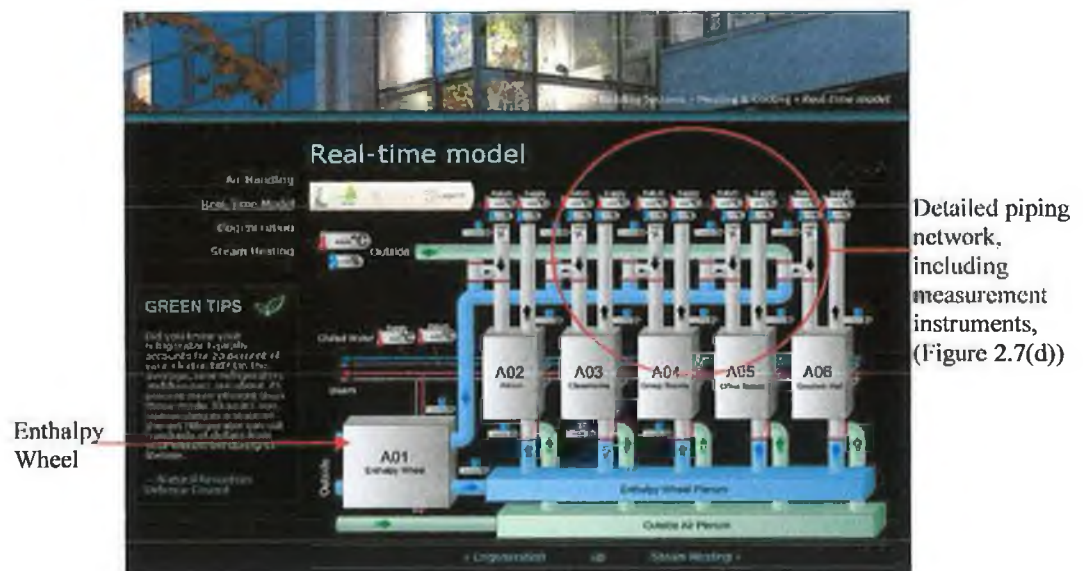


Figure 2.7(c) Schematic of the air-handling system and the data monitoring deployed to record its performance [Source: Queen's University, 2008].

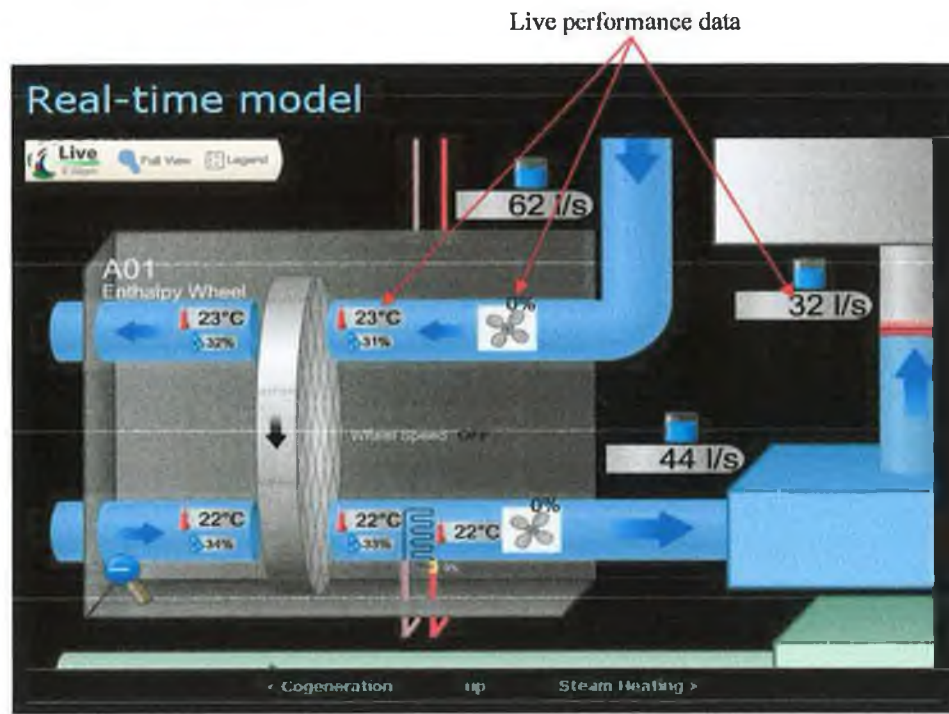


Figure 2.7(d) Detailed performance data of enthalpy wheel system from Figure 2.7(c) [Source: Queen's University, 2008].

Figure 2.7(e) shows the analytical functionality offered by the website, where the user has the option to select one of the 4 available solar arrays and to identify and download the data associated with specific dates or time periods while also specifying specific statistical formats from average, maximum, minimum or mean data. The local weather data is also available to further support the learning and performance analysis of the sustainable energy systems.

The screenshot shows a web interface titled "CHOOSE DATA POINT AND RANGE" and "RESULTS". It includes a dropdown menu for "Solar Array", date and time pickers, a "TIMING & STATISTICAL ANALYSIS" section with radio buttons for "Original Values", "Interpolated Values", "Average", "Minimum", and "Maximum", and a "RESULTS" table. Red arrows point to five features: 1. Select specific system (Solar Array dropdown), 2. Select start date (18-Jul-08), 3. Select end date (18-Aug-08), 4. Select type of statistical analysis (Interpolated Values), and 5. Download data (Get Values button).

Features:

1. Select specific system
2. Select start date
3. Select end date
4. Select type of statistical analysis
5. Download data

CHOOSE DATA POINT AND RANGE

Solar Array
 Select an item
 Mechanical
 Electrical
 Solar Array
 Weather
 Lighting
 Learning Column

Temperatures
 Flashing 3

START TIME
 18-Jul-08
 dd-Mon-YY (08-Aug-06)
 18:52
 24h format (19:00)

END DATE
 18-Aug-08
 dd-Mon-YY (09-Aug-06)
 18:52
 24h format (23:00)

TIMING & STATISTICAL ANALYSIS

Original Values
 Interpolated Values
 Average Std Dev
 Minimum Maximum
 Mean (event-weighted)

Period:
 1 day

RESULTS

Table: Interpolated
 Step Interval: 1d
 From: 18-Jul-08 18:52
 To: 18-Aug-08 18:52

EV Temp Level 4 Flashing 3 (DegC)

| | | |
|------------|----------|--------|
| 2008-07-18 | 18:52:00 | 27.131 |
| 2008-07-19 | 18:52:00 | 28.337 |
| 2008-07-20 | 18:52:00 | 22.654 |
| 2008-07-21 | 18:52:00 | 22.605 |
| 2008-07-22 | 18:52:00 | 22.623 |
| 2008-07-23 | 18:52:00 | 22.437 |
| 2008-07-24 | 18:52:00 | 22.352 |
| 2008-07-25 | 18:52:00 | 22.266 |
| 2008-07-26 | 18:52:00 | 22.121 |
| 2008-07-27 | 18:52:00 | 22.055 |
| 2008-07-28 | 18:52:00 | 22.010 |
| 2008-07-29 | 18:52:00 | 21.924 |
| 2008-07-30 | 18:52:00 | 24.812 |
| 2008-07-31 | 18:52:00 | 29.678 |
| 2008-08-01 | 18:52:00 | 27.202 |
| 2008-08-02 | 18:52:00 | 21.950 |
| 2008-08-03 | 18:52:00 | 21.707 |
| 2008-08-04 | 18:52:00 | 21.743 |
| 2008-08-05 | 18:52:00 | 21.710 |
| 2008-08-06 | 18:52:00 | 21.676 |
| 2008-08-07 | 18:52:00 | 21.643 |
| 2008-08-08 | 18:52:00 | 21.610 |
| 2008-08-09 | 18:52:00 | 21.576 |
| 2008-08-10 | 18:52:00 | 21.543 |
| 2008-08-11 | 18:52:00 | 21.509 |
| 2008-08-12 | 18:52:00 | 21.476 |
| 2008-08-13 | 18:52:00 | 21.442 |
| 2008-08-14 | 18:52:00 | 21.409 |
| 2008-08-15 | 18:52:00 | 21.375 |
| 2008-08-16 | 18:52:00 | 21.342 |
| 2008-08-17 | 18:52:00 | 21.308 |
| 2008-08-18 | 18:52:00 | 21.275 |

Get Values
 Values will need to be saved in a text file with the
 Copy values to clipboard

Figure 2.7(e) Details of the functionality offered to the viewer to access, customise, analyse or download historical performance data from a menu of monitored energy systems [Source: Queen's University, 2008].

Section 2.3 has reviewed the state-of-the-art learning environments that utilise live and historical performance data from sustainable energy systems. They highlight the need for good quality, high resolution performance data, clear graphical representation for each energy system and supporting descriptions of the system. These features are employed within the DAQ-WBL environment.

The next section details some of the remote and virtual laboratories developed by a number of educational institutions.

2.4 Remote and Virtual Laboratories

The most advanced E-learning environments now offer students the opportunity to conduct their own online or virtual experiments using very well instrumented equipment located at a remote location. There are two scenarios that the developers can create, either virtual or remote laboratories. A virtual laboratory is one that is carried out entirely over the web using a software simulation and a remote experiment actually connects to physical equipment over the web.

One such remote experiment has been created by Michaelides *et al.*, (2004), through the Higher Technical Institute (HTI), Cyprus with the support of an EU project called MARVEL. MARVEL was project funded by the European Commission (EC) as part of the Leonardo Da Vinci European vocational training programme. The project is supported by a network of colleges, industry partners, and other institutions from Cyprus, Germany, Greece, Portugal, United Kingdom and Switzerland. The HTI solar energy remote laboratory comprises of a solar energy conversion plant which is equipped with all the necessary instrumentation and control devices required for remote access, control, data collection and processing (Michaelides *et al.*, 2004).

The overall architecture of the experimental facility is presented in Figure 2.8(a). It consists of four different sections, the user, the site server, the TestPoint web server and the physical solar system. The user has access to the system via the internet and only communicates with the physical system via the web server. The web server communicates the parameters and booking details set by the user to the TestPoint server. This TestPoint server which is located within the Institute's LAN, returns images and the performance data of the solar system to the web server which is viewed by the user.

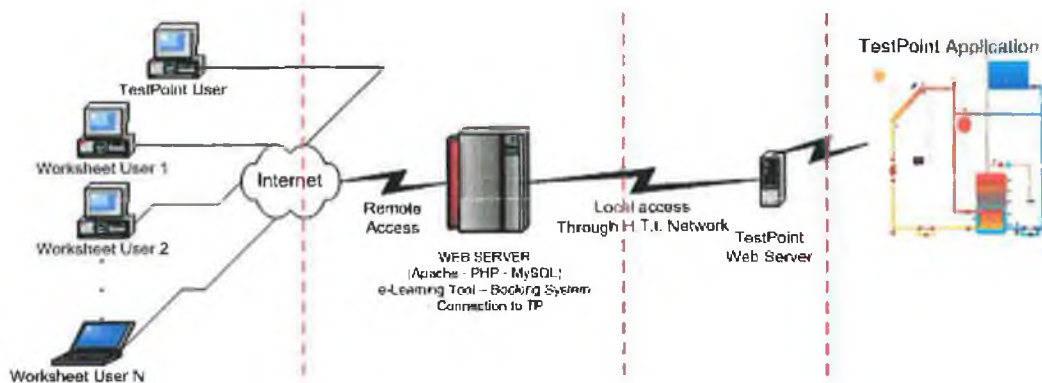


Figure 2.8(a) Schematic diagram of the architecture of the solar thermal remote laboratory constructed as part of the MARVEL project [Source: Michaelides *et al.*, 2004].

The equipment consists of two, 3m² flat plate collectors, a thermal storage tank and instrumentation and control equipment. A schematic of the solar facility is presented in Figure 2.8(b).

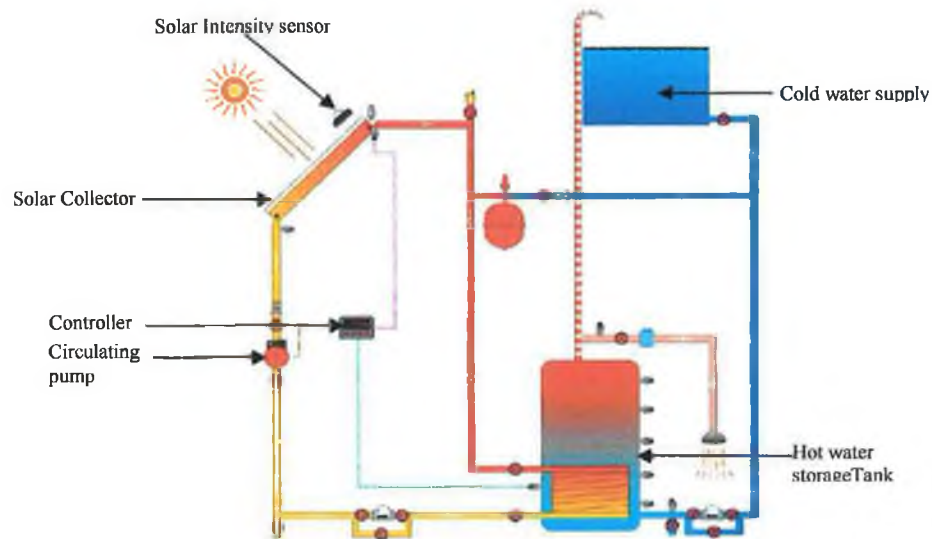


Figure 2.8(b) Schematic diagram of the solar thermal remote laboratory constructed as part of the MARVEL project [Source: Michaelides et al., 2004].

The facility was established to educate technical and engineering students about solar energy and technologies through experimental based learning and an operational diagram is shown in Figure 2.8(c).

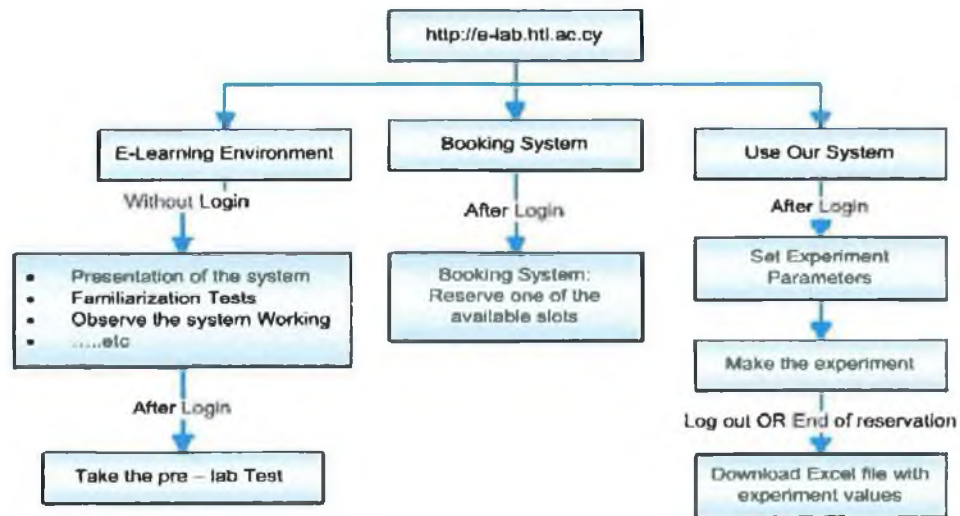


Figure 2.8(c) Operational flow diagram for the solar thermal remote laboratory constructed within the MARVEL project [Source: Michaelides et al., 2004].

The system has been designed to facilitate the following:

- Familiarisation with the system (without login) through reading notes and presentations about the solar system and each labelled components from Figure 2.8(b) and also a theoretical background on solar energy through downloadable notes.

- Familiarisation with each operational component and also the 'operation of the system' by following an animated working system and then by carrying out a 'pre-lab test' where the user has the opportunity to label each system component and answer a set of multiple-choice questions. This test must be passed by attaining a mark of 50% or more, before gaining access to the live experiments. Pre-registration controls entry to this section and users can also view photographs of the solar facility at this point.
- After passing the 'pre-lab test' users must register and 'log in' to book the system on a date and time that is convenient to the user and availability of the system.
- When the test time arrives the user must 'log in' and configure the experimental parameters (remove hot water from storage tank or set differential temperature controller to 2°C, 4°C or 6°C) with the aid of downloaded sheets. When the experiment is started the live data presented in Figure 2.8(d) is displayed on screen. The user can download the recorded data to excel files and analyse the solar facilities performance. This concludes the experiment and the viewer must logout to exit the experiment.

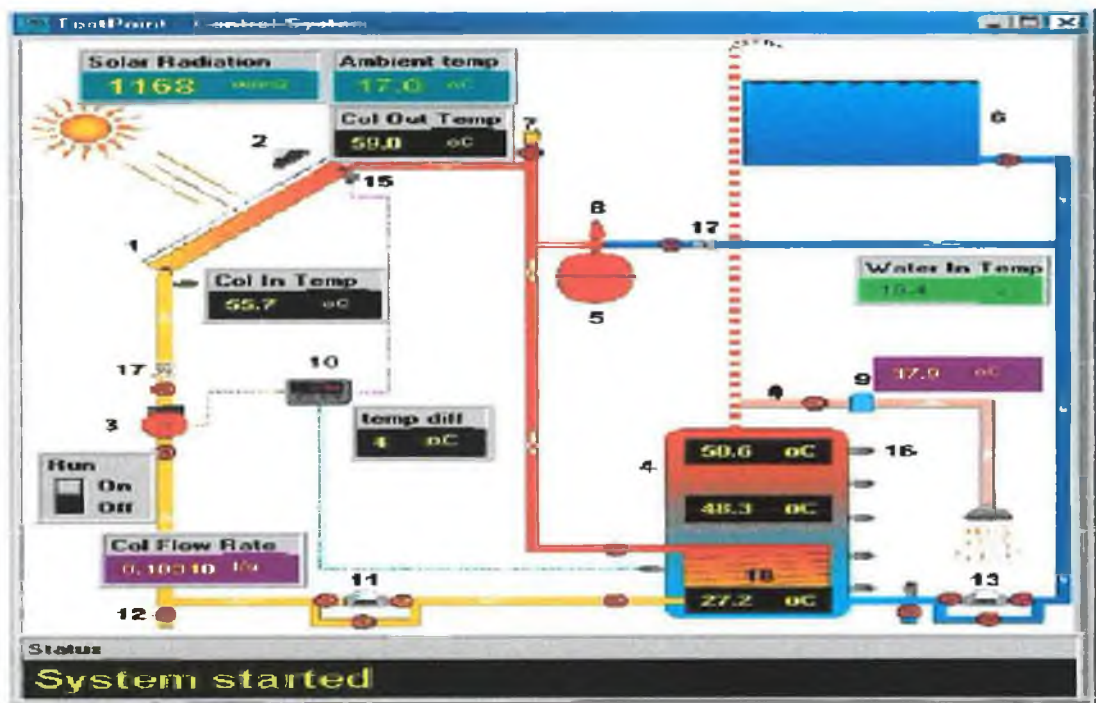


Figure 2.8(d) Screen-shot of the live system during experimentation of the solar thermal remote lab [Source: Michaelides et al., 2004].

Reflecting the recent growth in popularity of E-learning, other similar facilities have been created by Drigas *et al.*, (2005), Hutzet *et al.*, (2006) and Hamar *et al.*, (2007) and the functionality of these environments are reviewed in Table 2.4.

However since all the cited examples in Table 2.4 have been developed with the support of significant funding, it highlights the huge effort and resources required to develop such a facility. Despite this, the DAQ-WBL project sought to establish the basis for a remote laboratory for passively monitoring and performance analysis of the two solar thermal collectors and two GSHP's operating on the GMIT campus. It was not feasible to design in remote access to control (switch on/off) these systems since they were live functioning systems and not laboratory based teaching aids.

Table 2.4 List of remote/virtual laboratories created by academic institutes to support E-learning initiatives in sustainable energy

| # | College/Company/ <u>url</u> | Technology | Features of lab; Motivation. Target audience, Success, funding body |
|---|---|---|---|
| 1 | Michaelidis <i>et al.</i> , (Higher Technical Institute, Cyprus) http://www.e-lab.hti.ac.cy/ | Live data, Solar Thermal Collector | "To create a live laboratory in a virtual environment and provide online access to students on or off campus". RES University students Accessed in 400 locations in 75 countries (2005), Leonardo da Vinci Project (EU) |
| 2 | Drigas <i>et al.</i> , (National Centre of Scientific Research, N.C.S.R, Greece.) http://imm.demokritos.gr/solwin/Project/project.html | Solar PV Collector, Solar Thermal Collector | "Promotion of self teaching in RES through multimedia" RES Technical support Funding body Leonardo da Vinci Project (EU) |
| 3 | Hutzet <i>et al.</i> , Purdue, University, USA http://www2.tech.purdue.edu/Met/Facilities/knov427/remote/nsf/index_rev.htm | Live data, RES systems, labs | "Testing RES and an innovative way of displaying this data for students to learn about RES" RES University students Improvement in educational experience, National Science Foundation, Automated logic, Carrier and KMC Controls |
| 4 | Blanchard <i>et al.</i> , (Loughborough University, UK) http://engcetl.lboro.ac.uk/activities/portfolio/ | Biomass, hydro Power, Solar PV | "Provide an interactive simulated lab for MSc. Renewable Energy course" RES University students Continued funding and expansion and increased number of courses Higher Education Academy Engineering Subject Centre |
| 5 | Siemens Challenge http://www.wecanchangeheworldchallenge.com/resources/student-resources/virtual-labs/ | Wind Turbine | "Create sustainable, environment that improves in their local communities" Primary school students Siemens and Discovery Education |

Taking all these scenarios into consideration some of the advantages of remote/virtual laboratories include;

- Accessible any where in the world, thereby overcoming geographical and travel impediments.
- Flexibility of access time, which allows the learner control study patterns and enables education Institutes achieve better utilisation of resources outside peak hours.
- Students motivated by carrying out learning exercises and multiple choice tests before gaining access to the on-line Laboratory, as apposed to just viewing a demonstration.
- Laboratory can be carried out at learners own pace as they navigate through the site. It also ensures better participation from the learner as some students may not gain too much access to the laboratory in group based laboratories.
- Exposes and promotes laboratory/Institute to a larger audience.
- Cheaper, safer and greener in-keeping with environmentally friendly ethos.
- Always available regardless of budget or facility access.
- The log-in system can track which student actually conducts experiments and results they downloaded. Even the report could be submitted online.

As discussed in the previous sections these websites are developed to educate viewers about SET's but they are also developed to promote and create an awareness of SET's, therefore the next section will reviews such websites.

2.5 Promoting Energy Awareness via the Internet

In line with the goals of the Energy White paper (2007) 'Delivering a Sustainable Energy Future for Ireland', this DAQ-WBL project sought to promote greater awareness and understanding of sustainable energy systems and their performance. As a result this section investigates how a growing number of commercial and educational entities now use web-based interfaces to achieve similar goals.

Seven of the leading web-based interfaces that have emerged to promote SET's are listed in Table 2.5. It is clear that both commercial companies and the educational institutes are exploiting advances in Information and Communication Technologies (ICT's) to support commercial and educational activities associated with promoting an increased

awareness of SET's. There are two main options available to those interested in promoting sustainable energy systems or energy efficient initiatives via the internet and are either; custom designed or commercial website formats.

2.5.1 Custom Designed Websites

This option requires the development of custom designed web pages. Although more time consuming and demanding, since a greater knowledge of web design and programming is required, this solution is more flexible and less expensive. Users also have the freedom to customise the data display to their own requirements and not be confined to the generic platforms provided by commercial providers. Two examples of such an approach are presented in Figures 2.9 and 2.10.

Table 2.5 Commercial and research organisations that promote the awareness of sustainable energy systems using the internet.

| # | Organisation (URL) | Technology Promoted | Country/ Business |
|---|--|---|--|
| 1 | City of Loma Linda Fire Station http://www.fatspaniel.com/swfs/LomaLinda_fireStation.swf | Solar PV panels, weather station | USA, Fire Station |
| 2 | Maquoketa Valley Electric Cooperative www.mvec.com | Solar PV collector, weather station, wind turbine | USA, electric power supplier |
| 3 | Research Institute for Sustainable Energy www.rise.org | Solar PV collector, battery banks, weather station, wind turbine, solar thermal collector | Australia, University research centre |
| 4 | Wisconsin Energy Conservation Cooperation http://wecc.greentouchscreen.com | Solar PV collector, building monitoring | USA, energy conservation co-op |
| 5 | Woods hole Research Center www.whrc.org | Solar PV collector, solar thermal collectors, wind turbine, weather station, building performance | USA, energy and conservation research |
| 6 | Yahoo http://buildingdash board.com/clients/yahoo/ | Weather station, building monitoring | USA, online network for internet services |
| 7 | Beaufort Sustainable Energy Research Centre http://www.beaufortcourt.com/ | Wind turbine, solar PV, solar thermal, bio-mass boiler | England, promote a sustainable future through research and demonstration |

Maquoketa Valley Electric Cooperative (MVEC) presents a custom designed display of the performance of a Photo-Voltaic (PV) array, a wind generator and a weather station through their website in Figure 2.9. The data is displayed in their custom interface where

the user can select different systems and different time scales as shown in Figure 2.9. The time scales are presented as tabs across the top of the graph. Each tab represents a different predefined time scale's (today, yesterday, current week, last week, current month, last month) that the viewer can select. These products allow users to interrogate the performance of both their buildings and the sustainable energy based power sources. The performance of their energy systems can be compared to similar facilities in nearby geographical locations. Organisations use the platform to promote their efforts in sustainable living and in doing so promote their organisation or product/service while also acting as models for others.

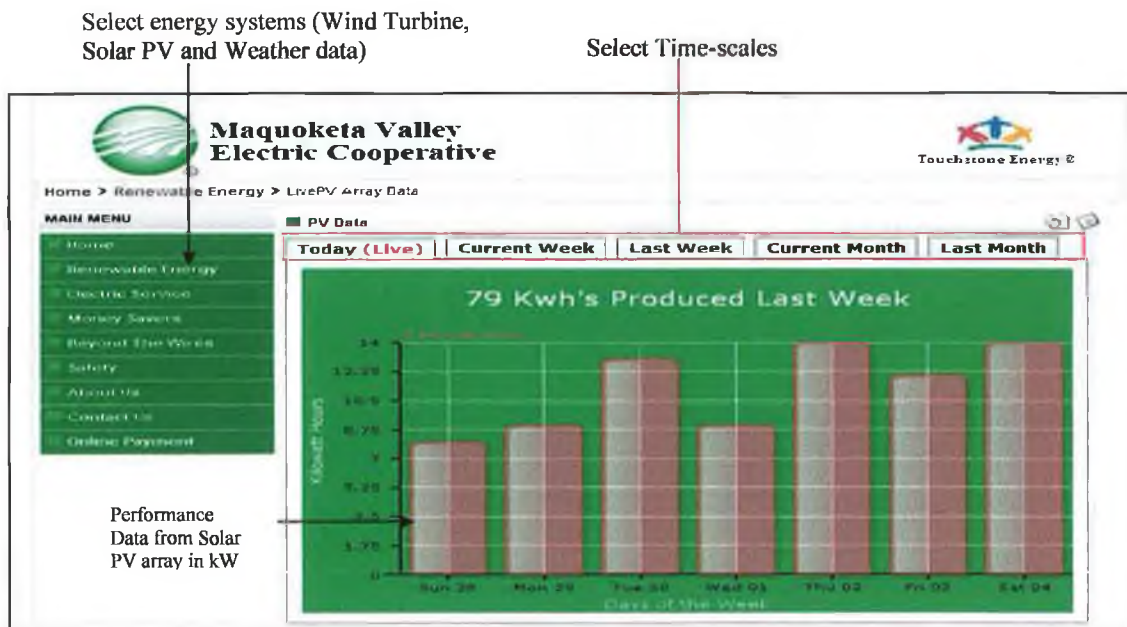


Figure 2.9 Online promotion of sustainable energy systems from MVEC [Source: Maquoketa Valley Electric Cooperative, 2008].

A similar customised initiative was created by Beaufort Court to promote their sustainable energy systems and promote a greener environment. Their systems include a wind turbine, solar PV collector, solar thermal collector and a bio-mass boiler.

Select sustainable energy system (Wind Turbine, Solar PV, Solar Thermal and Bio-mass Boiler)

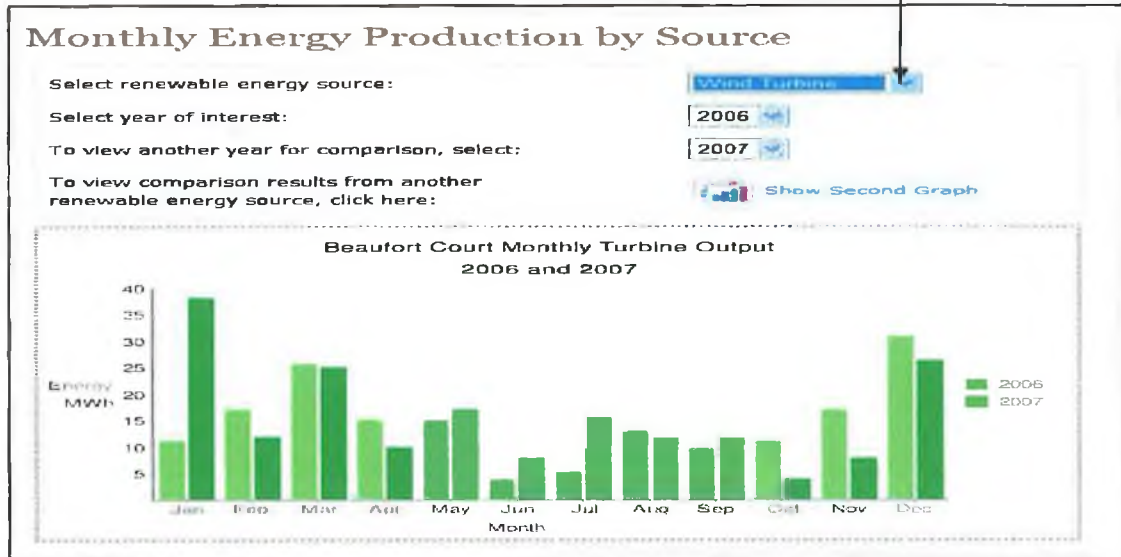


Figure 2.10 Online promotion of sustainable energy systems by Beaufort Research Centre [Source: Beaufort Court, 2009].

2.5.2 Commercial Designed Websites

The second option is to use commercially available software such as Greentouchscreen, Fatspanel, Building Dashboard, DECK monitoring and Sunviewer who provide off-the-shelf solutions. These products provide the platform for users to display system performance data and promote their sustainable energy systems, green features or initiatives online. A typical screen shot from a site developed by Building Dashboard on behalf of the Yahoo Company is presented in Figure 2.11 and displays the electricity consumed by all Yahoo buildings during a particular day. A similar dashboard generated image is presented in Figure 2.5(a) for a different client, Emory University.

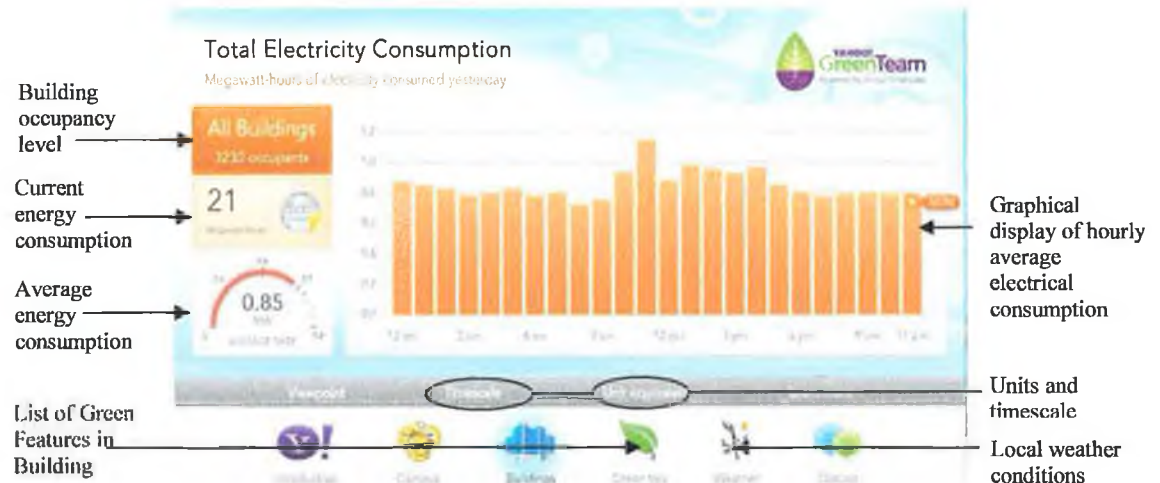


Figure 2.11 Interactive Energy monitoring website showing hourly averaged electrical consumption within all Yahoo's building on the 20-10-2008 [Source: Yahoo, 2008].

These software products are installed on a local server and connected to the host organisation's Building Energy Management System (BEMS), or monitoring devices/data loggers, similar to those described in Section 2.2, and display measured data online via graphical displays (Figures 2.5(a), 2.9, 2.10 and 2.11). These software products provide a range of data analysis and presentation tools outlined in Table 2.6.

Table 2.6 Functionality of commercial software tools available for the promotion of sustainable energy systems.

| Software Functionality | Commercial Software Tools | | | | | |
|---|---------------------------|-------------------|--------------------------------------|----------------|--------------|--------------|
| | Fatspaniel | Green Touchscreen | Building Dashboard | Noveda Systems | Sunviewer | SolarQuest |
| Present current live energy consumption | Fig 2.5 (b) ✓ | Fig B.5(d) — | Fig 2.5(a) Fig 2.12(a) ✓ | ✓ | ✓ | ✓ |
| Present historical energy consumption as a function of user defined timeframe, (e.g day, week or month) | Fig 2.5 (b) ✓ | Fig B.5(d) ✓ | Fig 2.5(a) Fig 2.12(a) ✓ | ✓ | ✓ | ✓ |
| Converts actual consumption (kWh) into other equivalent units such as km of walking, number of burgers, dollars, oil barrels | ✓ | ✓ | Figs 2.14(a) Fig 2.12(a) ✓ | — | — | ✓ |
| Present a breakdown of energy supply from each energy source (electricity, oil/gas, sustainable energy system) | — | Fig B.5(d) ✓ | Fig 2.5(a) Fig 2.12(a) — | ✓ | — | ✓ |
| Present local weather data | Fig 2.5 (b) ✓ | ✓ | ✓ | ✓ | ✓ | — |
| Provides a description or further information of the green features or sustainable energy systems | ✓ | Fig B.5(d) ✓ | Fig 2.5(a) ✓ | — | — | — |
| Highlights contribution of energy saving green features (e.g. Grass covered roofs, recycled mats, recycling low energy exterior lights) | ✓ | Fig B.5(d) ✓ | Fig 2.5(a) ✓ | ✓ | — | — |
| Options to download performance data for each energy system | — | — | — | — | ✓ | ✓ |
| Performance data of the sustainable energy system can be plotted against local weather conditions | Fig 2.5 (b) ✓ | — | — | — | — | — |
| Examples provided in | Fig 2.5 (b) | Fig B.5(d), | Fig 2.5(a), Figs 2.12(a) & (b) | Appendix B.4 | Appendix B.4 | Appendix B.4 |

They also allow the client limited options to custom design the interface to reflect their local green initiatives and infrastructure by including a pallet of photographs and brief descriptions of such features. Another example is presented in Figure B.5(d) where Wisconsin Energy Conservation Corporation (WECC) utilises GreenTouchscreen technology to inform others of their facility and energy saving initiatives.

Such organisations share their own experience and understanding of the environmental benefits of using sustainable technologies to promote good practice in displaying SET's and energy efficient technologies with the aid of kiosk displays placed within the organisation as well as online displays. Viewers are aware of the amount of energy they or their building consumes in standard kilo-Watt-hour units. To help viewers to relate energy consumption rates to everyday events consumption is sometimes converted into equivalent units such as money, number of light bulbs, distance travelled by car or number of burgers as indicated in Figures 2.12(a) and (b). This enables the viewer to quickly equate a building's energy consumption with universally recognised quantities that all users and age-groups can relate to, which aids the promotional, educational and awareness process.

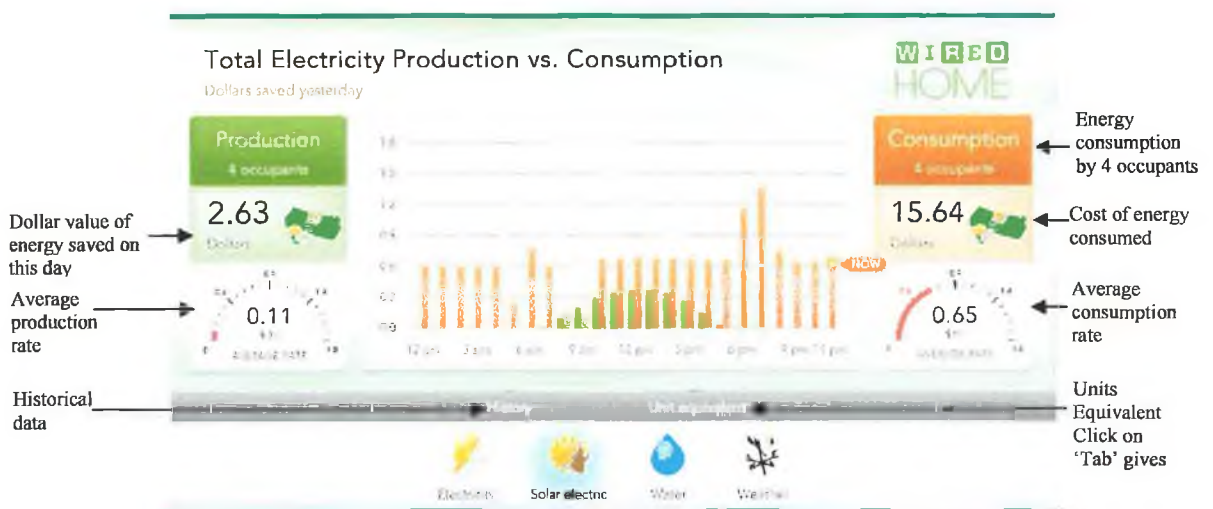


Figure 2.12(a) Value of energy consumed and produced in dollars [Source: <http://buildingdashboard.com/clients/wired/>, 2008].



Figure 2.12(b) Screenshot of available options presented by pressing "Units equivalent" in Figure 2.12(a).

Users of these monitoring systems are able to select a particular energy system and view historical performance data in graphical format over a predefined time period as presented in Figure 2.12(c). Similar systems can be compared at the same location and during the same time period.

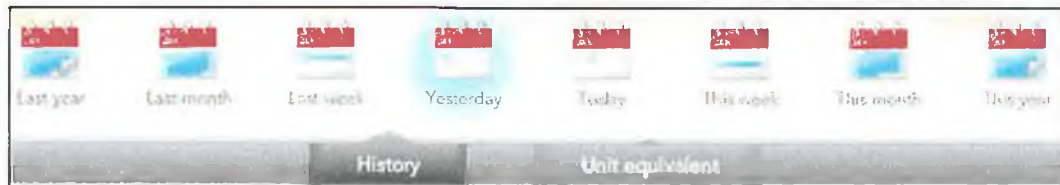


Figure 2.12(c) Screenshot of the various timeframes over which current and historical performance data in Figure 2.12(a) can be presented and analysed.

The data presented in Figure 2.12(a) has been logged at time intervals of between 1-15 minutes depending on the applications and stored in a database to be retrieved at a later date for analysis. The monitoring systems can provide data from buildings, sustainable energy technologies and weather stations. The performance of the system can be graphed against current weather conditions and in some cases, like Sunviewer from Heliotronics, where the data can be downloaded to a PC for further analysis.

Clearly, the motivations and benefits of such online interfaces include;

- a) They draw attention to companies or institutes who wish to promote themselves as environmentally friendly and/or their products and services, therefore they are very effective marketing tools.
- b) Provide potential customers with performance data to make an informed choice about the likely performance and payback times of a SET prior to purchase.
- c) Gaining a wider audience for sustainable energy systems and energy efficient technologies, best practices and green initiatives.
- d) Highlights the sensitivity of system output to climate conditions and to increase awareness and understanding.
- e) Provides students with access to quality data for educational and research purposes.

While the software tools presented in Table 2.5 and 2.6 are effective means of promoting sustainable energy systems and have educational benefits, they are not designed to support structured learning.

The next section reviews best practice design for such web based learning facilities and environments.

2.6 Design Guidelines for E-Learning Facilities/Environments

The emergence of E-Learning environments cited in Tables 2.3 and 2.4 has enabled best practice guidelines to emerge that help educationalists generate suitable site structures, technical content, graphical presentation and functionality. The design of such learning environments needs to reflect the following considerations:

- Target Audience: To ensure the appropriate content is developed. In the case of the DAQ-WBL project a diverse audience from the general public, primary/secondary/third/fourth level students, research or commercial audiences was being targeted. Other audiences may include visually impaired, different language/nationality etc.
- Site Design/Plan: Plan the structure, layout, information flow and ease of navigation for each target audience.
- Function: Whether informative, educational or commercial (research, marketing, promotional).
- Authoring Software: Type of website to be created i.e. tutorials, quizzes, simulations/virtual labs. Also target audience and ability of programmer.
- Graphical User Interface (GUI): Consistent graphics throughout, attractive and appropriate to target audience.
- Page Design and Layout: Correct mix of text, graphics and animations, menus consistently placed from one page to another.
- Animation and Graphics: To convey information clearly and effectively, with colourful graphics of interactive elements to excite and involve the viewer.

The overall site design is a key parameter. It is important to plan the structure, the layout, the information flow for the target audience prior to commencing the design process. It is important to develop a hierarchy as part of the structure in order to maximise the site's potential. Lynch *et al.*, (2003) recognised that "most sites depend on hierarchies moving from the most general overview of the site (homepage), down through increasingly specific submenus and content pages". It is also recommended to keep the hierarchy as flat as possible and restricting the submenu to three to four levels.

Horton (2003) stressed the need for the careful selection of the authoring software. Some software's are optimised for tutorial type websites where others are more suited to simulations. Also to be considered is the IT restrictions, such as firewall or other security protections and download limits that might exist in place at a local level. Financial constraints and time scale for website creation are also limiting factors.

Another important factor for the creation of an E-Learning environment is the GUI. The interface design is a crucial part of the site and dictates the overall feel and impression portrayed to the viewer. User interfaces that model transparency adhere to a consistent look and feel using a standardised naming scheme, graphics, orientation, navigation and other

interface elements (Shneiderman, 1998). Therefore, it is important to create an interface that will catch the viewer's attention, but will not have inconsistencies that will distract the viewer as they navigate through the site. Aust (2005) states that the use of standard types of pull down menus, navigation aids and positioning found in the Operating System (OS) and browsers should be applied throughout the site. Menus and toolbars should be located in the same position on each page on the site to avoid confusion and disorientation for the users. This is also reiterated by Fox (2005), Handke (2006), Lund *et al.*, (2005), Lynch *et al.*, (2003) and Piskurich, (2006).

Page design is also very important for engaging the user and retaining their attention. The correct mix of text, graphics and animations all combine to ensure a good learning experience for the user. The use of video and flash animations can also be very helpful, but getting the balance is the key. "Video and flash animations should generally only be used to serve a learning purpose" (Guralnick, 2006) which is also reiterated by Ebner *et al.*, (2002). Each page should appear uniform and menus consistently placed from page to page where the user will expect to find them. It is recommended to use text and images as much as possible to explain ideas or scenarios, and to place printed words next to corresponding pictures (Clark *et al.*, 2003 and Sam *et al.*, 1999). Lynch *et al.*, (2003) presents more detailed explanations of these concepts. The DAQ-WBL environment presented in Chapter 4 embraces many of these best practices and concepts.

2.7 Summary

A cross-section of DAQ enabled web-based learning and commercial online environments for SET's have been reviewed. These have provided an excellent overview of how to build a DAQ system for monitoring sustainable energy systems and how to translate measured data into an accessible, informative and educational learning environment. Many of these features will be implemented and discussed in Chapters 3 and 4. This DAQ-WBL facility is designed to serve both research and education equally well. As a result the complexity of the DAQ system is driven by the research demands and the web interface is driven by a desire to explore the educational potential, and thereby support the Institute achieve increased cohesion between research and teaching.

Chapter 3 Data Acquisition System

This Chapter details the DAQ system developed to monitor CiSET's research infrastructure. The DAQ system was built based on the best practice and recommendations outlined in Section 2.2. The hardware and software used are both described, as are the SET's, the weather station and the IiBC building which hosts the entire facility.

3.1 Introduction

The project brief required that four aspects of CiSET's research infrastructure shown in Figure 3.1 to be continuously monitored. These were:

- i) local climate, using a new weather station,
- ii) two solar thermal collectors,
- iii) two 15 kW ground source heat pumps,
- iv) IiBC building's internal air temperature.

Reflecting the deficit in the literature for detailed experimental studies on sustainable energy technologies in maritime climate regions discussed (Greene *et al.*, 2007a), the DAQ system was designed to;

- i) gather operating data to demonstrate how these relatively new systems to the Irish market function,
- ii) show how well these systems perform under the Irish maritime climate, and monitor their impact on the surroundings,
- iii) support research on how best to optimise their performance or integrate these systems into buildings or other applications in Ireland.

The many elements to a modern DAQ system were introduced in Section 2.2. As indicated in Figure 3.1 these elements include sensors (A), DAQ hardware (B), and the DAQ PC/software and database (C), used to activate and manage the DAQ process. The first element of the system is the sensors (A) that are used to measure the physical variables. The next element is the hardware (B) which gathers the signals from the sensors then conditions the signal and transfers this signal to the PC. Finally, the PC with aid of either application or driver software (C), interprets these signals and presents them in a format desired by the user.

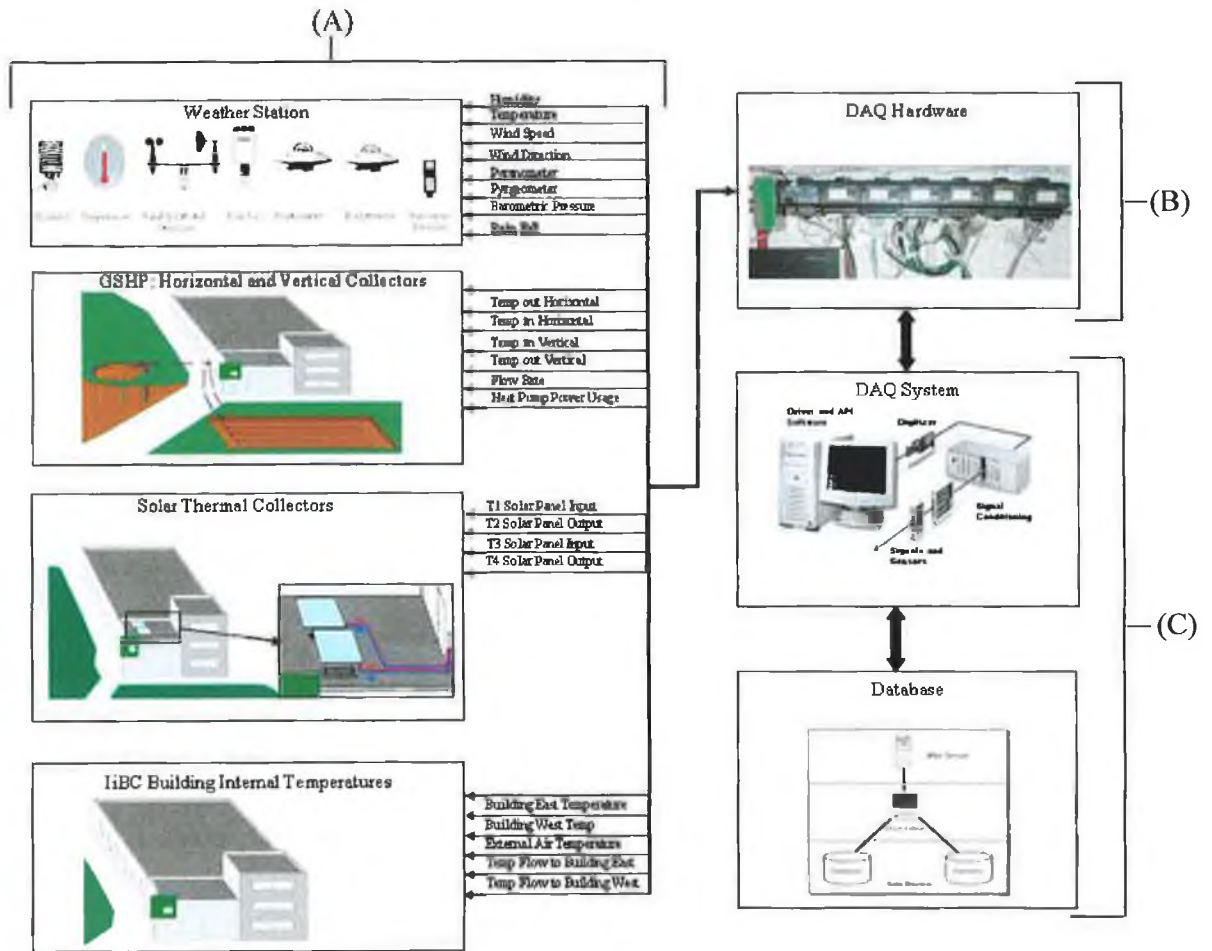


Figure 3.1 Schematic of the DAQ system architecture developed within the DAQ-WBL project.

A detailed breakdown of these aspects of the DAQ facility is presented in the following sections.

3.2 DAQ System Sensors

A total of 108 sensors were deployed to monitor the four aspects of the DAQ facility shown in Figure 3.1 and this section presents a detailed description of each sensor type along with the installation and calibration procedures carried out to create a reliable high performance DAQ system. Each sensor was calibrated using the same DAQ setup as in the eventual facility setup. These 108 sensors were allocated the four sub-systems as follows;

- i) Weather station: 12 sensors
- ii) Solar thermal collectors: 10 sensors
- iii) Ground source heat pumps and ground collector monitoring: 79 sensors
- iv) IiBC building environment: 7 sensors

3.2.1 Weather Station

In order to fully characterise and understand the performance of sustainable energy systems, the local climate conditions must be monitored. The climate variables to be measured were decided based on research conducted by Lohan *et al.*, (2006a) and included; air temperature, relative humidity, rainfall, rain temperature, wind speed, wind direction and solar radiation (infrared and shortwave). Ideally, the weather station should be located within close proximity of the systems being monitored, and this was achieved by mounting the weather station, shown in Figures 1.1 and 3.2, on the iBC building roof.



Figure 3.2 Photograph of the weather station positioned on the iBC building's plant room roof. The numbers refer to the sensor numbers listed in Table 3.1.

This weather station has the capacity to continually monitor 11 aspects of the local climate and Table 3.1 lists these parameters and the characteristics of the sensors used, including sensor output and measurement accuracy.

Sensor Numbers 1 and 2 - Air Temperature and Relative Humidity: The ambient air temperature and relative humidity was measured using a HMP45C instrument from Vaisala. The instrument includes a radiation shield as standard to enhance accuracy on sunny days. The wiring details for the HMP45C sensor are presented in Table E.1(a) and Figure E.3, Appendix E. The sensor is activated using a 24V signal and generates a 0-1V output for both weather variables. The output voltage signal is proportional to air temperature and relative humidity within the range of -40°C and +60°C and 0 to 100% respectively. Both sensors were connected to the FieldPoint module FP-AI-100. The air temperature sensor was calibrated against a PT100 temperature sensor with an accuracy of

$\pm 0.03^{\circ}\text{C}$ at 0°C and the humidity sensor had a manufacture's guaranteed accuracy of $\pm 2.5\%$ between 10-100% RH. The wiring diagram and configuration details for both these sensors are presented in Table E.1(a) and Figure E.3, Appendix E.

Table 3.1 Characteristics of the 12 sensors used to establish the weather station.

| # | Weather Variables | Sensor Type/Supplier | Sensor Input | Sensor Output | Sensor Measurement Accuracy |
|----|--------------------------|--------------------------------------|--------------|--------------------|--|
| 1 | Humidity | HMP45C/Vaisala | 24V | 0-1V | $\pm 2.5\%$ @ (10-100 % RH) |
| 2 | Air Temperature | HMP45C/Vaisala | 24V | 0-1V | $\pm 0.35^{\circ}\text{C}$ @ 0°C |
| 3 | Atmospheric Pressure | Model 278/Setra, | 24V | 0-2.5V | ± 0.3 hPa |
| 4 | Rain Gauge | Tipping Bucket Rain Gauge/R.M. Young | 24V | 24V Pulse | $\pm 2\%$ up to 25mm/hr |
| 5 | Rain Temperature 1 | Type K Thermocouple | — | $^{\circ}\text{C}$ | $\pm 0.35^{\circ}\text{C}$ @ 0°C |
| 6 | Rain Temperature 2 | Type K Thermocouple | — | $^{\circ}\text{C}$ | $\pm 0.35^{\circ}\text{C}$ @ 0°C |
| 7 | Wind Speed | A100L2/Vector Instruments | 24V | 0-2.5V | $\pm 1\%$ between 0.36-180 km/hr, $\pm 2\%$ between 180-277.8 km/hr |
| 8 | Wind Direction | AI00L2/Vector Instruments | 3.288V | 0-3.249V | $\pm 2^{\circ}$ |
| 9 | Solar Longwave Incoming | CMP-3 Pyranometer/Kipp and Zonen | — | 0-15mV | $\pm 10\%$ of daily totals |
| 10 | Solar Shortwave Incoming | CMP-3 Pyranometer/Kipp and Zonen | — | 0-15mV | $\pm 10\%$ of daily totals |
| 11 | Solar Longwave Outgoing | CGR-3 Pyrgeometer/Kipp and Zonen | — | 0-15mV | $\pm 10\%$ of daily totals |
| 12 | Solar Shortwave Outgoing | CGR-3 Pyrgeometer/Kipp and Zonen | — | 0-15mV | $\pm 10\%$ of daily totals |

Sensor Number 3 - Atmospheric Pressure: The atmospheric pressure is measured using a pressure sensor, Model# 278 from Setra. This sensor is supplied with a 24V input signal and outputs between 0-2.5V which is equivalent to 600 to 1100 hPa. The pressure sensor is wired to FieldPoint module FP-AI-100 and the measurement accuracy is ± 0.3 hPa. The wiring diagram and configuration details are presented in more detail in Table E.1(a) and Figure E.4, Appendix E.

Sensor Number 4 - Rainfall Level: The rainfall is measured using tipping bucket 52202 from the R.M. Young Company. The instrument is supplied with a 24V input signal and outputs a 'pulse' signal of 24V. Each 24V 'pulse' is equivalent to 0.1mm of rain fall. As the rain falls the bucket fills up with water and when full it tips over and the reed-switch makes contact, completing the circuit and returning a 24V 'pulse' signal to the DAQ module. The counter module FP-CTR-502 records each pulse and the measurement accuracy is $\pm 2\%$ up to 25 mm/hr. Since the sensor cable length to the DAQ hardware exceeds 30m, a 100Ω resistor was fitted to prevent both electrical interference and the reed switch from arcing. The bucket is also supplied with a heater to prevent freezing in sub-zero degrees Celsius weather. The bucket is connected to FieldPoint module FP-CTR-502

and a wiring diagram and configuration for the sensor is shown in Table E.1(a) and Figure E.5 in Appendix E.

Sensor Numbers 5 and 6 - Rainfall Temperature: The rainfall temperature is also measured using two type-K thermocouples placed within a custom made fixture which is capable of capturing and holding a small amount of rain in a pocket, containing the thermocouples. The thermocouples are connected to FieldPoint module FP-TC-120. A more detailed wiring and configuration diagram can be viewed in Table E.1(a) and Figure E.6, Appendix E.

Sensor Number 7 - Wind Speed: The wind speed was measured by an A100L2, low power anemometer from Vector Instruments. The anemometer outputs a voltage signal between 0-2.5V and requires an input voltage of 24V. This voltage range represents the wind speeds of between 0-277.8 km/hr (0-77m/s). The anemometer has an accuracy of $\pm 1\%$ for 0.36 km/hr up to 180 km/hr, and $\pm 2\%$ for 180-277.8 km/hr. The sensor is connected to FieldPoint module FP-AI-100. The wiring and configuration diagram for this sensor is also presented in Table E.1(a) and Figure E.4, Appendix E.

Sensor Number 8 - Wind Direction: This sensor outputs a voltage signal of between 0-3.294V to display wind direction. This output signal is directly proportional to the value of the input signal which is set to 3.288V. If the input voltage changes then the output voltage changes accordingly and the input range can be set between 1V and 5V. The range between 0-3.294V corresponds to 0-360°, thereby enabling all wind directions to be recorded, based on 0° representing a north wind. It can measure wind direction to an accuracy of $\pm 2^\circ$. The sensor is connected to FieldPoint module FP-AI-100. The wiring and configuration diagram for this sensor can be seen in more detail in Table E.1(a) and Figure E.4 in Appendix E.

Sensor Numbers 9 to 12 - Solar Radiation: The solar radiation is measured using Kipp and Zonen solar radiation sensors. Two CGR-3 pyrgeometers were deployed as net pyrgeometers (infrared) and two CMP-3 pyranometers were used as an albedometer (short wave). The sensors are also used in combination to identify the net radiation. Shortwave diffuse radiation is (sunlight not directly for the sun) measured using a pyranometer (sensor 12) and fitting a shade ring around it, as shown in Figure 3.3, to block direct sunlight during the day.

The solar radiation is determined by measuring the temperature difference across a highly sensitive thermopile. The thermopile converts the temperature difference into a

proportional electromotive force (EMF) or voltage. Each of the pyranometers generates an output signal of between 0-15mV. The pyrgeometer emits a signal of between -4mV and +4mV. Both sensors are wired to FieldPoint module FP-AI-110 and the measurement accuracy is $\pm 10\%$ of daily totals input. For more wiring and configuration details, see Table E.1(a) and Figure E.3, Appendix E.



Figure 3.3 Photograph of the pyranometer measuring shortwave diffuse radiation fitted with a shade ring positioned on the liBC building's plant room roof.

3.2.2 Ground Source Heat Pumps: Operational Performance

This section overviews the DAQ infrastructure developed to monitor heat pump performance. The sensors required to monitor the operational performance of both heat pumps were defined by co-researchers whose interests focussed on understanding the heat pumps performance ((Coefficient of Performance (COP) and seasonal performance factors) and their impact on the collector regions from where heat is extracted. This research investigated the thermal charging and discharging dynamics of the ground and the impact of the local climate on the soils temperature and moisture content; Burke *et al.*, 2008, Greene *et al.*, (2007a), Greene *et al.*, (2008b), Lohan *et al.*, (2006a) and Lohan *et al.*, (2006b). Figure 3.4 presents a schematic of the two heat pump systems and which identifies the location of the 14 sensors deployed to continuously monitor heat pump performance. These consisted of 8 temperature sensors, 4 fluid flow meters and 2 electric power meters, whose detail are summarised in Table 3.2

Table 3.2 Characteristics of the sensors used to monitor heat pump operational performance.

| # | Sensor label/location | Sensor Type/Supplier | Sensor Input | Sensor Output | Sensor Measurement accuracy |
|----|-----------------------|----------------------|--------------|---------------|-----------------------------|
| 1 | T201 | PT100 class B/Omega | — | °C | ±0.03°C at 0°C |
| 2 | T202 | PT100 class B/Omega | — | °C | ±0.03°C at 0°C |
| 3 | T203 | PT100 class B/Omega | — | °C | ±0.03°C at 0°C |
| 4 | T204 | PT100 class B/Omega | — | °C | ±0.03°C at 0°C |
| 5 | T205 | PT100 class B/Omega | — | °C | ±0.03°C at 0°C |
| 6 | T206 | PT100 class B/Omega | — | °C | ±0.03°C at 0°C |
| 7 | T207 | PT100 class B/Omega | — | °C | ±0.03°C at 0°C |
| 8 | T208 | PT100 class B/Omega | — | °C | ±0.03°C at 0°C |
| 9 | Power Meter 1 | LC-UPC-230V/Vydas | 240V | 4-20mA | ±1% |
| 10 | Power Meter 2 | LC-UPC-230V/Vydas | 240V | 4-20mA | ±1% |
| 11 | Flow Meter 1 | Flow meters/Burkett | 24V | 1,2,3,4,5.. | ±0.5% full scale at 10m/s |
| 12 | Flow Meter 2 | Flow meters/Burkett | 24V | 1,2,3,4,5.. | ±0.5% full scale at 10m/s |
| 13 | Flow Meter 3 | Flow meters/Burkett | 24V | 1,2,3,4,5.. | ±0.5% full scale at 10m/s |
| 14 | Flow Meter 4 | Flow meters/Burkett | 24V | 1,2,3,4,5.. | ±0.5% full scale at 10m/s |

a) **Fluid Temperature:** 8 temperature sensors were installed to measure the flow and return temperature to/from the vertical and horizontal collectors and the flow and return temperatures to/from the buffer tank. These temperature sensors were PT100 class B 1/10

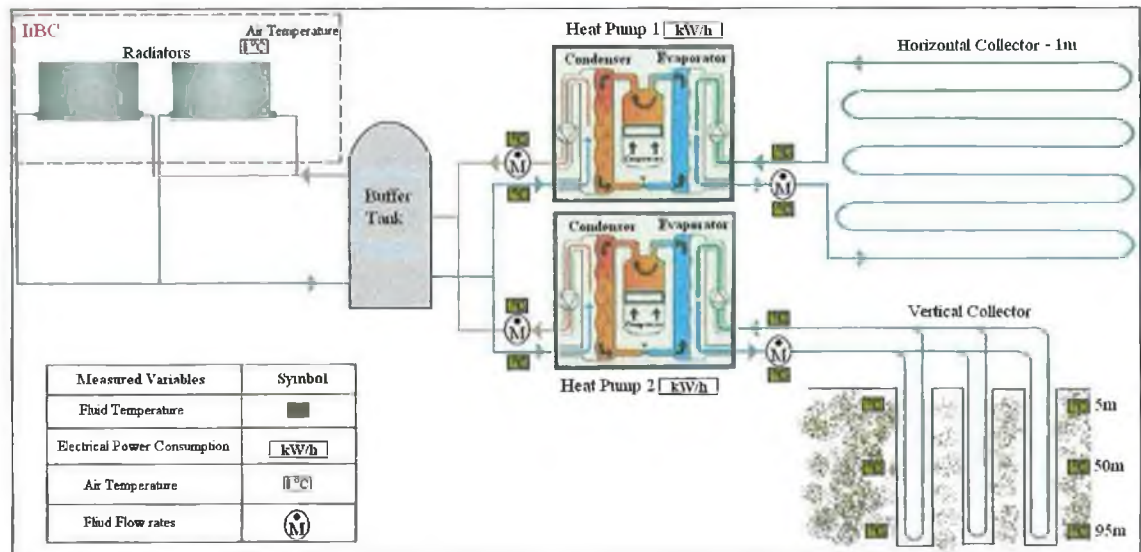


Figure 3.4 A schematic of the heat pump facility and the sensors deployed to monitor heat pump operational performance.

DIN element, with an accuracy of $\pm 0.03^\circ\text{C}$ at 0°C . Figure 3.5(a) presents a view of the temperature sensors during calibration. The sensors are connected to the FieldPoint modules (FP-RTD-124) and the readings are displayed on the PC in MAX software.

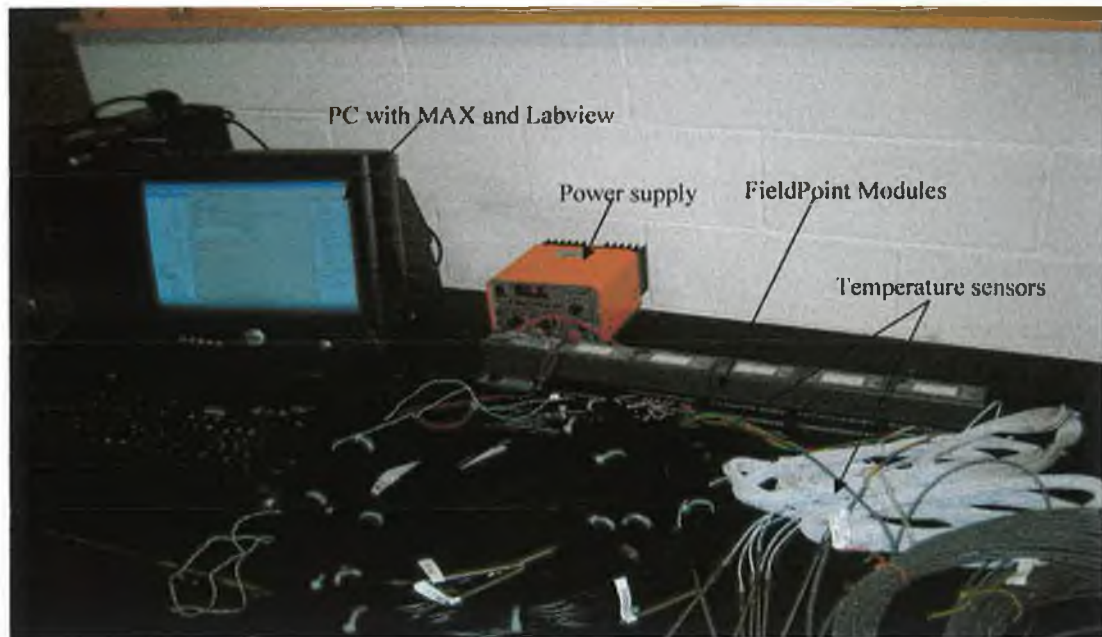


Figure 3.5(a) Photograph of temperature sensors and DAQ setup during calibration.

Figure 3.5(b) presents a photograph of the temperature sensors placed in the Jofra calibrator and the ice slurry during calibration.

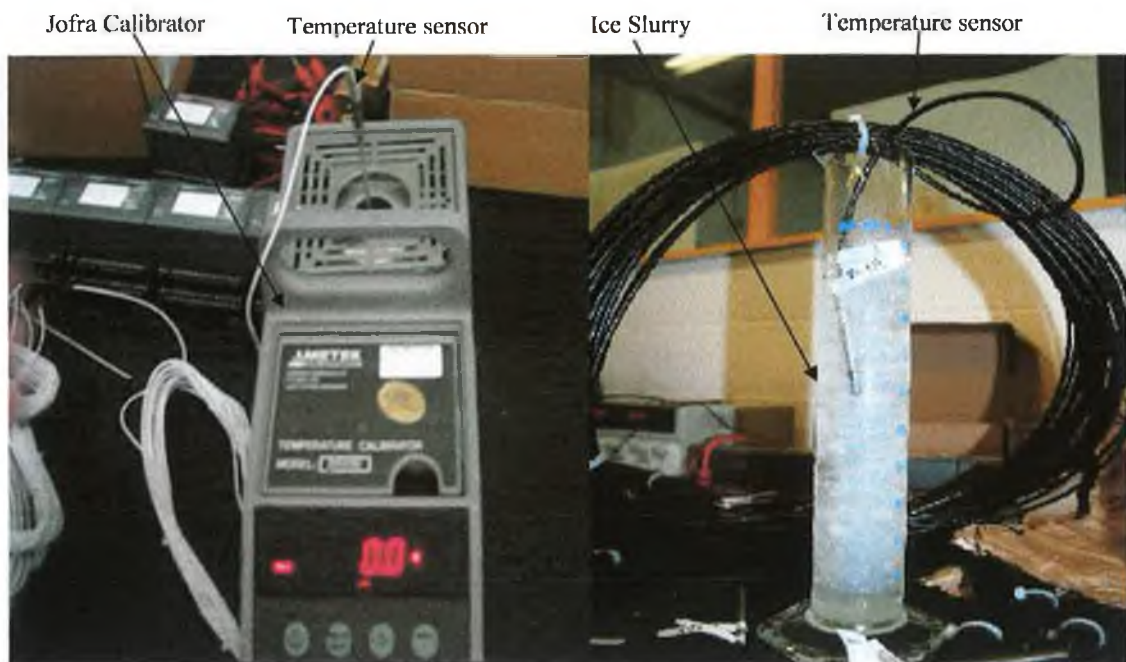


Figure 3.5(b) Photograph of temperature sensors during calibration with the Jofra Calibrator (at 0°C) and the ice slurry.

These sensors were connected to FieldPoint module FP-RTD-124. Temperature measurement accuracy was evaluated using a calibrated D555E Jofra Calibrator as shown in Figure 3.5(a) with an accuracy rating of $\pm 0.3^{\circ}\text{C}$. The temperature sensors were also

calibrated in an ice bath. A more detailed wiring and configuration diagram of the sensors is presented in Table E.1(b) and Figure E.9, Appendix E.

b) Fluid Flow Rate: Since the calculation of the heat delivered to the liBC building demands that the fluid flow rate be known, 4 Burkett flow meters were used. As indicated in Figure 3.4 the flow meters measured the flow rate to both the collectors and the buffer tanks. The flow meters emitted a pulsed signal per litre flow. Each flow meter was calibrated by pumping 35 litres of water through the meters. The 'pulsed' signal is set by assigning a K-Factor (constant) to each flow meter depending on flow of water through the meter. This K-factor is attained by using a flow transmitter on which the K-factor is display. The calibration tables are discussed in Section E.6, Appendix E. The meters have an accuracy range of $\pm 0.5\%$ full scale at 10m/s and were connected to FieldPoint module FP-CTR-500. The wiring and configuration diagram is presented in more detail in Table E.1(b) and Figure E.7, Appendix E.

c) Electric Power Consumption: Since the COP of the heat pump requires the heat pump's compressor power consumption to be evaluated, the electrical power consumed by the compressor and the collectors circulating pumps was measured using universal power cells, Model LC-UPC from Vydas International. The meters could measure single-phase and three-phase power and were installed into the electrical wiring of the heat pump power circuit. The power metres have an accuracy of $\pm 1\%$ and were connected to FieldPoint module FP-AI-100. A detailed wiring configuration diagram can be viewed in Table E.1(b) and Figure E.4, Appendix E.

All of these 14 sensors are connected to the FieldPoint modules located in the liBC's plant room shown in Figures 1.1 and 3.3. The combined accuracy of the temperature sensors, flow and electric power meters deployed enabled the heat pump COP to be continuously monitored to an accuracy of $\pm 3.28\%$ (Burke *et al.*, 2008), which meets the requirements of CiSET's co-researchers. Section 3.2.3 describes the intense measurement infrastructure deployed in the heat pump collector region.

3.2.3 Ground Source Heat Pumps: Collector Region

A plan view of the collector region that supplies heat to both heat pumps is presented in Figure 3.6. It identifies the perimeter of the 430m² horizontal collector region (heavy dashed blue line) and the position of three, 100m deep vertical boreholes positioned within the horizontal collector region. This section describes the instrumentation used to monitor the combined influences of both heat pump operation and the climate on both collector regions.

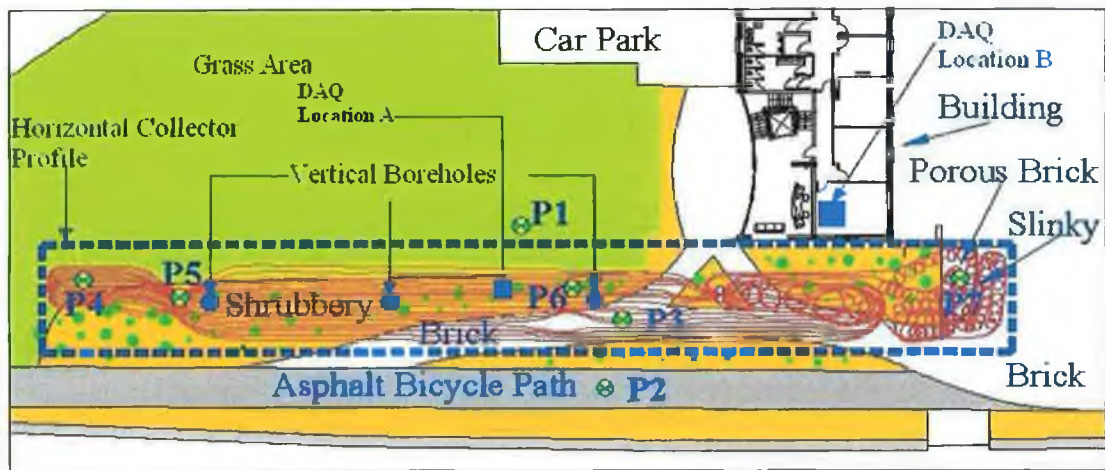


Figure 3.6 Overview of the collector region showing its position relative to the liBC building and positions of measurement profiles (P1-P7) [Source: Lohan et al., (2008a)].

a) Horizontal Collector: Since the horizontal collector was positioned beneath a number of different types of ground covers (grass, porous paving, non-porous asphalt and shrubbery) shown in Figure 3.6, it was of research interest to record both the soil temperature and moisture content under each ground cover type. It was also of interest to identify the influence of heat pump operation on collector ground temperature and this could only be established by also placing a reference monitoring position (P1) outside the collector region. Measurement points P1 through P7, shown in Figure 3.6, represent the locations at which soil temperature and moisture was measured, within and outside the collector region. While these locations appear as points in the plan view, a series of temperature and moisture sensors were positioned at different depths, as indicate in Figure 3.7, to allow the soil temperature and moisture content to be established to a depth of 1.8m. These points (P1-P7) are therefore referred to as profiles.

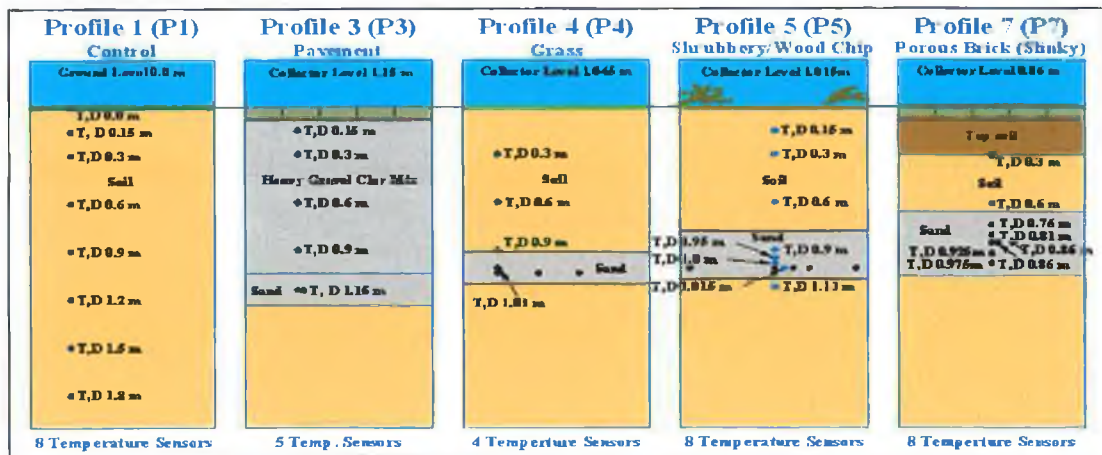


Figure 3.7 Cross Sectional View of five Soil Moisture and Temperature Measurement Profiles [Source: Greene et al., (2007a)].

Profiles P1 and P2 was setup to generate reference data, 3m outside the collector region. The remaining 5 profiles were positioned within the collector region and under different ground cover types (grass, porous paving, non-porous asphalt and shrubbery). A more detailed analysis of the sensor breakdown and justification for their use is presented in Lohan *et al.*, (2006a) and Lohan *et al.*, (2006b). A cross-sectional view of a selection of the profiles is presented in Figure 3.6 and 54 sensors were used to record soil temperature using 44 PT100 sensors and 10 soil moisture content using CS625 sensors from Campbell scientific. The DAQ system was required to monitor and record these 54 sensors and a detailed specification on each sensor is presented in Tables 3.3(a-d).

Table 3.3(a) Temperature sensors horizontal collector: Class A PT100, $\pm 0.35^{\circ}\text{C}$ between 0°C - 100°C .

| Sensor # | Profile # | Sensor Label |
|----------|-----------|------------------|
| 1-7 | P6 | T001 - T007 |
| 8-15 | P1 | T008 - 014, T040 |
| 16-20 | P3 | T015 - T019 |
| 21-24 | P2 | T021 - T024 |
| 25-32 | P5 | T026 - T033 |
| 33-40 | P7 | T034 - T042 |
| 41-44 | P4 | T043 - T046 |

Table 3.3(b) Temperature sensors vertical collector: Class A PT100, $\pm 0.35^{\circ}\text{C}$ between 0°C - 100°C .

| Sensor # | Well # | Sensor Label |
|----------|--------|--------------|
| 45 | 1 | Well 1 No 1 |
| 46 | 1 | Well 1 No 2 |
| 47 | 1 | Well 1 No 3 |
| 48 | 3 | Well 3 No 2 |
| 49 | 3 | Well 3 No 3 |

Table 3.3(c) Temperature sensors vertical collector: Class A PT100, $\pm 0.35^{\circ}\text{C}$ between 0°C - 100°C .

| Sensor # | Well # | Sensor Label |
|----------|-----------------------|--------------|
| 50 | 1 | T101-12m |
| 51 | 1 | T102-12m |
| 52 | 3 | T103-30m |
| 53 | 3 | T104-30m |
| 54 | 1,2 and 3 at manifold | T105-22m |
| 55 | 1,2 and 3 at manifold | T106-22m |

Table 3.3(d) Moisture sensors horizontal collector: CS625, $\pm 2.5\%$ of volumetric moisture.

| Sensor # | Profile # | Sensor Label |
|----------|-----------|----------------|
| 56 | P5 | MS03-P5@0.6m |
| 57 | P4 | MS01-P4@1.045m |
| 58 | P1 | MS05-P1@0.9m |
| 59 | P5 | MS02-P5@1.015m |
| 60 | P1 | MS04-P1@0.3m |
| 61 | P1 | MS06-P1@1.8m |
| 62 | P3 | MS10-P3@1.15m |
| 63 | P3 | MS09-P3@0.3m |
| 64 | P7 | MS07-P7@0.3m |
| 65 | P7 | MS08-P7@0.3m |

b) Horizontal Collector Soil Temperature Sensors: The 44 temperature sensors were distributed among the seven vertical profiles (P1-P7) as shown in Figures 3.6 and 3.7. As indicated in Figure 3.7 each of the sensors was positioned at different depths throughout the profiles ranging from ground level down to 1.8m. The temperature sensors installed were 4-wire PT100 Class A sensors with an accuracy of $\pm 0.35^{\circ}\text{C}$ between 0°C - 100°C . The temperature sensors were connected to the FP-RTD-124 FieldPoint modules which outputs a signal in $^{\circ}\text{C}$. Temperature accuracy was evaluated using both a D555E Jofra Calibrator and an ice bath. Calibration details can be seen in Tables E.2 (a-f), Appendix E. All of these sensors were connected back to a central location within the collector area as shown in Figure 3.6. A stainless steel Control Box (CB) with a water proof protection rating of IP66 was installed at location A, shown in Figure 3.6. A total of 9 FieldPoint modules (7 x FP-RTD-124 and 2 x FP-CTR-502) were installed in the CB along with a network module and 2 power supplies. A more detailed wiring and configuration diagram for the temperature sensors is shown in Table E.1(c) and Figure E.9, Appendix E.

c) Horizontal Collector Moisture Content Sensors: The 10 moisture sensors installed were the CS625 water content reflectometers from Campbell Scientific. These displayed an accuracy of $\pm 2.5\%$. The moisture sensors were connected to two FP-CTR-502 FieldPoint counter modules via a customised electrical circuit. The moisture sensor transmitted a signal of between 0-3.3V square-wave with the frequency dependent on water content. The sensor outputs a frequency range between 32,258 kHz representing 0% moisture content (in air) and 68,027 kHz for 100% fully saturated. The signal had to be manipulated so that the FieldPoint module could interpret the signal since it can only read a pulsed signal of between 0 kHz and 50 kHz. Therefore the sensor signal was modified with the aid of the circuit in Figure 3.8. A solid state relay (DM 0063) was used to generate a 'pulsed' excitation signal in order to enable the moisture circuit emit a 'pulsed' output that would be suitable for the FP-CTR-502 counter module input requirements. The signal was then split to create a new signal that was half of the original signal. This was accomplished using a dual type flip-flop (4013) semi-conductor. The signal voltage was first amplified from 4.5V to above 10V so that the flip-flop could read the signal. This was completed using a transistor (bc107- b represents silicon and c represents low power) which boosted the voltage signal without interfering with the frequency of the signal. The signal was then connected to the FieldPoint module for processing. The moisture sensor was calibrated in samples of soil only and a mix of soil and sand extracted from the horizontal collector area.

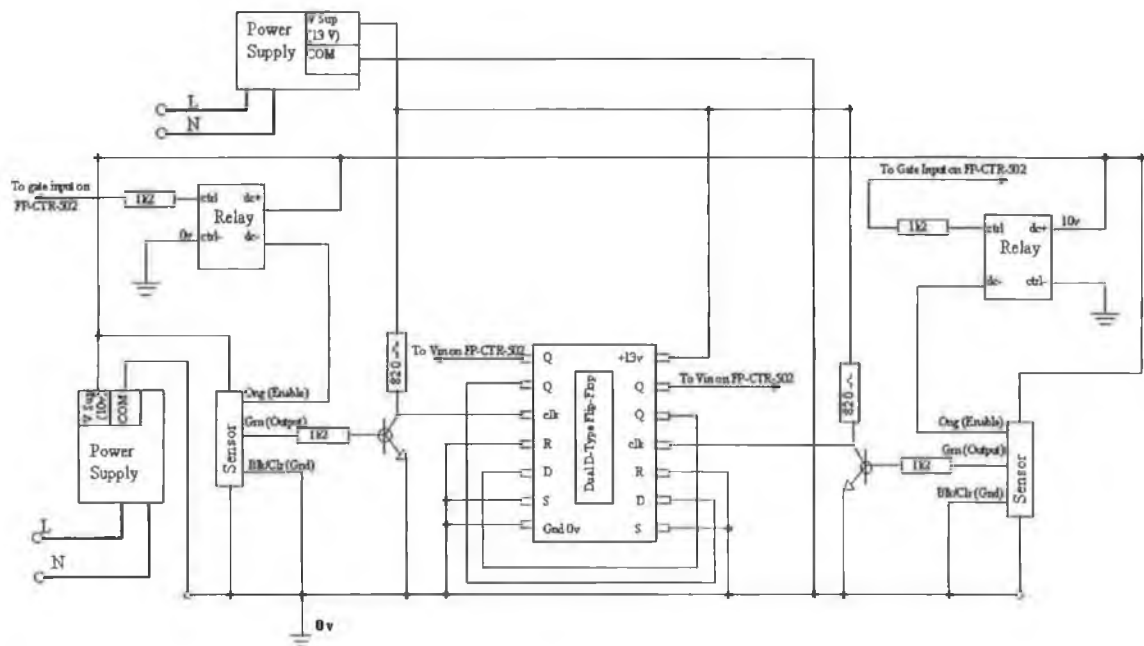


Figure 3.8 Moisture sensor signal manipulation circuit for two moisture sensors.

The resulting frequency reading was 32,396 kHz for 100% water content and 57,786 kHz for 1.5% water content for the soil only sample. They were also calibrated in a soil and sand sample, between 100% saturated to 0.5% water content. The resulting frequency was 34,910 kHz for 100% and 58,374 kHz for 0.5% water content. The moisture content of the samples was measured using a soil moisture content measurement procedure undertaken by another CiSET Masters researcher. These calibrated values were later used as part of the percentage moisture calibration in Labview and are shown in Section E.7, Appendix E. A more detailed wiring and configuration diagram for the sensor and circuit components is presented in Table E.1(c) and Figures E.5 and E.8, Appendix E. A network cable was connected from the GMIT network in the liBC building to the FieldPoint network module in the control box. A power supply cable was also connected to the control box.

d) Vertical Collector Pipe Temperature Sensors: The vertical collectors were also monitored using 11 temperature sensors on two of the 100m deep bore holes and they were instrumented with 3 temperature sensors at different depths of 5m, 50m and 95m intervals on the bore-hole pipes. There were also 6 sensors installed to measure the fluid flow and return temperatures to the vertical collectors. These sensors were all connected to the FP-RTD-124 FieldPoint module in the CB. The temperature sensors installed were 4-wire PT100, Class A sensors with an accuracy of $\pm 0.1^{\circ}\text{C}$ between -5°C and $+5^{\circ}\text{C}$ and $\pm 0.3^{\circ}\text{C}$ between $+5^{\circ}\text{C}$ and $+25^{\circ}\text{C}$. A more detailed wiring and configuration diagram for the temperature sensors is presented in Table E.1(c) and Figure E.9, Appendix E.

3.2.4 Solar Thermal Collectors: Operational Performance

Figure 3.9 presents images of the two solar thermal collectors that required their operating performance to be monitored. An evacuated tube type collector was positioned on a stationary frame and a flat plate type collector on a solar tracking system. Both the flow rates and flow temperatures to and from the collectors required monitoring. Four temperature sensors were installed to measure the flow and return temperature to/from each collector. These sensors were PT100 class B 1/10 DIN element sensors and with an accuracy of $\pm 0.03^{\circ}\text{C}$ at 0°C . The temperature accuracy was evaluated using both a calibrated D555E Jofra Calibrator and an ice bath. The sensors were connected to FieldPoint module FP-RTD-124.



Figure 3.9 Photograph of Solar thermal collectors on the liBC building roof.

The flow rate of fluid through both the solar collectors was measured using a Proline Prosonic Flow 93 ultrasonic flow meter from Endress & Hauser. Figure 3.10 presents a schematic of the two solar thermal collectors and identifies the location of the 10 sensors deployed to continuously monitor solar collector performance.

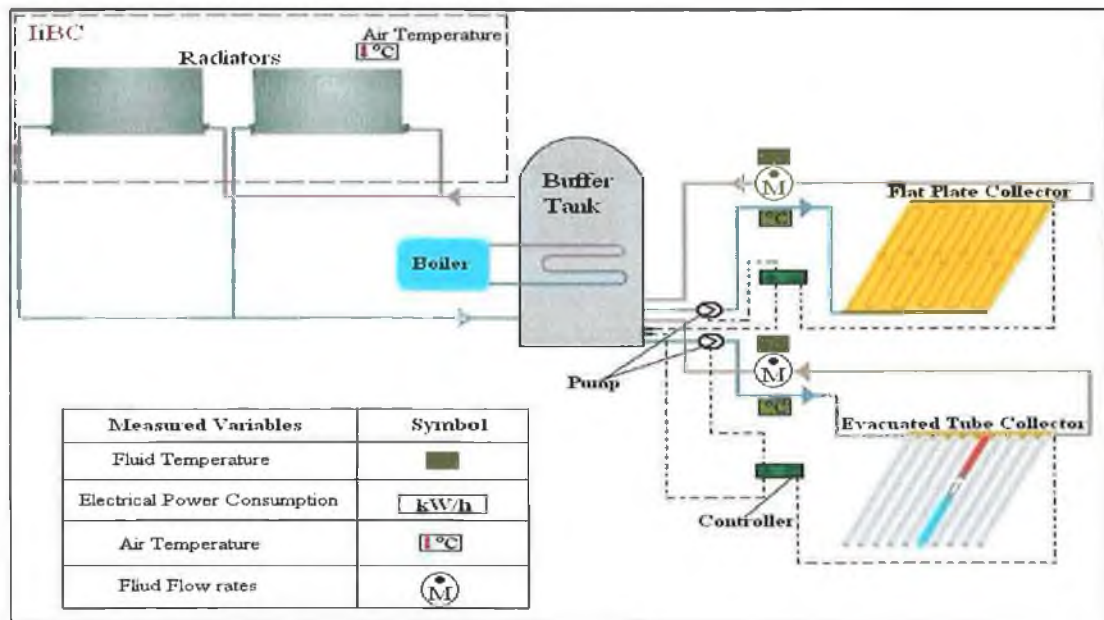


Figure 3.10 A schematic of the solar facility and the sensors deployed to monitor solar thermal collectors operational performance.

These consisted of 7 temperature sensors, 1 fluid flow meter and 2 modular contacts, whose detail are summarised in Table 3.4.

Table 3.4 Characteristics of the sensors used to monitor the operational performance of both solar thermal collectors.

| # | Sensor label/ location | Sensor Type/Supplier | Sensor Input | Sensor Output | Measurement Accuracy |
|----|---------------------------------|------------------------------------|-----------------|------------------|-------------------------|
| 1 | Stationery Solar Panel Input | Class B PT100/Sontay | — | °C | ±0.03°C at 0°C |
| 2 | Stationery Solar Panel Output | Class B PT100/Sontay | — | °C | ±0.03°C at 0°C |
| 3 | Tracking Solar Panel Input | Class B PT100/Sontay | — | °C | ±0.03°C at 0°C |
| 4 | Tracking Solar Panel Output | Class B PT100/Sontay | — | °C | ±0.03°C at 0°C |
| 5 | Solar Stationery Cylinder Lower | Class B PT100/Sontay | — | °C | ±0.03°C at 0°C |
| 6 | Solar Tracking Cylinder Upper | Class B PT100/Sontay | — | °C | ±0.03°C at 0°C |
| 7 | Solar Stationery Cylinder Upper | Class B PT100/Sontay | — | °C | ±0.03°C at 0°C |
| 8 | Solar Pump 1 Monitor | CT modular contactors/Merlin Gerin | 24/240V | 24V | n/a |
| 9 | Solar Pump 2 Monitor | CT modular contactors/Merlin Gerin | 24/240V | 24V | n/a |
| 10 | Ultrasonic Flow Meter | Class B PT100/Sontay | 240V | 4-20mA | ±2% |

The flow meter outputs a 4-20 mA signal which requires configuration. The expected maximum flow rate (plus 10% to allow for flexibility) had to be inputted to the sensor control panel before connection to the DAQ. This required a number of test runs and re-configuration of the system in order to attain the maximum flow rate. The closer the maximum flow rate value is to the actual value, the greater the resolution and therefore the greater the measurement accuracy. The accuracy of the flow meter is ±2% of the reading. The flow meter was connected to FieldPoint module FP-AI-100. The solar collector pumps on/off state is measured using modular contacts which are connected to the pump's 240V

input and outputs a 24V signal to the DAQ when the pumps are activated. A more detailed wiring and configuration diagram of the sensors can be seen in Table E.1 (b) and Figure E.4 and E.9, Appendix E.

3.2.5 IiBC Building Air Temperature

The air temperature within the IiBC building was monitored at 3 locations using type-T thermocouples. One was placed in both the East and West facing sides of the building. The third thermocouple was installed in the plant room to monitor the impact of the radiators connected to the solar collectors on the plant room's air temperature. Each of these sensors were calibrated against a high accurate PT100 temperature sensor with an accuracy of $\pm 0.3^{\circ}\text{C}$ and connected to FieldPoint module FP-TC-120. A detailed wiring and configuration diagram of the sensors connections is shown in Table E.1(a) and Figure E.6, Appendix E.

3.3 DAQ System

This section details the DAQ system hardware and software employed to monitor the 108 sensors defined in Section 3.2.

3.3.1 DAQ System: Hardware Selection

The DAQ system hardware was selected to meet the following system specifications;

- a) **Number and Range of Sensor Inputs:** The ability of the DAQ system to interpret different input signals such as voltage, current, frequency and temperature was also an area that required attention during the planning stage. Not only were there 6 different types of signals, but also different ranges of signals (0-1V; 0-10V; 4-20mA; 0-15mA).
- b) **Flexibility, Stability and Accuracy:** The flexibility of the DAQ to add or subtract modules or sensors in the future was also a crucial factor as the DAQ system expanded. The reliability and stability of the system was very important as interrupted data streams pose problems during the data analysis phase.
- c) **Sensor Cable Lengths:** As indicated in Figure 3.4 the GSHP's collector area ranged from 50m to 150m away from the DAQ location. Because the sensors were situated at these locations, care was required to ensure stable and reliable outputs from the DAQ system. The DAQ system accuracy must be able to match the accuracy of the sensors (Stum, 2006) which also influenced the hardware selection as described in Section 2.2.8.

Similar to the software selection, NI's FieldPoint modules met all the stated requirements. FieldPoint modules includes a variety of isolated analog and digital I/O

modules, counter or pulse modules, terminal bases and network interfaces for ease of connection to standard network technology, such as ethernet, serial or wireless as shown in Figure 3.10. The modules accept all types of signals such as voltage, current frequency and pulses. The modules can accept signal ranges of $\pm 30\text{V}$, $\pm 20\text{mA}$, -40°C to $+70^\circ\text{C}$ and 0-50kHz. The FieldPoint modules are attached to terminal bases to provide the communication link between each other, the network module and wiring field connections. These modules are hot swappable and are easily connected to the network module. The modules have a 50Hz or 60Hz built-in low pass filter which rejects unwanted mains noise.

3.3.2 DAQ System: Hardware Configuration

Six different types of modules were required to connect the 108 sensors, defined in Section 3.1, to the DAQ PC/software. These were installed in two different locations, in the Control Box (CB) and in the liBC plant room as shown in Figures 1.1 and 3.4. Seven resistance input modules (FP-RTD-124) and two counter modules (FP-CTR-502) were installed in the CB, location A as presented in Table 3.5.

Table 3.5 List of 19 FieldPoint modules that formed the core of the DAQ system.

| # | Module /Item | Number | Function | Location (A or B) | Accuracy |
|---|--------------|--------|---|--|-------------------------|
| 1 | FP-AI-100 | 1 | Voltage and current analog input module | B: liBC plant room | 0.19 - 0.22% |
| 2 | FP-AI-110 | 1 | Voltage and current analog input module | B: liBC plant room | 0.19 - 0.22% |
| 3 | FP-RTD-124 | 2 | 4 Wire RTD input module | B: liBC plant room | 0.15°C |
| 4 | FP-RTD-124 | 7 | 4 Wire RTD input module | A: Control Box in HP collector profile | 0.15°C |
| 5 | FP-CTR-500 | 1 | Counter input module | B: liBC plant room | $\pm 0.762951\text{Hz}$ |
| 6 | FP-CTR-502 | 2 | Counter input module | A: Control Box in HP collector profile | $\pm 0.762951\text{Hz}$ |
| 7 | FP-TC-120 | 1 | Thermocouple input module | B: liBC plant room | 0.15°C |
| 8 | FP-1601 | 2 | Network module | B: liBC plant room | n/a |
| 9 | Power supply | 2 | Supply 24V to the FP modules | B: liBC plant room | n/a |
| | | | Total | 19 | |

A FieldPoint network module (FP-1601) and 3 power supplies (one for the DAQ modules and two for the moisture sensor circuit) were installed at location A. The DAQ configuration is presented in Figures 3.11 and 3.12. Two analog input modules (FP-AI-100, FP-AI-110), two resistance input modules (FP-RTD-124), one thermocouple module (FP-TC-120) and one counter module (FP-CTR-500) was installed at location B. These modules were also connected to network module (FP-1601) and a power supply. These modules can be connected side by side or in a cascading system with the aid of a FieldPoint extender

cable. The modules are attached to a FieldPoint terminal base (FP-TB-123) and each of these terminal bases are connected to each other to allow communication between the FieldPoint modules and the network module.

A maximum of nine modules plus the network module can be connected together. The network modules at both locations A and B were connected to the GMIT LAN with shielded Category 5 network cable. An NI power supply was used as part of the DAQ hardware to supply 24V to the modules. The power supply was supplied power via an Uninterruptible Power Supply (UPS) to prevent power loss and prevent power surges. The FieldPoint modules were assigned an IP address by GMIT's network administrator to allow communication between the modules and the DAQ system PC. The specification of these modules is shown in Table 3.6.

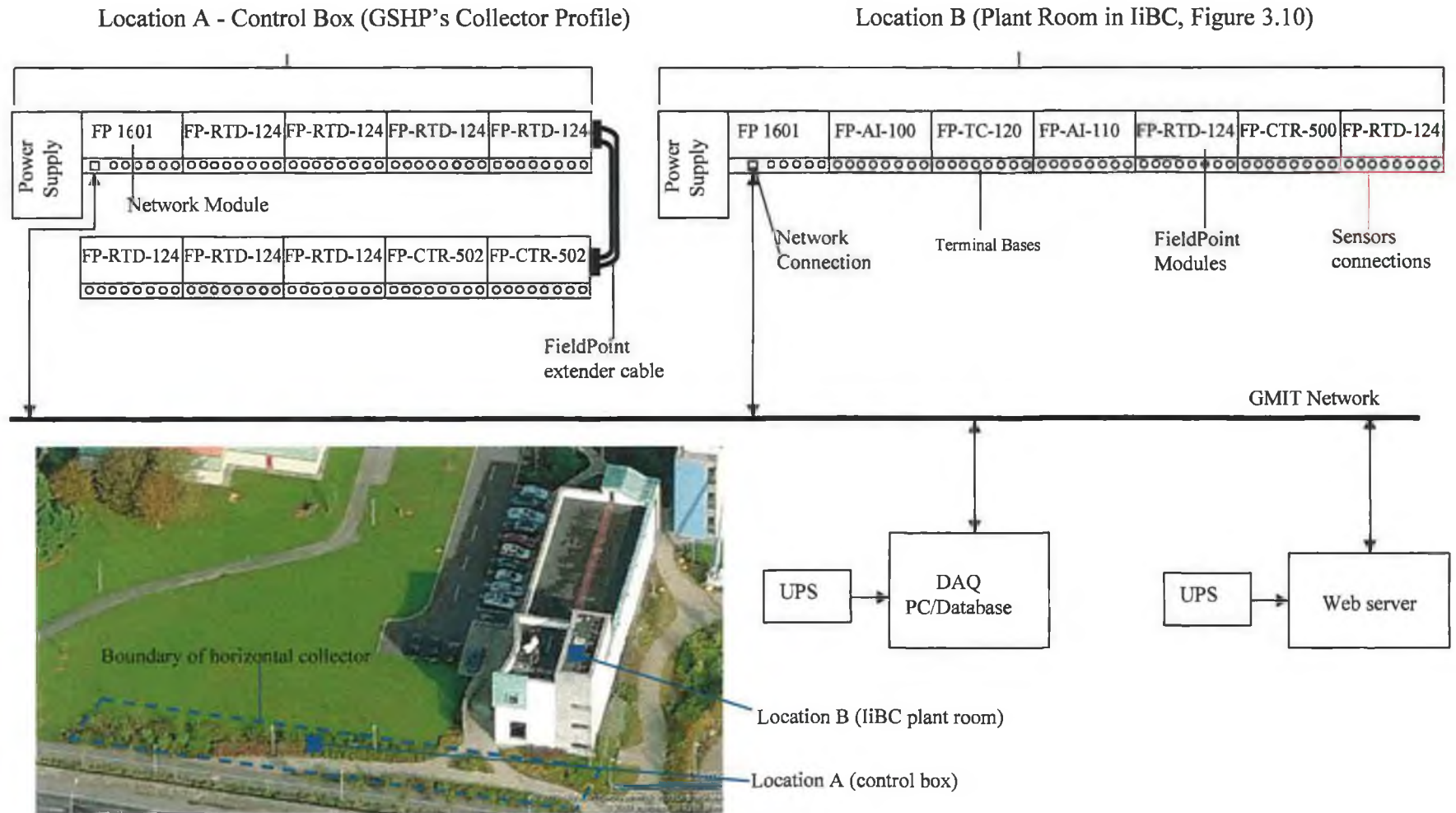


Figure 3.11 Schematic of DAQ facility, including Network Modules, Terminal bases, FieldPoint Modules, GMIT Network, DAQ PC/Database and Web server. Location A and B is also shown, as presented also in Figures 1.1 and 3.6.

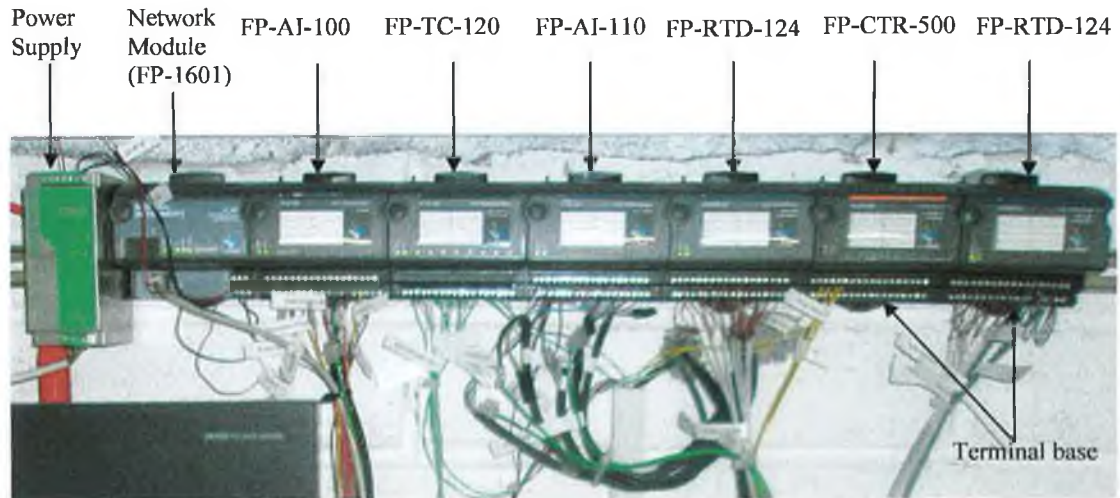


Figure 3.12 Photograph of DAQ configuration at Location B in the liBC plant room.

The specification of these FieldPoint modules is shown in Table 3.6.

Table 3.6 Specifications of FieldPoint Modules [Source: www.ni.com, 2008]

| | |
|---|---|
| <p>FieldPoint Module FP-CTR-502</p> <ul style="list-style-type: none"> • 8 inputs • 5 to 30 VDC inputs • 16-bit counter registers • 50 kHz, maximum • Gate inputs and digital outputs • Cascadable counters for higher counts • 2,300 Vrms bank isolation for transient overvoltage protection • Hot-swappable with auto configuration • -40 to 70 °C operating range | <p>FieldPoint Module FP-CTR-500</p> <ul style="list-style-type: none"> • 8 inputs • 5 to 30 VDC inputs • 16-bit counter registers • 50 kHz, maximum • Gate inputs and digital outputs • Cascadable counters for higher counts • 2,300 Vrms bank isolation for transient overvoltage protection • Hot-swappable with auto configuration • -40 to 70 °C operating range |
| <p>FieldPoint Module FP-AI-100</p> <ul style="list-style-type: none"> • 8 or 16 voltage or current inputs • ± 120 V input range, maximum • 0 to 20, 4 to 20 mA input ranges • Built-in signal conditioning • 50, 60, and 500 Hz noise rejection • 12 and 16-bit resolution • Software-configurable input ranges per channel • 2,300 Vrms bank isolation for transient overvoltage protection • Hot-swappable with auto configuration • -40 to 70 °C operating range | <p>FieldPoint Module FP-AI-110</p> <ul style="list-style-type: none"> • 8 or 16 voltage or current inputs • ± 120 V input range, maximum • 0 to 20, 4 to 20 mA input ranges • Built-in signal conditioning • 50, 60, and 500 Hz noise rejection • 12 and 16-bit resolution • Software-configurable input ranges per channel • 2,300 Vrms bank isolation for transient overvoltage protection • Hot-swappable with auto configuration • -40 to 70 °C operating range |
| <p>FieldPoint Module FP-TC-120</p> <ul style="list-style-type: none"> • 8 temperature inputs • Thermocouple or millivolt • 2, 3, or 4-wire RTD inputs • Built-in signal conditioning • 50 and 60 Hz noise rejection • 16-bit resolution • Input ranges software configurable per channel • 2,300 Vrms bank isolation for transient overvoltage protection • Hot-swappable with auto configuration • -40 to 70 °C operating range | <p>FieldPoint Module FP-RTD-124</p> <ul style="list-style-type: none"> • 8 temperature inputs • Thermocouple or millivolt • 2, 3, or 4-wire RTD inputs • Built-in signal conditioning • 50 and 60 Hz noise rejection • 16-bit resolution • Input ranges software configurable per channel • 2,300 Vrms bank isolation for transient overvoltage protection • Hot-swappable with auto configuration • -40 to 70 °C operating range |

3.3.3 DAQ System: Software Selection

The factors that influenced the selection of the data logging and monitoring software was ease of programming, capacity for graphic display, data analysis, display and monitoring capabilities, cost, previous experience, software capabilities and limitations and integrating with hardware and suitability to project out line. Labview™, supplied by NI was selected as the software of choice for this project based on;

a) Experience of Two Earlier CiSET Researchers: Labview was successfully used by earlier CiSET researchers Václavek *et al.*, (2002) and Donnellan *et al.*, (2005), and some of the infrastructure and experience gained was made available to this DAQ-WBL project.

b) Department Licence: The decision was also influenced by the existence of an academic site licensed for Labview within the Department.

As discussed earlier Labview is a very popular programming package in the scientific and research community and meets all the DAQ requirements of this project. Labview can program each of the DAQ modules and also analyse, display and log the resulting data. Additional Labview features allow the user to carry out detailed data analysis or create real-time graphical displays. These displays can be accessed/viewed across a LAN via a web server built into Labview.

The programming and setup of the FieldPoint modules is carried out through Measurement and Automation eXplorer (MAX) software. The network module is either assigned an IP (Internet Protocol) address locally by the user (direct communication) or for the LAN by the LAN administrator. The FieldPoint modules are connected to the network module and will appear in the MAX software screen when updated. The modules can be configured to user requirements by specifying more appropriate module names and measurement ranges. The MAX configuration screen can be seen in Figure 3.9.

3.3.4 DAQ System Software: Configuration

The DAQ system was controlled and monitored using Labview 8.20, running on a Dell Optiplex Gx280 with a Pentium IV processor (2.8GHz) and 2 GB of RAM. This PC was connected to the GMIT network to facilitate communication between remote PC's and the DAQ hardware. The PC was powered by a UPS to prevent either power failure or surges to the DAQ system.

3.3.4.1 Measurement and Automation eXplorer (MAX) Configuration

As indicated in Section 3.3.3 the programming of the FieldPoint modules was carried out using MAX software. The MAX software runs separate to Labview and controls all the setup and programming of the modules. When the modules are assigned an IP address and connected to the network, MAX is able to locate these modules on the wider network. Each module can be assigned a default name or be assigned a customised name. A quick search for the connected FieldPoint modules will automatically find and display all the modules connected to the network module, as shown by the MAX display in Figure 3.13. This screen can be used to test each of the modules and sensors connected to the system.

Under 'Channel Configuration' in the 'Remote System' section, the sensor outputs can be configured. For example, a sensor with a current output of between 4-20mA must be configured within MAX so that the range is set to 4-20mA or to the nearest range. This is very important as each of the modules input channels must be configured to receive either a voltage or a current signal, depending on the sensor output, and also it will improve the accuracy of the readings by increasing the resolution. Each of the channels within the modules can be renamed to best reflect the sensor type or purpose, making it easier to identify/locate sensors in Labview during the programming stage. An example of the MAX configuration can be seen in Figure 3.13. This configuration must be saved in FieldPoint as a *.iak* file as it will be used later in Labview.

The type of sensor needs to be setup for the RTD modules measuring the temperature variables. Each of the temperature sensors may have a different Temperature Coefficient of Resistance (TCR) and this must be set according to the sensor's manufacturer specification. The same applies to the thermocouple sensors where the thermocouple type (T, K or J) must be assigned. The noise elimination, as discussed in Section A.2.2., can also be set in the configuration page for counter modules. The setup and configuration for the moisture sensors connected to FP-CTR-502 in the CB required a specialised electrical circuit presented in Section 3.2.2. This also requires a specialised configuration within MAX.

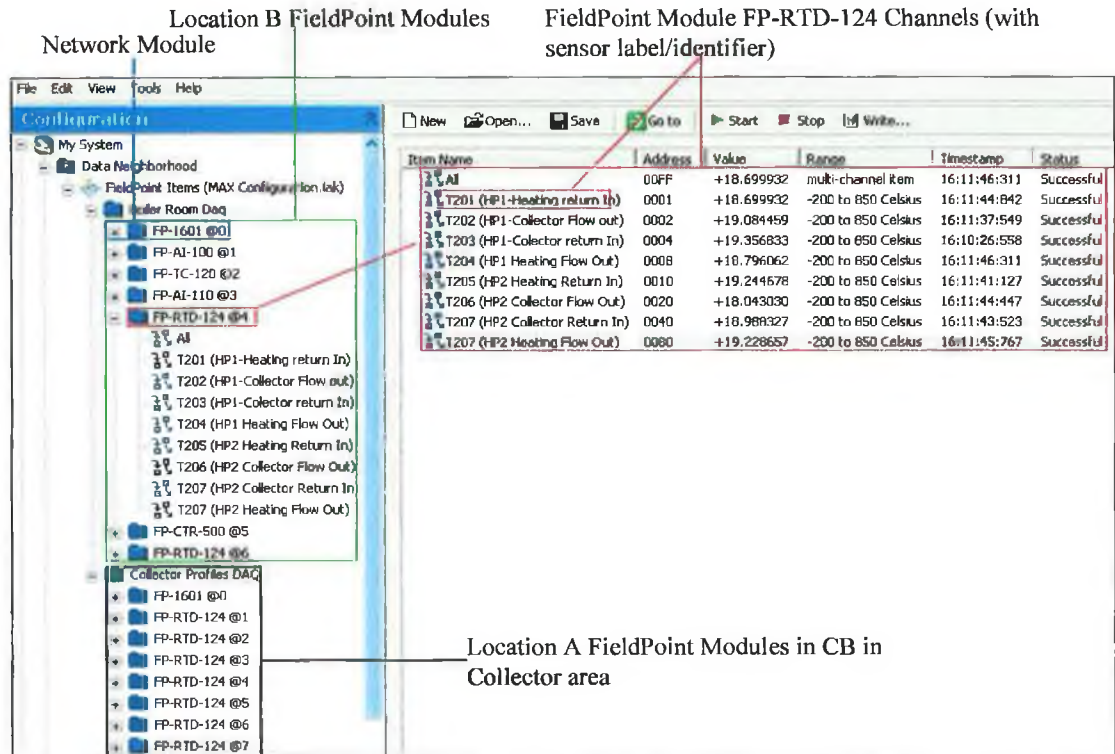


Figure 3.13 Screen shot of the MAX display used during for the FieldPoint Module configuration stage.

Count input channel 0 was configured to generate a pulse frequency signal on output 0. This pulse from output 0 is used as an input for gate 0 which is connected to the 'enable input' on the moisture sensor (orange wire). A more detailed setup and configuration for the moisture sensor setup is outlined in Section E.7, Appendix E.

3.3.4.2 Labview Software Configuration

A total of 18 Virtual Instruments (VI's) and 42 sub-VI's were created to construct and operate the DAQ systems. A screenshot of one of the front panels first developed to display outputs from the weather station, heat pump and iIBC building is shown in Figure 3.14. These VI's were used to program and display the sensor outputs via the FieldPoint modules. Labview is made up of a front panel (Figure 3.14) and a block wiring diagram display panel (Figure 3.15). The front panel is used as the display screen for the live data and control icons to configure each VI. The block diagram (Figure 3.15) is used for the setup and virtual wiring of each VI's configuration which allows the programming of each FieldPoint module, sensor logging and recording intervals and signal manipulation.

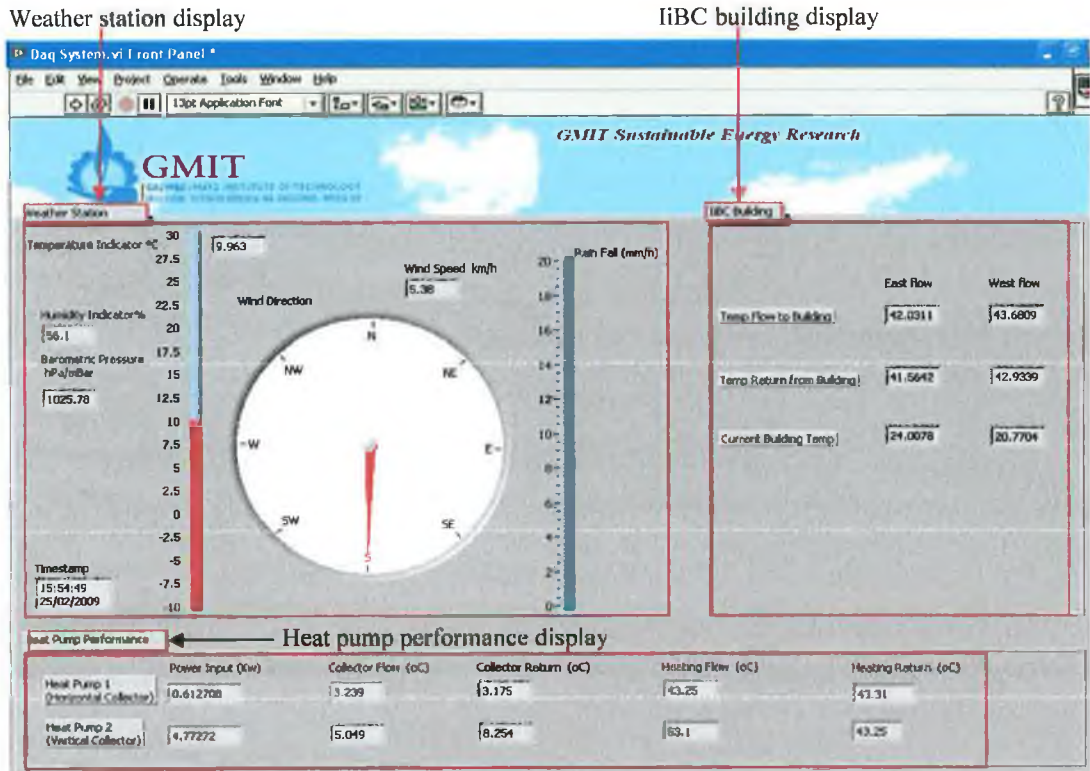


Figure 3.14 Screenshot of Labview VI front panel first developed to display outputs from the weather station, heat pump and liBC building sensors.

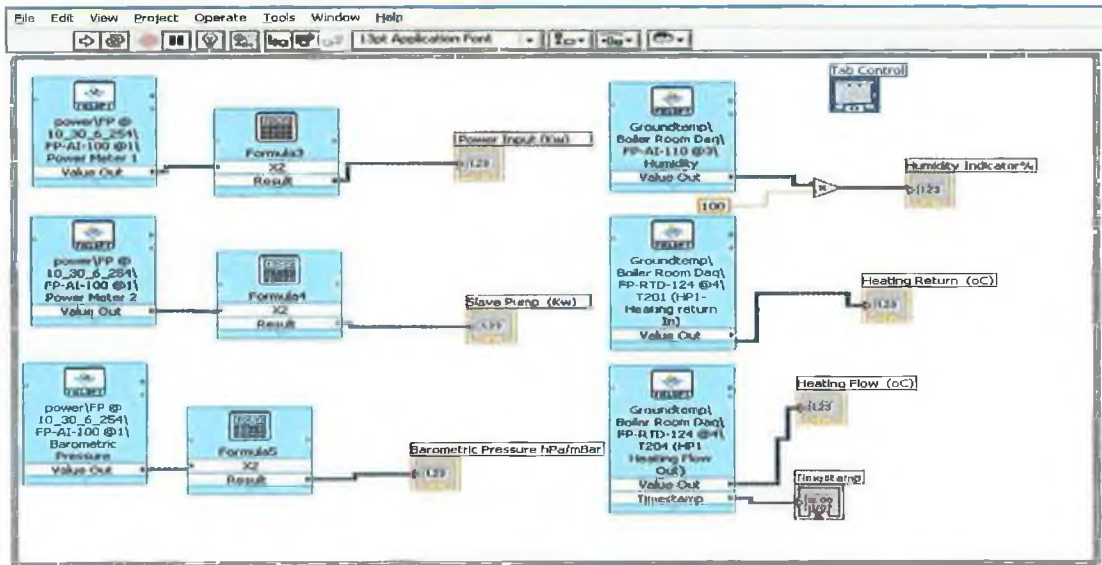


Figure 3.15 Section of the weather station VI (Figure 3.14) block diagram in Labview.

The various steps involved in developing the Labview software control interface for this DAQ-WBL project are briefly described using 4 steps described in Section A.3, Appendix A.

3.3.4.3 Development of the Weather Station VI's

This section describes the procedure involved in establishing the weather station VI's shown in Figure 3.14. The 12 weather station sensors were divided into 6 different VI's so as to enable different logging schedules, displays and performance analysis to be performed on each weather sensor. These are summarised in Table 3.7.

Table 3.7 Summary of the 6 weather station VI's configuration.

| # | Sensors | FieldPoint Module/location | Channel Number | VI Title | Logging Interval |
|----|--------------------------|----------------------------|----------------|--------------------|------------------|
| 1 | Humidity | FP-AI-110/B | 1 | MAX | 5 Minutes |
| 2 | Air Temperature | FP-AI-110/B | 0 | MAX | 5 Minutes |
| 3 | Barometer Pressure | FP-AI-100/B | 2 | Power and Pressure | 5 Minutes |
| 4 | Rain Gauge | FP-CTR-502/A | 7 | Moist Sensor | During Rainfall |
| 5 | Rain Temperature 1 | FP-TC-120/B | 0 | Rain Temperature | 5 Minutes |
| 6 | Rain Temperature 2 | FP-TC-120/B | 1 | Rain Temperature | 5 Minutes |
| 7 | Wind Speed | FP-AI-100/B | 5 | Wind Vane | 1 Minute |
| 8 | Wind Direction | FP-AI-100/B | 6 | Wind Vane | 1 Minute |
| 9 | Solar shortwave Incoming | FP-AI-110/B | 5 | Solar | 5 Minutes |
| 10 | Solar shortwave Outgoing | FP-AI-110/B | 6 | Solar | 5 Minutes |
| 11 | Solar longwave Incoming | FP-AI-110/B | 4 | Solar | 5 Minutes |
| 12 | Solar longwave Outgoing | FP-AI-110/B | 7 | Solar | 5 Minutes |

The air temperature, relative humidity and barometric pressure were all setup as part of the 'DAQ system' VI. Each of these sensors was setup to read, log and then average the data every five minutes. The sensors were reading the temperature, humidity and pressure in voltage so the output required signal conversion in labview to the appropriate output variable ($^{\circ}\text{C}$ - temperature, % - relative humidity or hPa - atmospheric pressure respectively). This was completed using the equation for the slope of the line.

$$m = \frac{Y_2 - Y_1}{X_2 - X_1} \quad (\text{Equation 3.1})$$

Sub VI 1 - Atmospheric Pressure: An example of the conversion equation programmed within labview follows;

The output from the pressure sensor was 0-2.5V and this was equivalent to 600hPa - 1100hPa so by substituting in the appropriate values the slope of the line is established;

$$X_1, Y_1 = 0\text{V}, 600 \text{ hPa}$$

$$X_2, Y_2 = 2.5\text{V}, 1100 \text{ hPa}$$

$$m = \frac{1100 - 600}{2.5 - 0}$$

$$m = 200 \text{ hPa/V}$$

Rearrange the Equation 3.1 and solving for Y2;

$$Y2 = (X2 - X1) * m + Y1 \quad (\text{Equation 3.2})$$

Where;

$Y2$ = the unknown or current measured pressure value (hPa)

$X2$ = the output voltage reading from the sensor (V)

$X1 = 0V$ (the minimum sensor output voltage corresponding to atmospheric pressure of 600 hPa)

$m = 200 \text{ hPa/V}$ (using equation 3.1)

$Y1 = 600 \text{ hPa}$

Therefore, if the pressure sensor returned an output of 1.5V then the actual pressure, $Y2$ is;

$$Y2 = (1.5 - 0) * 200 + 600$$

$$Y2 = 900 \text{ hPa}$$

The block diagram for the atmospheric pressure VI is presented in Figure 3.16. The same principle was applied to the calculation of the temperature and the humidity sensor outputs and the outcomes are listed in Section E.8, Appendix E.

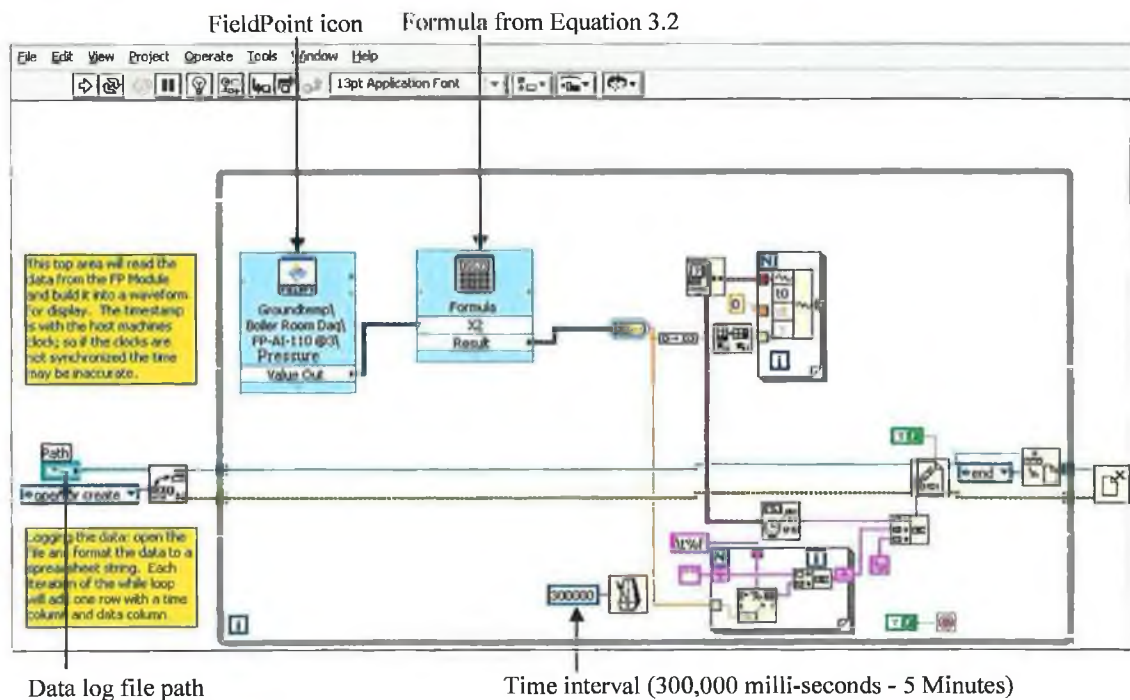


Figure 3.16 Block diagram of the atmospheric pressure VI.

3.3.4.4 Development of the Ground Source Heat Pumps Performance VI's

The following measurements were requested to establish the heat pumps COP;

a) Fluid Flow Temperature: These 14 temperature measurements were recorded using a VI entitled 'Power and Pump' VI. The direct reading from the temperature sensor was in degrees Celsius so no signal manipulation was required. The VI had to be setup to read the

temperature sensor every five minutes and log the value with a time and date stamp. This applied to both the horizontal and vertical heat pumps.

b) Electric Power Consumption: The power consumption of each heat pump was measured using FieldPoint module FP-AI-100 in milli-amps (4-20mA). This required conversion (from 4-20mA) to kilowatts which was equivalent to 0 - 11.19 kW.

Therefore using Equation 3.1;

Where; $X1, Y1 = 0.004A$ (output from sensor), 0 kW (power consumption of heat pump)

$X2, Y2 = 0.02A$ (output from sensor), 11.19 kW (power consumption of heat pump)

$m = 0.00413$ kW/A

Then; $Y2 = (X2 - 0.004) * 0.00143 + 0$ (kW) (Equation 3.3)

c) Mass Fluid Flow Rate: The mass flow rate to and from the heat pumps was also measured using four flow meters. The counter module (FP-CTR-500) outputs a pulse for every litre/sec of fluid that flows through the meter. A VI was created to read this pulse every time the sensor changed state and log the value with a time and date stamp. The fact that the VI only logged the change in state of the sensor, resulted in the logging of relevant data and not logging the data when there was no fluid flowing. This principle was applied to the four flow meter VI's.

3.3.4.5 Development of the Ground Collector Profiles VI's

The ground collector temperature sensors output directly in degrees Celsius, so no signal manipulation was required. A VI was setup to record the data at 5 minute intervals as well as log, date and time stamps each scan to the appropriate *.txt* file. A number of outputs of the measured data are presented in Figures 5.1(a-c) in Chapter 5. As stated in Section 3.2.2 the moisture sensors required a customised VI in order to read the frequency output of the sensor. The frequency VI was created by NI and was altered to enable the reading of frequency output from the moisture sensor circuit. A VI was built for each of the 10 moisture sensors.

There were four control settings that required configuration on each VI which is discussed in more detail in Section E.7, Appendix E and a screenshot of the moisture sensor VI is presented in Figure 3.17.

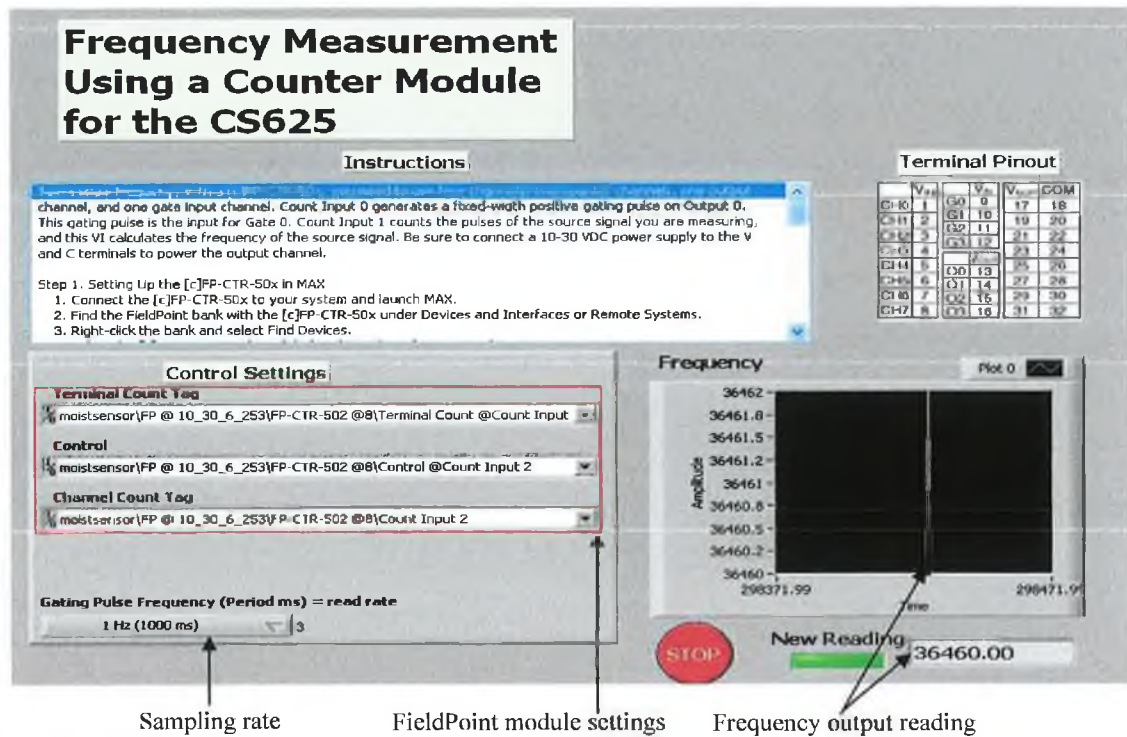


Figure 3.17 Screen shot for the moisture content sensor configuration VI.

3.3.4.6 Development of the Solar Thermal Collectors VI's

The solar collector temperature signals required no signal manipulation as the sensors output values directly in degrees Celsius. The VI was setup to read the flow and return temperature to both collectors and log the data every five minutes with a time and date stamp. The flow rate to and from the solar collectors was measured by the ultrasonic flow meter. The meter outputs a signal of between 4-20mA which is equivalent to 0-80 litres/minute and the meter configuration is presented in Section 3.2.3. A VI was created to convert this milli-amp signal to a flow rate of litres/min. Using Equation 3.1 the following equation was created;

Where; $Y2 = \text{Unknown flow rate of fluid (litres/min)}$

$Y1 = 0 \text{ (litres/min)}$

$X2 = \text{output from the flow meter (A)}$

$X1 = 0.004A$

$m = 5000 \text{ litres/min/A}$

Then; $Y2 = (X2 - 4) * 5000 + 0 \text{ (litres/min)}$ (Equation 3.4)

The VI was setup to read the flow only when the fluid was flowing through the flow meter so as to avoid unnecessary data logging.

3.3.4.7 Development of the liBC building VI's

The building's internal air temperature was measured using thermocouples which output a value directly in degrees Celsius. A VI was created to record the building temperature at five minutes intervals and log the data with a time and date stamp.

All of the VI's for the 108 sensors were developed to log the data a different instances so as not to overload the PC. There is a 15 seconds lag between the first sensor logging and last sensor logging. The PC processor was at its limit when all the sensors were logging at exactly the same instant in time, so the solution was to expand out the logging time period over 15 seconds. A number of outputs of the measured data for the weather station, GSHP's and solar collectors are presented in Chapter 5.

3.4 Summary

This chapter describes the hardware and software used to create a DAQ system capable of acquiring data from 108 sensors for CiSET's energy research, development and demonstration facility. These sensors are connected to seven different types of analog and digital I/O FieldPoint modules from NI, which in turn are connected to the GMIT network via a FieldPoint network module. The DAQ setup is a flexible system that allows the user to easily add or subtract more sensors and modules to the system. The control program used for the monitoring and controlling of the system was developed using Labview 8.20 software from NI. This DAQ system has been configured to scan and record the output of each sensor at five minute intervals and thereby generates approximately 10 million data points annually. Over 25 million data points have been logged without interruption since being commissioned in March 2007, and some examples of the research output based upon this data has also being presented.

Chapter 4 Sustainable Energy Online Learning Environment (SEOLE)

This Chapter presents the ‘Sustainable Energy Online Learning Environment’ (SEOLE) that was developed to help various learners discover more about the performance of sustainable energy systems in Ireland maritime climate. The needs of each learner group are identified so that the most appropriate structure and functional specification for the learning environment could be defined. The resulting site plan, navigation, best practice learning aids and development timeline are also presented. The proposed website invites learners to discover information and knowledge about energy efficiency and SET’s, using this online learning environment and two examples of the learning environment developed for the solar thermal collectors and the weather station are presented.

4.1 SEOLE Concept Development

As outlined in Chapter 2, the demand for information on basic system operation and performance data on sustainable energy systems is increasing and the task for both system suppliers and educators is to find better ways of providing this information. The internet provides a very accessible medium, but it challenges the developers to design layouts that are attractive, easy to navigate, informative, interactive and delivers high quality and relevant data. The SEOLE seeks to achieve these desirable features.

The SEOLE also aims to encourage the transfer and sharing of knowledge and research outcomes to all interested learners within primary, secondary, third and fourth level schools as well as end users within the broader community and industry, so as to maximise the returns to education, the economy and community. This will allow GMIT to deliver new learning opportunities to both its undergraduate students and the wider community as identified in Table 4.1. This dovetails well within GMIT’s teaching and learning remit which strives to integrate research, teaching and regional development. The SEOLE will increase awareness of ongoing research within GMIT by promoting the exchange of ideas between the education and the research community, policy makers and the private sector.

It will also provide a platform for the CiSET research group to increase their profile through the promotion of sustainable energy systems and the dissemination of performance data from the SES’s under investigation. The design and implementation of SEOLE is discussed in the next section.

Table 4.1 Target groups and specific audiences which SEOLE might support.

| Target Groups for SEOLE | Specific audiences which could benefit from tailored information |
|-------------------------|--|
| 1. Community | <ul style="list-style-type: none"> • Those not in education or energy industry but with an interest in building a new energy efficient home or renovating an existing house/building • Those interested to reduce energy costs • Those interested in sustainable energy technologies and creating a cleaner environment through projects in their community, town, region or island |
| 2. Education | <ul style="list-style-type: none"> • Primary level students are exposed to sustainable energy technologies (SET) and concepts in subjects such as Geography and Science, see section D.1, Appendix D. • Second level students are exposed to SET and concepts in Geography, Science, Physics and Technology, see section D.1, Appendix D. • Third level students in Science and Engineering have opportunities to study courses in SET's or Energy Engineering. SEOLE is being developed to support GMIT's Degree in Energy Engineering but equally it could have wider applicability within the 3rd level sector. • Fourth level students undertaking taught masters programmes. For instance, SEOLE will potentially support students undertaking GMIT's MSc. in Environmental Systems. • SEOLE will also support mature learners who enrol for Continual Professional Development (CPD) courses such as; <ul style="list-style-type: none"> - Building Energy Rating (BER) assessor training - Installer courses for sustainable technologies, solar thermal, solar PV and heat pumps. |
| 3. Research | <p>Since SEOLE is developed upon a research infrastructure, it should also present an insight of the research projects, a profile of the researchers, the CiSET research centre and the employment opportunities that may arise for either postgraduate researchers at MSc., MEng. and PhD levels or for Research Engineers or Scientists.</p> |
| 4. Commercial | <p>SEOLE also offers the potential to support specific commercial interests such as those within;</p> <ul style="list-style-type: none"> • Sustainable energy technologies industry: Those business that sell, install and commission solar thermal, solar PV, heat pumps, wind power or heat recovery systems could use SEOLE as a support to explain how these systems work and perform under Irish weather conditions. • Building/Construction Industry: Could utilise SEOLE to explain how these SET's may be integrated into a house or building and what the likely performance might be. |
| 5. Collaborators | <ul style="list-style-type: none"> • CiSET is also anxious to recognise the valuable contribution and collaborators from academia, industry or public bodies. |

While SEOLE offers the potential to reach the diverse audience defined in Table 4.1, there is clearly many years of development work required to establish such a comprehensive interface. Table 4.2 presents a suggested 5-year development timeline for the SEOLE project. It identifies the contribution of the current DAQ-WBL project in delivering suitable material for the community and secondary schools, and also shows the current CiSET research projects that are contributing to its development. For instance the following four projects will contribute to the development of SEOLE once this DAQ-WBL project concludes;

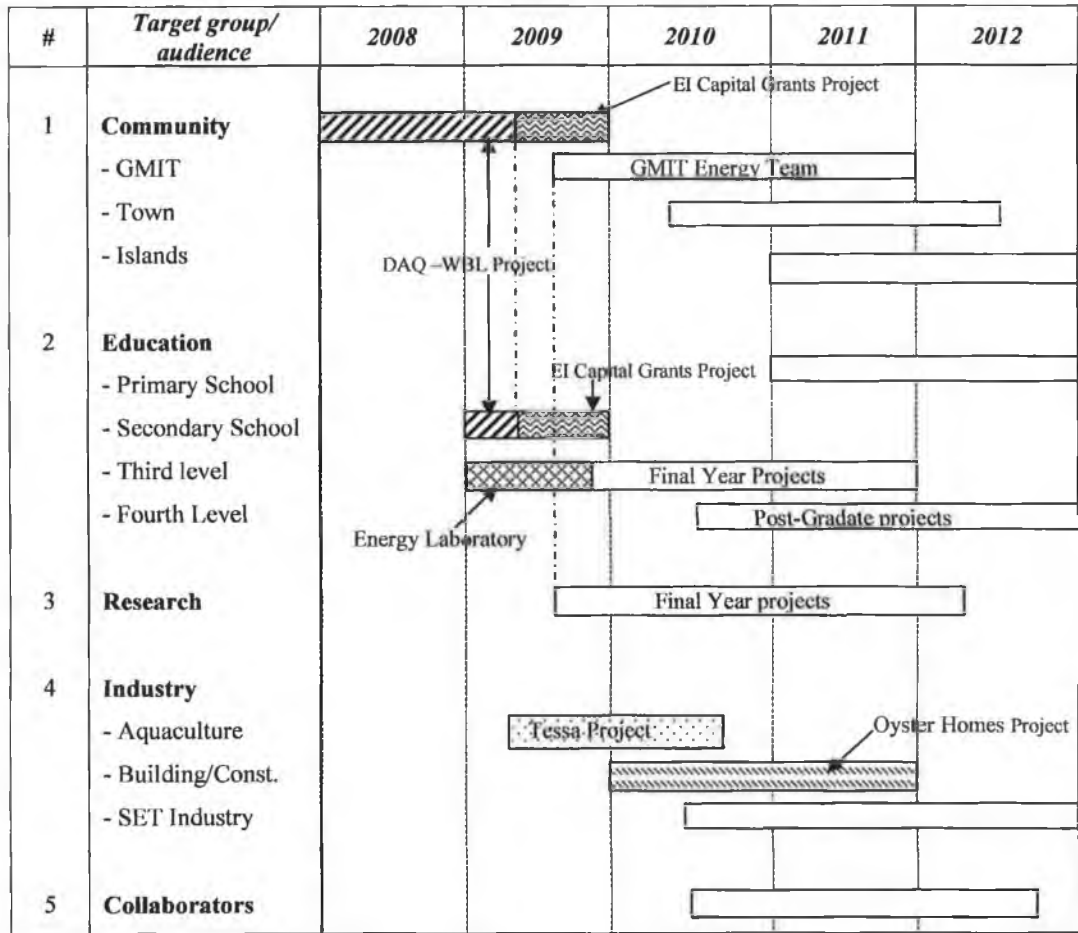
- Enterprise Ireland's capital grants scheme project will add system descriptions and performance data from additional solar thermal collectors, 2 solar PV arrays and 4 micro-wind turbines, to the community and secondary school pages by the end of 2009.

- The Department of Education and Science's Strand III TESSA (Total Energy Solutions for Sustainable Aquaculture) project will add a user interface for a recirculating aquaculture system that will support the aquaculture industry by the end of 2010.
- The Oyster Homes Ltd. project will add an interface describing the design features and energy performance of 3 different styles of A-rated domestic houses by the end of 2011.
- The Energy Laboratory Project will provide an interface with the performance of 2 x solar thermal collectors, biomass boiler, gas boiler, solid fuel stove, air source heat pump, heat recovery unit, under flooring heating and three types of radiators to be monitored.

These four projects are funded and underway.

This DAQ-WBL project focussed on building a demonstration site to support community based users and some of the content created conveniently overlaps with the interests and syllabi of secondary school level learners. The site design focused on building an informative, easy to navigate, learner centered and interactive learning environment, which leverages access to live performance data to embellish standard system descriptive information and to stimulate the learner.

Table 4.2 Development timeline for SEOLE (2008-2012).



4.2 Software Selection

A selection of the many different types of sustainable energy focussed online monitoring environments is discussed in Section 2.3. Some offer descriptions of the operating systems and historical performance data, whereas others offer both live and historical performance data through off-the-shelf software packages.

The SEOLE was developed based on best practices presented in Sections 2.3-2.6 and used software such as Microsoft Visual Studio, Flash CS3, Dreamweaver and Photoshop. These packages were used by a computer programmer to develop the web pages, toolbars, buttons and energy systems schematics within the site. The programming languages used were asp.net, T-SQL, action script and web development skills such as html, cascading style sheets (css) and JavaScript were also deployed. These packages were used to build the site and program the interactions between the web pages. The database used to store the performance data recorded by the DAQ was setup and managed by Microsoft SQL (Structured Query Language) 2000 on Windows Server 2003.

4.3 Hardware Selection

A Dell Poweredge 2900 was used as the web server. This server has a quad core Intel™ Xeon processor (2.66GHz) with 4Gb of RAM and two hard drives (1TGb and 100 Gb). The server is connected to a UPS to prevent loss of power and power surges. The second server used for hosting the website was located within GMIT's protected Demilitarised Zone (DMZ) and is connected to the GMIT network. A DMZ is a secure network zone that is located behind the institute's firewall.

4.4 SEOLE Structure

Based on the recommendations presented in Section 2.6, the SEOLE was designed and developed in accordance with best practices recommended by Fox, (2005), Handke, (2006), Lynch *et al.*, (2003), Lund *et al.*, (2005), Piskurich, (2006), Sam *et al.*, (1999) and Shneiderman, (1998).

The overall aim was to create a website that utilised attractive graphics, had an easy to navigate generic structure, was interactive and multi-level, was tailored to individual's background and needs, informative and delivered high quality relevant content to each potential user, whether for general interest, educational or commercial purposes.

4.4.1 Overall Site Plan

As presented in Table 4.1, SEOLE aimed to support learning across four broad user groups and supply each learner within these groups with an appropriate type and level of information to enable them to both understand the operation and performance of each sustainable energy system. These user groups include the general community, the educational sector, research and commercial groups and the SEOLE site plan was deigned accordingly. Figure 4.1 presents the low level site plan which identifies the four user groups and their sub-audiences.

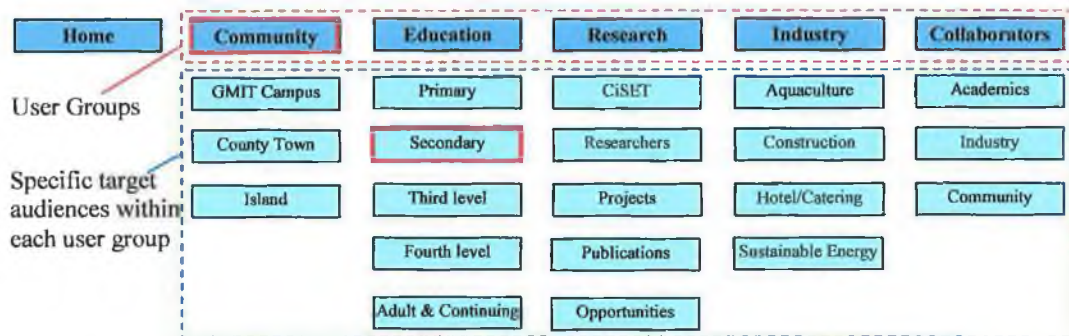


Figure 4.1 Low-level site plan for SEOLE, also showing the two users for which content was created during this DAQ-WBL project (highlighted in red outline).

Community User Group: The goal of the general community section was to raise awareness of our energy consumption nationally, locally and in the home and to highlight the potential of sustainable energy technologies to meet this demand. SEOLE sought to support this ‘awareness building’ within the community in two ways;

- i) by delivery a wide range of both general and system specific information in a non-technical format and language. General information being provided ranged from;
 - a profile of Ireland’s energy consumption to,
 - a profile of energy consumption in a typical home to,
 - considerations for improving the energy efficiency in a new home or a renovated home to,
 - a thorough description of the key features, principles of operation and live performance data from a range of sustainable energy systems installed at GMT.

The presentation of this information flows from the general to the specific and screen shots from this aspect of the site are presented in Section 4.2.2.

- ii) by developing a portal for the promotion of communities that initiate community based energy efficient projects, programmes or initiatives. The goal is to promote such worthwhile initiatives so that they may serve as models to other communities. As indicated in Figure 4.1, GMT’s CiSET research group has identified three diverse target communities that includes the GMT’s, Dublin Road Campus, a local town and profiling the energy consumption an island off Ireland’s west coast. CiSET will to work on these projects throughout the 2010 and 2011 period.

Educational User Group: Using a novel and accessible online format, SEOLE has the capacity to support learning within each of five levels that span the education system identified in Table 4.1. While it has yet to be developed, the SEOLE provides an excellent

opportunity to present information on energy efficiency and sustainable energy system performance that aligns with relevant subjects or courses syllabi at each level. For instance sustainable energy forms part of the 5th and 6th class primary level Geography and Science courses, as well as Geography, Science, Physics and Technology in secondary level. Extracts from the appropriate syllabi are presented in Section D.1, Appendix D. Equally, a more detailed version of the system descriptions and performance data can be used to support 3rd and 4th level courses. Each of the learner groups can be provided with the appropriate level and relevant amount of information in accordance with their age, experience and background. The 3rd and 4th level students are provided with the most detailed system information which may include information such as system efficiency, seasonal performance factors and capital payback periods. These students may access performance data from each system, including the option of downloading data to support self learning or laboratory projects. Similar to the MARVEL project, presented in section 2.5, this downloaded data may be used as part of the laboratory exercises in order to build a deeper understanding of system performance under Irish weather conditions. Obviously, the development of this extensive learning environment was beyond the scope and resources of this DAQ-WBL project, which focussed on generating content suitable for 2nd level students, which caters more towards understanding the system's principle of operation.

Research User Group: The research pages of SEOLE aim to promote the research activity and disseminate the findings of GMIT's Centre for the Integration of Sustainable Energy Technologies (CiSET), to GMIT's many regional, national and international stakeholders. As indicated in Figure 4.1, specific pages will be developed to profile CiSET's researchers, key research projects and their findings. One page will be devoted to CiSET's research and scientific publications, which will also help inform second and third level students of typical research projects, thereby giving them a greater insight to fourth level education. Employment opportunities will also be promoted on this page.

Commercial Industries User Groups: CiSET conducts publicly funded applied research that needs to be made available for the commercial benefit of Irish industries. Each research project is aligned to a specific industry and the broad categories of industry are identified in Table 4.1 and Figure 4.1. The goal of SEOLE is therefore to present information and performance data for either the energy system, the building or the aquaculture system in as clear, unbiased and as comprehensive fashion as possible so that the industry and its market is furnished with high quality performance data, which is currently absent. Such

information can be used by the Irish industry for marketing, staff and customer training or promotional purposes.

Collaborators: SEOLE will also recognise and promote the valuable contribution of CiSET's many collaborators from academia, industry, the community or other public bodies.

Upper Toolbar: The site also includes other links to users such as login options, where potential users could register their user details and be provided with access to more specific system information or performance data. As indicated in Figure 4.2 access to generic CiSET links like news, feedback, courses, contact details and further information is also provided.

4.4.2 SEOLE Development Process

Once the top-level site plan was agreed the SEOLE site was developed using the following process:

- i) The first site plans were created in Microsoft Word in order to provide a visual expression of the ideas. As indicated in Figure 4.1 this plan provided an overall hierarchy site plan that was to be created and provided a simple and definite starting point for the planning process.
- ii) The next stage was the layout of the site pages to be defined, beginning with a template for the home page. Taking best practice, outlined in Section 2.6 into account, a number of drafts were developed. These drafts are presented in Figures B.1 (a-d), Appendix B and the most recent Home Page design is shown in Figure 4.2. The Home Page was designed as a template for all other pages throughout the site. This was very important as the users attention should be focused on the content and learning on the page and not different layout and designs.

This was achieved by dividing the webpage into six sections identified in Figure 4.2;

1. Logo and banner associated with the CiSET research centre with a distinct background theme of sustainable energy.
2. Upper toolbar with quick access links to CiSET activities such as news, events and training courses.
3. Main navigation toolbar for the entire site. This toolbar appears on every page through-out the site. This ensures that the user avoids confusion and disorientation while navigating through the site. The toolbar was subdivided into 5 user-groups.

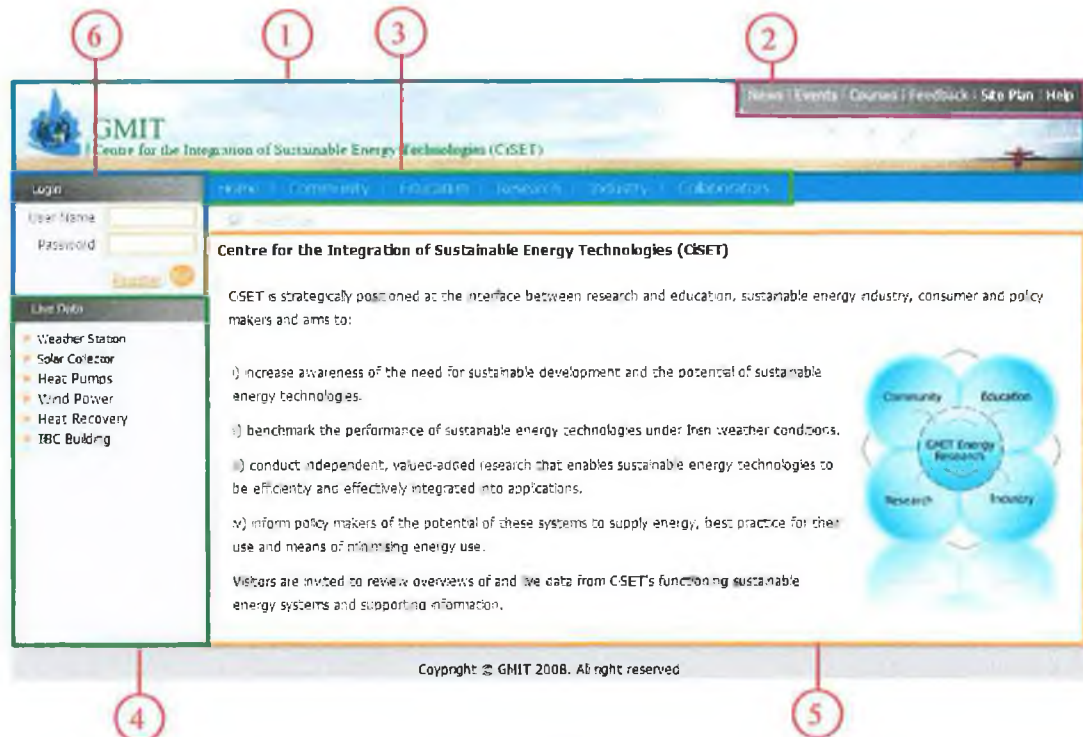


Figure 4.2 Six key sections of the 'Sustainable Energy Online Learning Environment' Home Page.

4. Navigation sub-menu from main navigation toolbar menu number 3. Access to live performance data for six sustainable systems.
5. Page content which was made up of text, images, drawings, links etc.
6. User login facility (not yet operational)

The use of scrollbars was minimised to allow for ease of viewing and to make the site more appealing (Handke, 2006 and Piskurich, 2006).

4.5 Content Developed for Community Based User

As indicated in Table 4.2, this DAQ-WBL project focussed on developing content and a model structure for the Community-based user who was provided with two types of information. The first was general information describing energy consumption in Ireland and in the domestic home as indicated in Figures 4.3(a) and (b). This section supplied the user with information on the energy usage and trends in Ireland and in a typical family home to help increase awareness of energy consumption. Additional general information is presented for those considering building a new home by outlining the energy requirements imposed by the current Building Regulations (Part L, 2007) as well as an overview of the Building Energy Rating (BER) initiative.

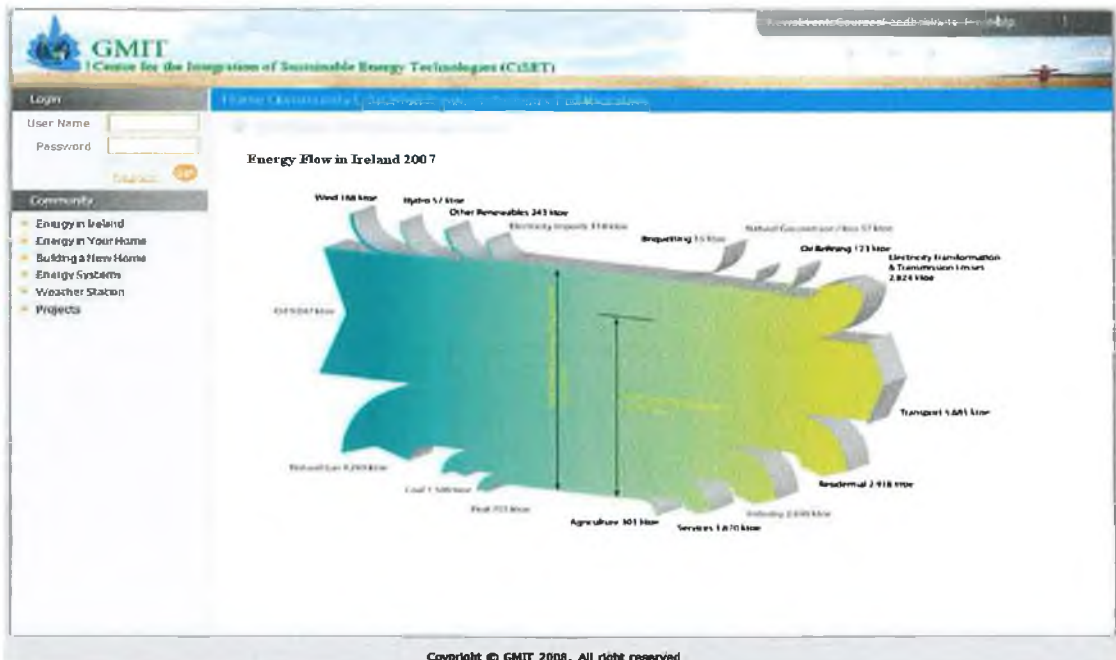


Figure 4.3(a) Community User Page providing information on: Energy consumption in Ireland in 2007.

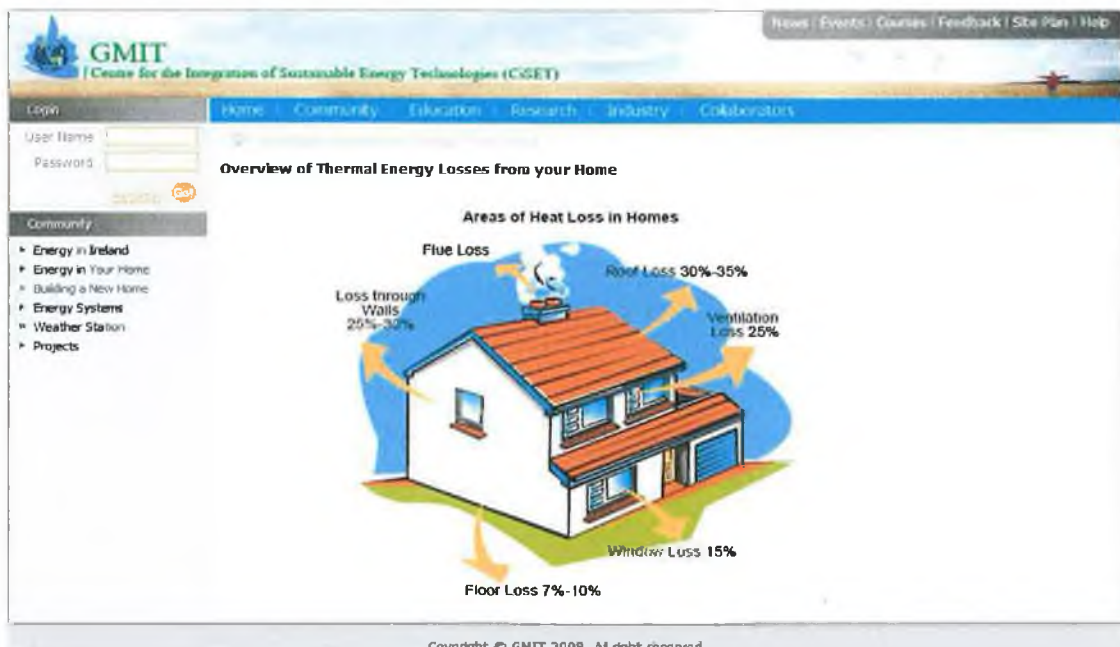


Figure 4.3(b) Community User Page providing information on: Energy consumption in a domestic home.

The second type of information provided is less frequently available and relates to the operation and performance of the sustainable energy systems. This embraced the best practice in e-learning environments described in Sections 2.3 through to 2.5 to build a multi-layered description of these systems using both flash driven graphics and text. This approach is based on earlier systems and learning facilities developed by Building Dashboard USA, DECK Monitoring USA, Fatspaniel USA, Greentouchscreen USA,

Hutzel *et al.*, (2006) USA, Iowa Energy Centre USA, Oberlin College USA, Queens University Canada, Remote Accessible Energy Laboratory (RAEL) USA and Research Institute for Sustainable Energy (RISE) Australia. The multi-layered system descriptions is sub-divided into five steps defined in Table 4.3. Similar step by step layouts have been incorporated by DECK Monitoring, Fatspaniel and Remote Accessible Energy Laboratory (RAEL) as presented in Figures in B.4 (a-c), Appendix B.

Table 4.3 Five steps of information used to present description of energy systems in SEOLE

| Steps | Toolbar Title | Associated Learning |
|-------|-------------------------------------|--|
| 1 | System Overview | Identifies the key physical features of the system |
| 2 | Principle of Operation | Describes how the system operates |
| 3 | GMIT System | Overviews the system developed at GMIT |
| 4 | Live (<i>and historical</i>) data | Presents live data from the GMIT systems |
| 5 | Further Information | Provides external sources of further information |

Using this multi-layered approach it was possible to increase the learner's level of understanding in steps, using conventional text book descriptions in steps 1 and 2, while supplementing this with a description of GMIT's system in step 3. Learning can be further enhanced by visiting GMIT's facility if so desired in step 3 or by viewing live or historical data from this system in step 4. Step 5 provides links to other sites for the learner to supplement their learning. These five steps are discussed in greater detail in the next section, using the weather station as an example.

4.5.1 Learning Environment for the Online Weather Station

Learners gain access to the learning environment weather station via the weather station Home Page presented in Figure 4.4(a), which outlines the 5-steps of information available. As recommended by Sam (1999) the simple guided step by step process ensures the viewers attention is focused on the learning environment and not on the interface.

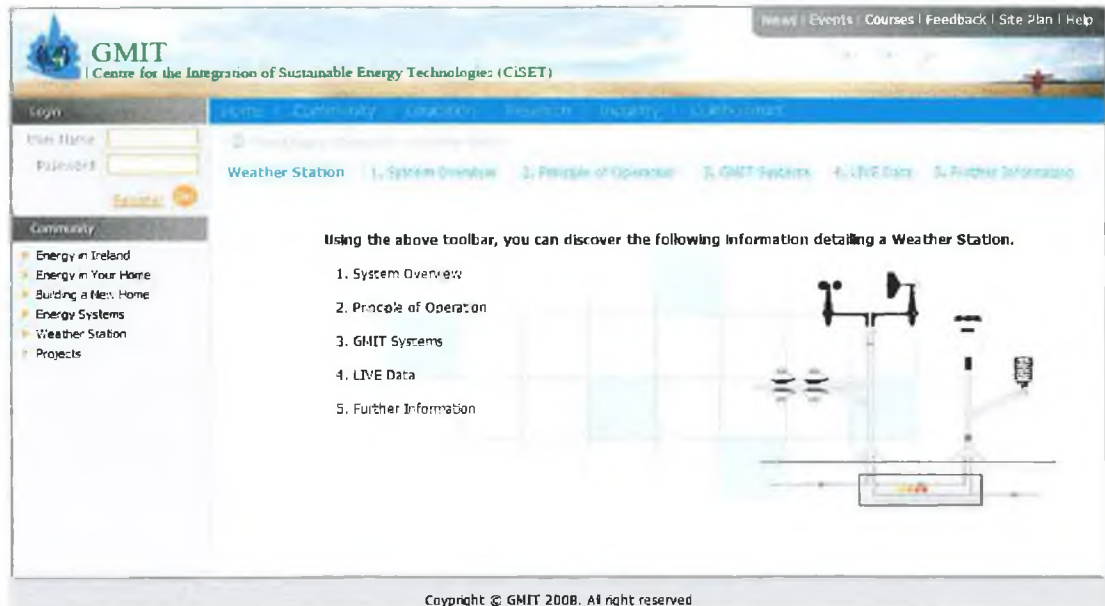


Figure 4.4(a) Home Page for the Weather Station learning environment.

Figure 4.4(b) presents a screen shot of the webpage developed to provide a ‘System Overview’ of a typical weather station. The aim of this page is to define the key features of the weather station. The learner’s attention is first drawn to the ‘system’ schematic (1) which dominates the centre of the page.

This schematic has been developed to give a pictorial representation of the actual instruments used by most weather stations. The name of each instrument is identified using the weather variable symbol and label (2) and its purpose is described using an extended description text box (3) which drops down (from the label) by floating the mouse pointer over the instrument symbol/label. Each instrument’s symbol is used consistently throughout the website whenever a weather variable is used adding to the flow and consistency of the website and shows how a more detailed insight can be conveyed by bringing certain elements of different systems together. One example will be presented for the solar system in section 4.5.2.

The provision of an extended description text box (3);

- i) increases the amount of information that can be presented using a single system graphic/schematic on one page,
- ii) improves interactivity between the learner and the site,
- iii) and a small amount of similar type of information is provided for each instrument, making it easy for the learner to achieve the same level of understanding for all key aspects of the system.

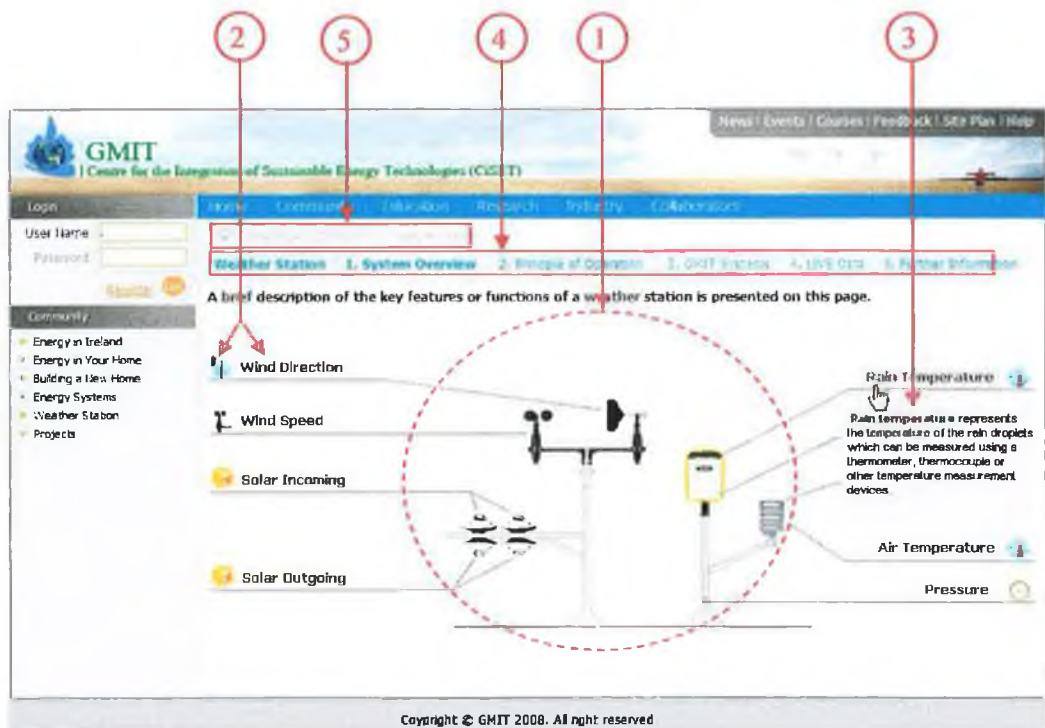


Figure 4.4(b) Step 1: 'System Overview' page from the SEOLE weather station.

Note that once the 'rain temperature' instrument label is 'moused-over' in Figure 4.4(b), the instrument in the system schematic is highlighted by a yellow outline, to boost interactivity and clarity.

Once the learner completes their "System Overview" step they can progress to gain a deeper understanding of how each instrument operates by clicking on the "Principle of Operation" button on the learning menu bar (4). The navigation root directory (5) is displayed on each webpage to assist the user's navigation and avoid disorientation as recommended by Fox (2005), Handke (2006), Lynch *et al.*, (2003), Lund *et al.*, (2005), Piskurich, (2006) and Sam (1999).

The “Principle of Operation” page shown in Figure 4.4(c) uses almost identical graphics to that in Figure 4.4(b). Since the weather station requires electric power to operate, a schematic for this element is added, along with one for a PC used to record the measured data. However, the content of the extended description text box (3) now describes the “Principle of Operation” of each instrument thereby extending the learners knowledge of how a weather station operates. This completes the ‘introduction’ to the weather station.

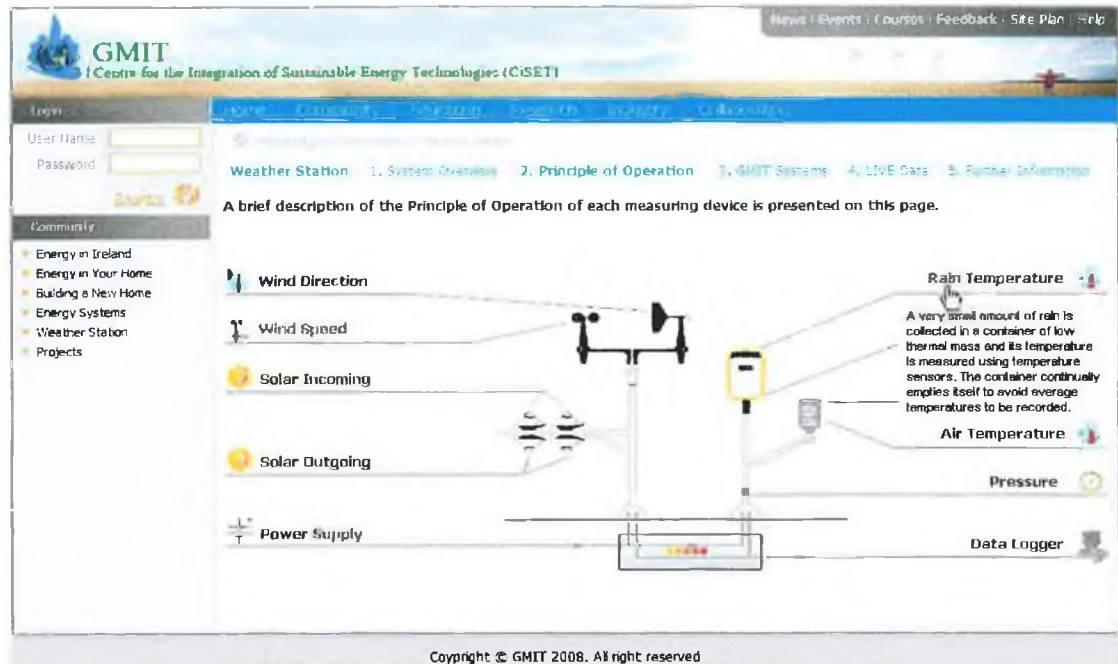


Figure 4.4(c) Step 2: ‘Principle of Operation’ page from the SEOLE weather station.

The general introduction is then supplemented by giving a detailed profile of GMIT’s weather station, which is accessed by clicking “GMIT System” from the learning navigation bar (4). It is evident from Figure 4.4(d) that a similar structure is again used. The schematic is replaced by a photograph of the weather station and each instrument is identified. Since only one photograph can be presented on the main page, a gallery of photographs is added to show different views of GMIT’s weather station including close shots of each instrument. Once again the key difference with Figure 4.4(b) and (c) relates to the nature of information in the extended description text boxes (3), which now identifies the actual instrument used in the GMIT system, along with their manufacturer and measurement accuracy. The learner should now have developed a real sense of what a weather station is, how it operates and where it can be sourced.

Gallery of photographs of the GMT weather station



Figure 4.4(d) Step 3: 'GMT System' page from the SEOLE weather station.

Live data from the GMT weather station can be accessed by clicking on the “Live Data” button from the learning navigation bar (4) and an example of the live data recorded data at 14:00hr on the 18th of June 2009 is presented in Figure 4.4(e). To aid continuity from earlier pages in Figures 4.4 (c, d, & e) each of the weather station symbols introduced in Figure 4.4(b) are also used. The data on this page is updated every 5 minutes.

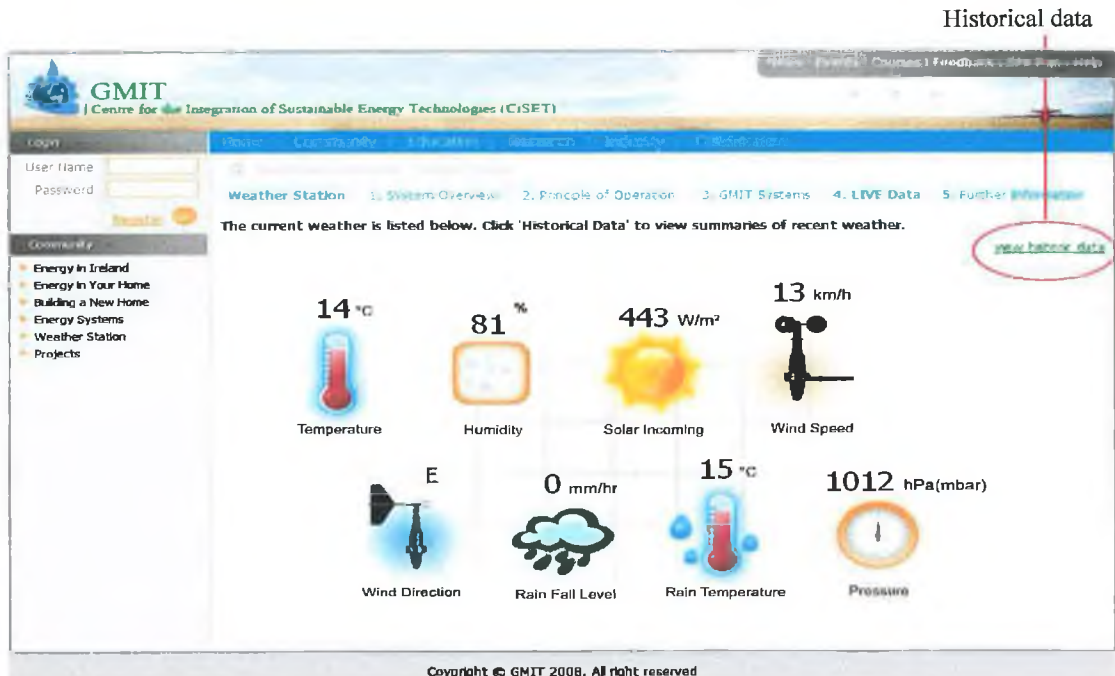


Figure 4.4(e) Step 4: “Live Data” page from the SEOLE weather station.

To aid analysis or to view weather patterns and trends, it is also possible to “View Historical Data” by clicking on the button on the top right hand corner of the image in Figure 4.4(e). This produces a flexible analysis tool shown in Figure 4.4(f), which can be configured to display any of the 8 measured weather variables, for any time periods varying from 1 day to 1 year.

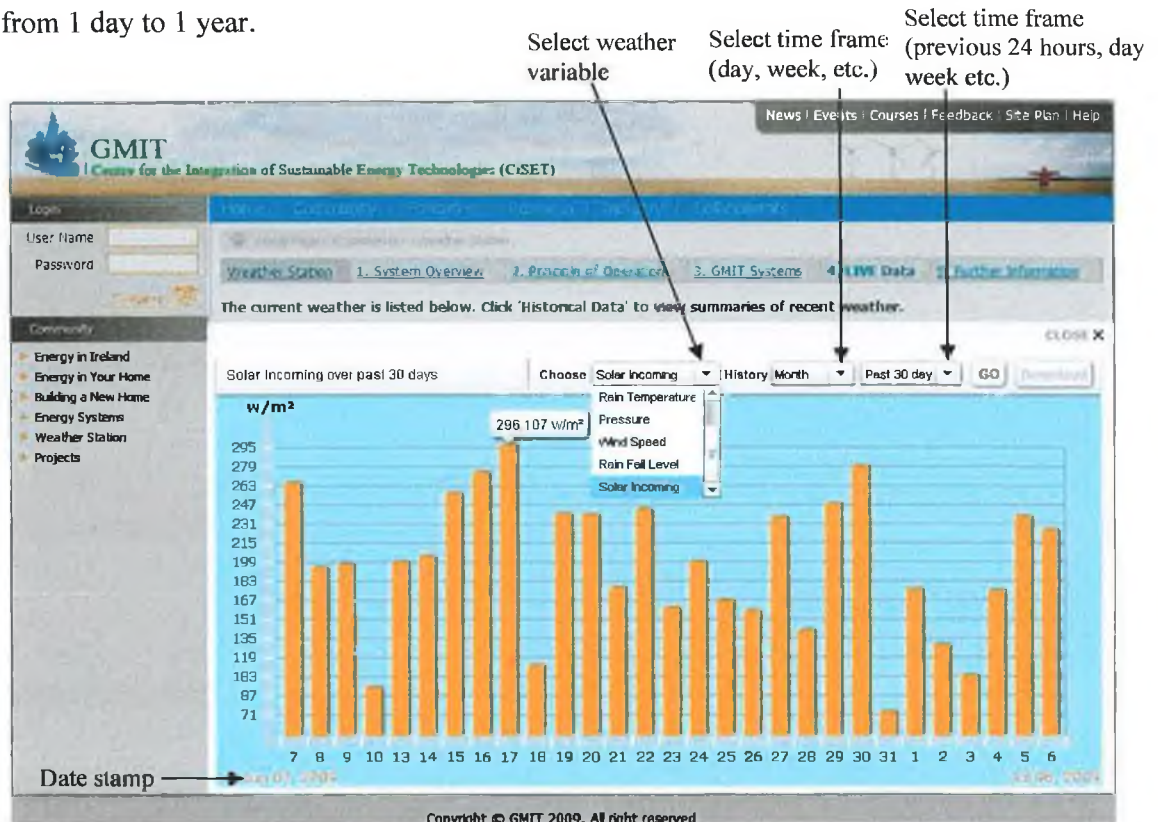


Figure 4.4(f) SEOLE's flexible analysis tool for viewing historical weather data.

Figure 4.4(f) has been configured to represent the solar gains for a 1 month from the 07th June, 2009 until the 06th of July, 2009 which clearly shows a peak solar intensity of 296.1W/m² on the 17th of June. Also when the learner ‘mouses over’ each graph bar the actual averaged numeric (296.107w/m²) value is displayed. This analysis tool is modelled on those available on Fatspaniel, Building Dashboard, Oberlin College Ohio, Queens University Ontario and GreenTouchscreen. To conclude the ‘weather station’ learning experience, the learner is invited to seek further information from external resources by clicking on “Further Information” from the learner menu bar (4) and a screen shot of this page is shown in Figure 4.4(g).



Figure 4.4(g) Step 5: "Further Information" page from the SEOLE weather Station.

The equivalent content generated for the solar thermal system is presented in the next section.

4.5.2 Learning Environment for the Online Solar Thermal Collector

Information describing the "System Overview" and "Principle of Operation" of a solar thermal collector is configured and presented in a similar way as the weather station but some differences were introduced to reflect the differences in the system configuration. In the "Principle of Operation" page, Figure 4.5(a), the sensor labels are numbered to guide the learner through the sequence of events which take place to activate and operate the system. As shown in Figure 4.5(a) the device labels are supported by dynamic flow arrows that indicate the direction of the energy or fluid flows through out the system. These are supplemented by using colour coded pipes to reflect the temperature of the fluid within the pipes or change in fluid temperatures i.e. red for warm and blue for cold fluid flows. These flash media generated moving flow lines not only grab the learner's attention, but also eases the explanation of system operation.

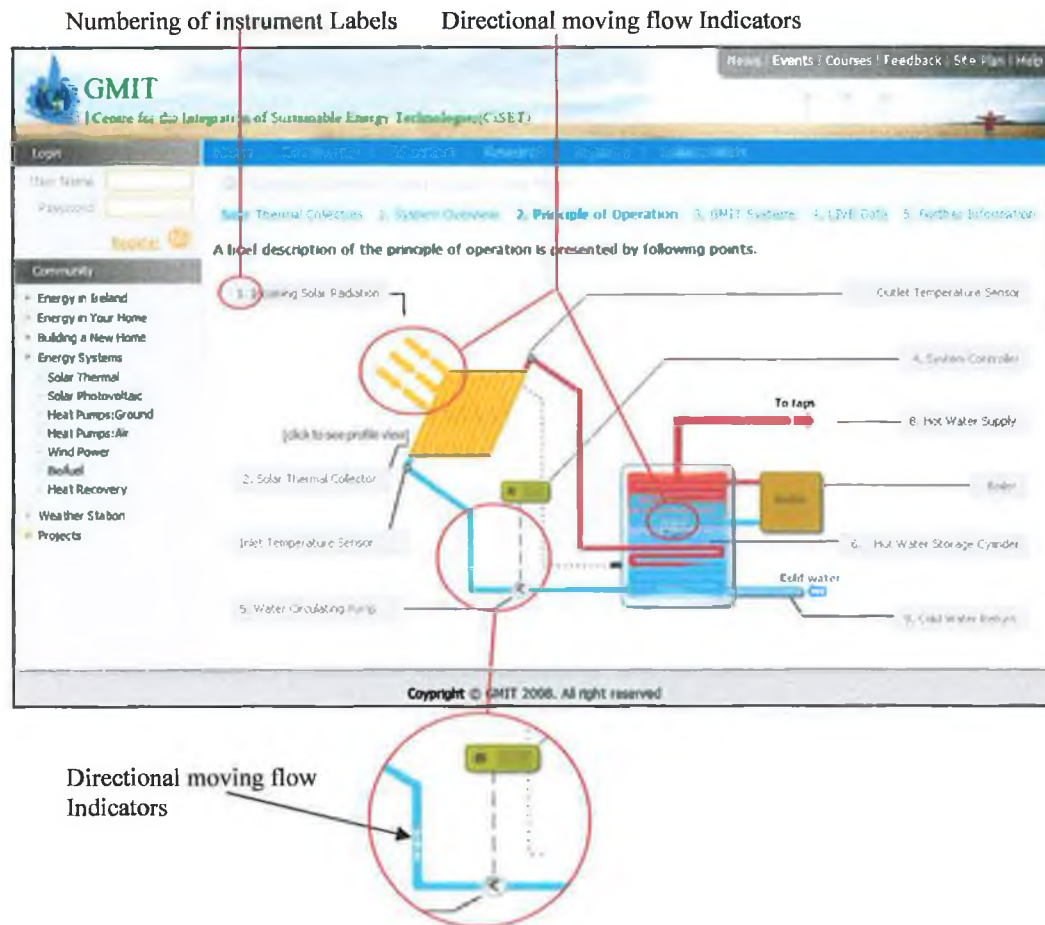


Figure 4.5(a) Step 2: "Principle of Operation" page of SEOLE's solar thermal collectors system

The live data is presented using a similar schematic to that in steps 1 and 2 ("System Overview" and "Principle of Operation"), but the labels are removed and replaced with live data outputs as shown in Figure 4.5(b). The learner can firstly view the live performance data from two collectors (flat plate and evacuated tubes) on a single screen with a number of influential weather variables (air temperature, wind speed and solar incoming). Figure 4.5(b) just details the inlet and outlet temperatures to/from each solar collector and this is sufficient for the calculation of secondary data shown in Figure 4.5(b) for each collector;

- a) actual thermal energy available to the collector,
- b) energy absorbed by each collector at that instant,
- c) collector efficiency at that time

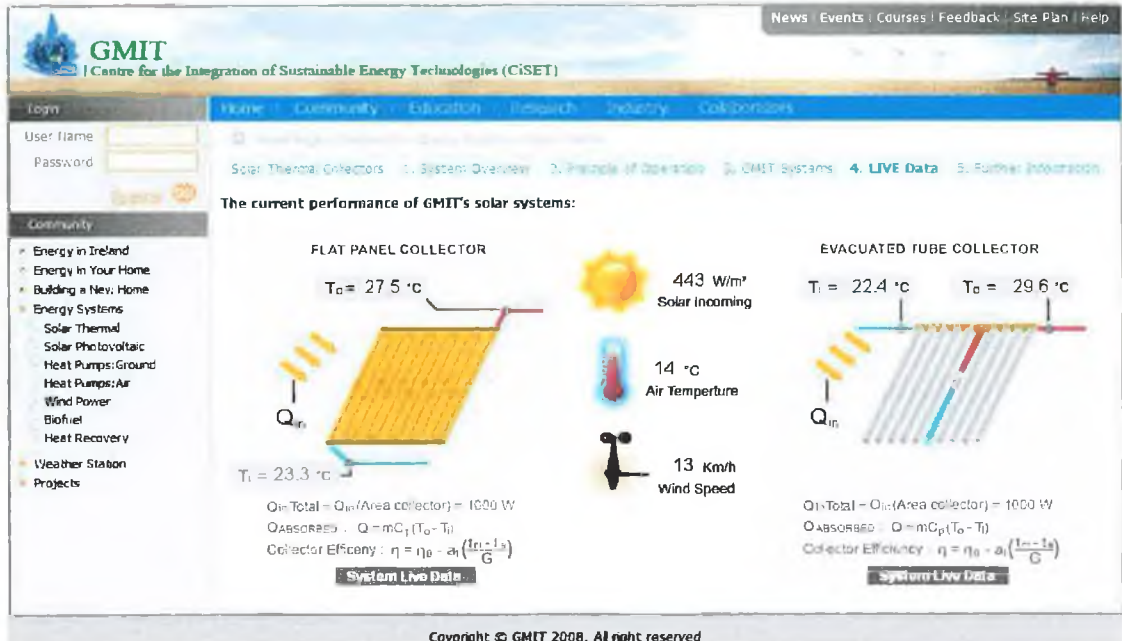


Figure 4.5(b) Step 4: “Live Data” for both flat plate and evacuated tubes based solar thermal collectors

To get a more detailed performance data from each solar system the learner must click on the “System Live Data” button (shaded grey) beneath each collector, which will present the view shown in Figure 4.5(c).

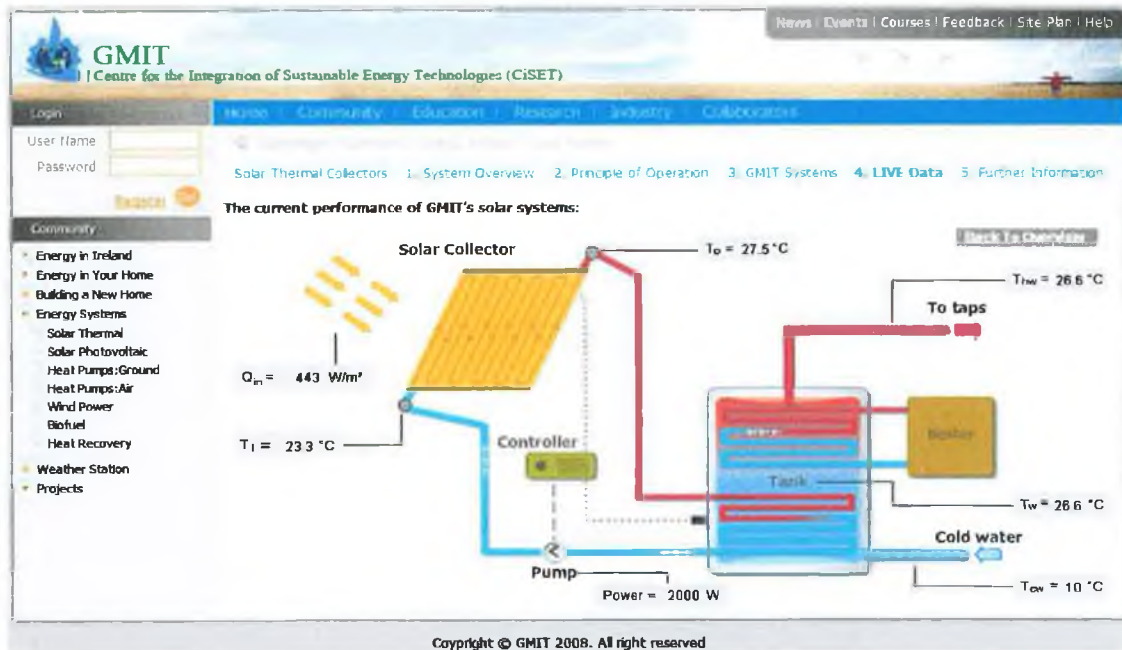


Figure 4.5(c) Step 4: “Live data” for the entire flat plate solar thermal collector systems

The learning environment displayed in Figures 4.4(a-g) and 4.5(a-c) extend those earlier versions built through labview which can be seen in Figures B.2 (a-b), Appendix B. The

earlier versions gave the students access to live performance data from the weather station, the solar thermal collectors and the GSHP's. However, the SEOLE presented in Figures 4.4(a-g) and 4.5(a-c) enable the students to view the live data from the working systems while also getting a deeper understanding of system performance in a fully operational environment. Once the performance data is available for download it can be used as a basis for learning exercises.

4.6 Features of SEOLE

The summary of the aforementioned features of the SEOLE are:

- SOELE has the capacity to deliver customised information to a wide cross-section of user groups who share an interest in sustainable energy systems (Community, Education, Research, Industry and Collaborators).
- Easy to follow and navigate website structure.
- Present both general and system specific information including live performance data in a novel 5-step learning environment.
- Modular format that allows different types of sustainable energy systems monitored.
- Promotion of research ideas between education to be presented, the research community, policy makers and the private sector.
- Promotion of sustainable energy systems in the Irish maritime climate.
- Promotion of sustainable energy systems to younger generations attending primary and secondary school.
- Photographic views of the GMIT CiSET's research and development facilities.

These features were desired features of SEOLE which are discussed in Section 4.1, and have been delivered.

The features of SEOLE's learning environment are:

- Development of a 5-step graduated learning environment that infuses interactive graphics and live system performance data with standard text-book system descriptions, to create an exciting and engaging learning experience.
- This learning environment is flexible and its features can be displayed equally well across each stage of the educational spectrum from primary level to adult learner.
- Tailored and informative content for each user, with drop down text boxes
- Step by step instructions through the 5-step learning process.
- Labelled sensors supported by sensor being highlighted (yellow outline) to increase interactivity and ease learning.

- Drop down text boxes with relevant information provided to increase the learner's understanding and deliver specific learning outcomes.
- Drop down text boxes encourages interactivity between the learner and the site
- Sensor/Instrument symbols used throughout the site to generate consistency and unity across the website.
- Flexible graphical analysis tool available to learners to plot and analyse the historical data.
- The functionality of the SEOLE has been demonstrated by the development of content for the weather station and the solar thermal collectors.
- Avoiding covering of schematics with text boxes, where possible.

SEOLE's navigation features include:

- The same text size and font style used consistently throughout the site.
- Navigation buttons and icons have a consistent appearance and position.
- Menu root directory appears on each page to avoid disorientation.
- Fixed navigation bar to guide user through learning environment.

4.7 Conclusion

This DAQ-WBL project delivered a simple, yet very flexible site structure and devised a novel 5-step learning environment [<http://www.kdp1.aquaculture.ie/index.aspx>]. Content has been generated for 2 systems, the weather station and the solar thermal collectors. The SEOLE will not only promote the sustainable energy systems in GMT and locally, but it will help excite younger generations about possible sustainable energy systems, promote on-going research and aid the development of the knowledge society regionally, nationally and internationally. The novel nature of the live and historical data for sustainable systems in the Irish maritime climate will engage the learners and enhance their skills and environmental awareness.

This facility not only captures the traditional methods of disseminating research findings such as publications and presentations, but also opens a new level of accessibility to the research environment through the web and matches the standards set by other researchers discussed in Sections 2.3 through to 2.5. It also emphasises best practice in E-learning (Clark *et al.*, 2003, Fox, 2005, Handke, 2006, Lund *et al.*, 2005, Lynch *et al.*, 2003, Piskurich, 2006, Sam *et al.*, 1999 and Shneiderman, 1998) and the results of surveys conducted on three potential user groups is presented in the next chapter which highlights

possible future enhancements. SEOLE is been further contributed to, through other projects as discussed in Section 4.1 and Table 4.2.

Chapter 5 DAQ-WBL Evaluation

The dual objective of this DAQ-WBL project was to create a reliable DAQ system to monitor SET's and display performance data through a web-based learning environment. This Chapter reviews the output of this project and the results obtained.

5.1 DAQ System

CiSET had established a number of functioning SET's (2 x solar thermal collectors, GSHP's vertical and horizontal) that required continuous monitoring to support other research programmes. These DAQ objectives were realised through the installation of over one hundred sensors throughout the facility that were connected to a custom designed DAQ system. The outputs of these sensors were scanned every 5 minutes and continuous operation since the commissioning of the system in March 2007 has generated a database of approximately 25 million data points, which bears testimony to the reliability of the system. The DAQ facility is setup to monitor the performance of different sustainable energy systems against the local climate and it is unique in the Irish maritime climate. The facility generates highly accurate and reliable data and the value of this data is demonstrated through a host of research papers [Burke *et al.*, 2008, Greene *et al.*, (2007a), Greene *et al.*, (2008b), Lohan *et al.*, (2006a) and Lohan *et al.*, (2006b), Lohan *et al.*, (2008c)]. Examples of the data generated from the weather station, heat pumps and solar collectors are shown in Figures 5.1(a-c). Three PhD researchers are currently using the experimental data recorded by this DAQ-WBL system as the basis for their research, and numerous other publications are planned.

5.2 Measured Data from DAQ System Database

A detailed set of measured data for the GSHP vertical collector is presented in Figure 5.1(a) which presents the performance over one month of operation and recovery. The month is broken into four operational periods A, B, C and E, with one recovery period, D. Figure 5.1(a) clearly displays the performance of the ground temperatures for the vertical collector through the measured data and gave valuable insights to the impact of the heat pump on the ground.

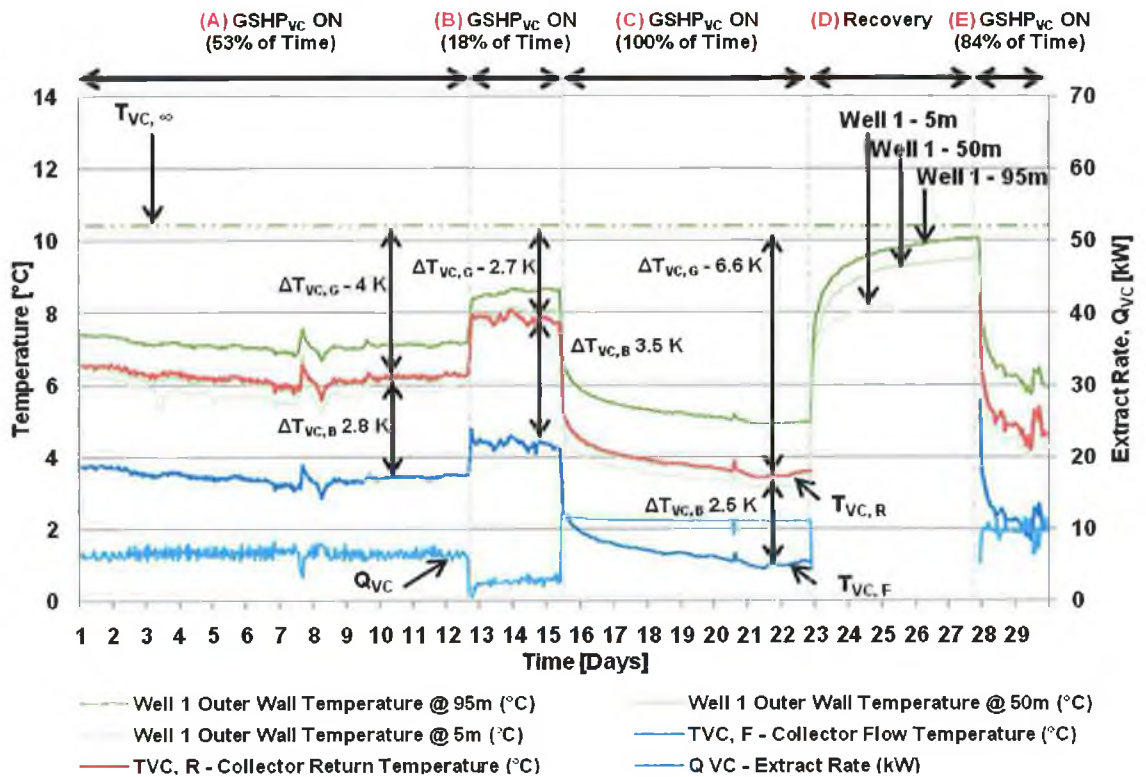


Figure 5.1(a) Drawdown and recovery of the ground for the GSHP (vertical collector) during February, 2008 [Source: Burke et al., (2008)].

A similar set of measured data is shown in Figures 5.1(b) and (c) for the horizontal ground collector. These graphs present a series of vertical soil temperature gradients recorded at logged intervals of 24 and 48 hours respectively during the period of October 14th - 23rd, 2007. The measured data shows the extent of the temperature change in the ground above and below the collector pipe at 1m deep. Figure 5.1(b) represents the effects of air/surface temperature change and heat pump operation over the period on the shallower depths of Profile 6, while Figure 5.1(c) displays the effects of just the GSHP's operation by presenting the temperature difference between Profile 1 and Profile 6 which is 1.85 °C at the collector depth.

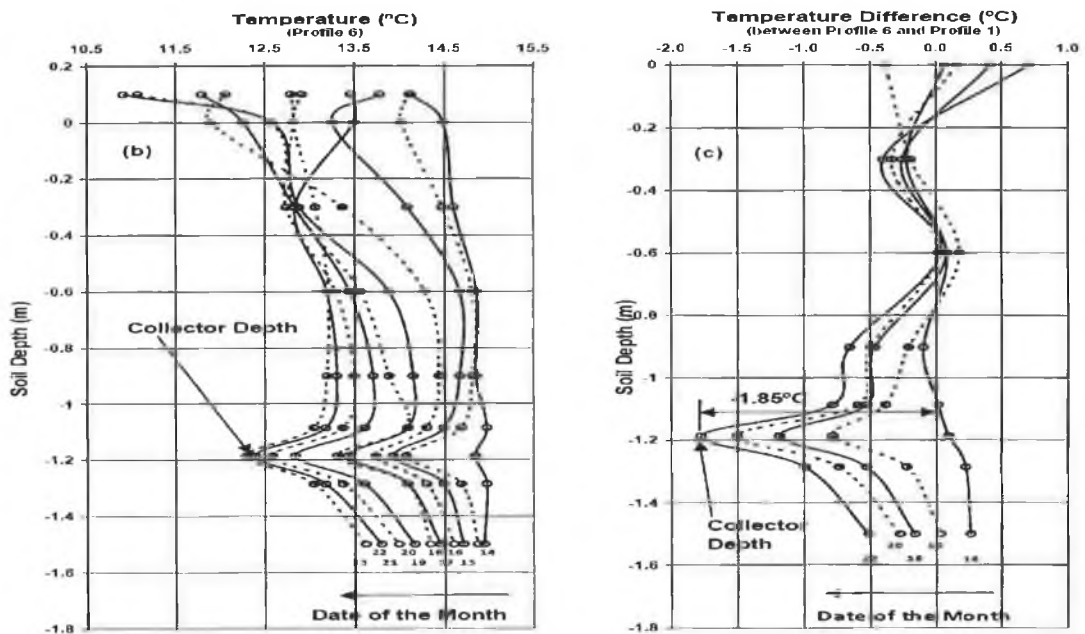


Figure 5.1(b) Series of soil temperature measurements in the GSHP's ground collector area taken at 24-hr intervals at midday each day in Profile 6 over the period October 14th to 23rd, 2007 including air temperature above the surface, (c) series of soil temperature differences between inside and outside the collector region (Profile 6 and Profile 1) taken at 48-hr intervals at midday, every second day over the period October 14th to 23rd 2007, [Source: Greene et al., (2008b)].

Figure 5.1(d) presents the measured performance data of the solar thermal collector on the 06/06/2009. The graph displays the output temperature of the two solar thermal collectors in degrees Celsius and as the solar radiation increases and peaks at approximately 12:00hrs in the afternoon, the solar collector output temperature does not peak until approximately 17:00hrs in the evening.

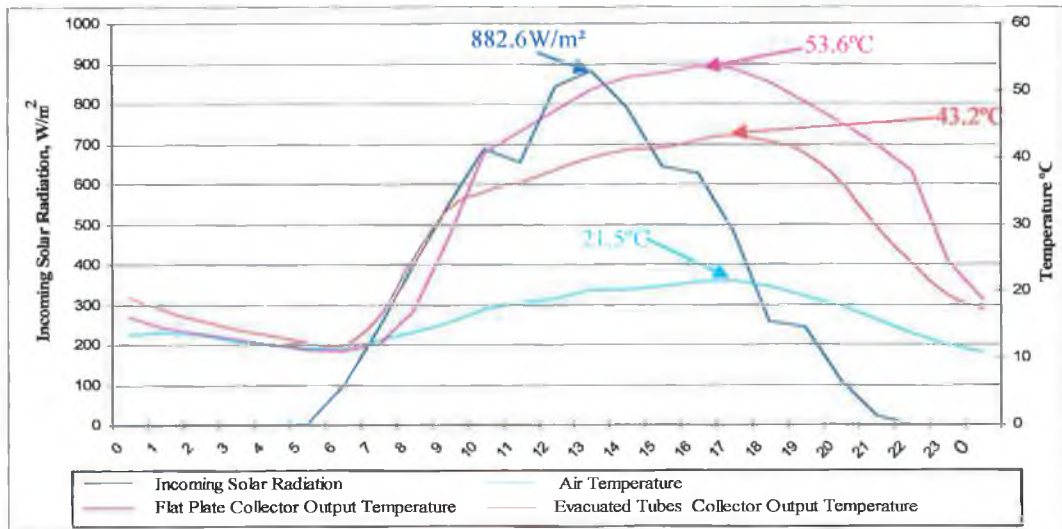


Figure 5.1(d) Performance output temperature for a full day from solar evacuated tube and flat plate collector on the 06/06/2009 with the air temperature and incoming solar radiation.

5.3 Sustainable Energy Online Learning Environment (SEOLE)

The database generated by the DAQ system is not only of significant importance to CiSET researcher's but is also being integrated into the web-based learning environment to support promotion and increased awareness of SET's within the community, educational and commercial sectors. This data provides a greater insight into the workings of the sustainable systems but it is difficult for a non-specialist individual to easily analyse or understand the data in its raw state. The demand for this information and data was one of the driving forces behind the Sustainable Energy Online Learning Environment (SEOLE).

This web-based learning environment provides interested parties with general information about sustainable energy systems and also detailed performance data on the working systems. The site is designed and characterised on best practices and the recommendations laid out in Chapter 2. The site provides the community and the commercial sector with a consistent 5-step learning process to each system which is complemented and embellished by live data from the SET's. SEOLE also provides the educational sector access to live data from fully operational sustainable energy systems. This approach is based on earlier online environments by Building Dashboard USA, DECK Monitoring USA, Fatspaniel USA, Greentouchscreen USA, Hutzet *et al.*, (2006) USA, Iowa Energy Centre USA, Oberlin College USA, Queens University Canada, Remote Accessible Energy Laboratory (RAEL) USA and Research Institute for Sustainable Energy (RISE) Australia. While SEOLE offers the potential to reach the diverse audiences, there is clearly many years of development work required to establish a comprehensive interface for all four target audiences (Community, Education, Research and Industry).

5.3.1 SEOLE Questionnaire

The questionnaire presented in Appendix C was designed so that systematic feedback could be obtained from the different groups or target audiences about SEOLE. In order to gain much needed feedback the questionnaire consisted of 6 questions that could be in the main answered by rating different aspects of the learning environment from excellent to poor. This allowed respondents to provide useful feedback quickly. Two closing questions were reserved for open ended answers for improvements or further comments. The following 6 aspects of the website were queried;

- Overall Impression: General information/awareness, benefit for teaching.
- Content: Is there sufficient information on each page?
- Web Site Design/Layout: Were the pages easy to read/use?

- Web Site Design/Layout: Does the Site Design/Layout facilitate learning?
- Website navigation: Was it easy to get to the information you were interested in?
- System Schematics: Are the system schematics easy to understand/follow?
- Suggestions for improvement of the website.
- Other comments.

5.3.2 SEOLE Questionnaire Feedback

The questionnaire was completed and returned by the following 2 groups:

- (i) 3rd year students from the Bachelor of Engineering in Mechanical Engineering (19 respondents).
- (ii) 4th year students from the Bachelor of Engineering in Mechanical Engineering (12 respondents).

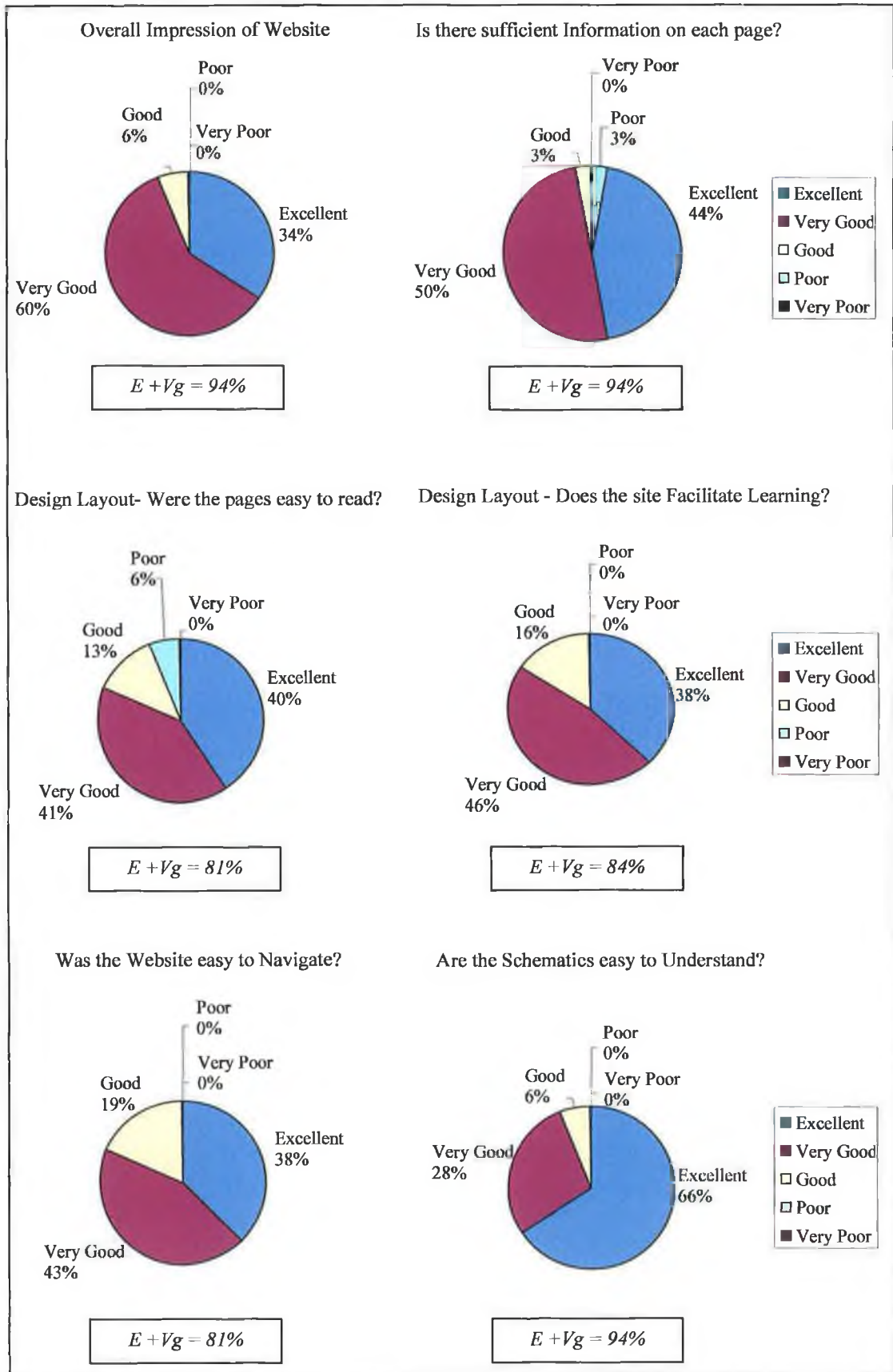
The current version of SEOLE was introduced to 3rd and 4th year students from the Bachelor of Engineering in Mechanical Engineering in GMIT and their comments and ideas were tabulated in Table 5.1.

The average of the percentages who responded either 'excellent' or 'very good' to all 6 questions in Table 5.1 can be found by;

$$94\% + 94\% + 81\% + 84\% + 81\% + 94\% / 6 = \underline{\underline{88\%}}$$

While only 27 students responded, the feedback from GMIT's undergraduate students was very positive, with 88% rating the site as very good or excellent. The system schematics were very well received with 66% of the respondents rating it as excellent which was in agreement with recommendations from the literature in Chapter 2. This provided evidence to strongly recommend the development of flash supported system schematics in the future.

Table 5.1 Feedback obtained from the SEOLE questionnaire



Other positive comments highlighted the website was easy to navigate, content easy to understand and that 84% of correspondents ranked the site as 'very good' when supporting learning. Some of the improvements comments by the respondents are as follows;

- Pop-ups could be bigger.
- Offer a detailed description of each technology.
- Ability to compare historical data from different weeks.
- Direct comparison of systems in historical graph.
- Comparison of "green company" performance data against GMIT data.
- Ability to download historical data.
- Display current weather conditions on home page.
- More general information about renewable energies.

Further comments and suggested improvements made by the students about the SEOLE are presented in Appendix C.

5.4 Summary

The DAQ facility is setup to monitor the performance of different sustainable energy systems against the local climate and it is unique in the Irish maritime climate. This facility generates highly accurate and reliable data and the value of this data is demonstrated through a host of research papers, posters and also presented in Figures 5.1(a-d). An online learning environment (SEOLE) has been developed and this environment provides interested parties with general information about sustainable energy systems and also detailed performance data on the working systems. A total of 27 GMIT's students provided feedback on their impression of SEOLE and 88% of the respondents rated the website as excellent or very good.

Chapter 6.0 Conclusions and Recommendations

This Data Acquisition (DAQ) enabled Web-based Learning (WBL) environment has been developed successfully and has combined two interrelated bodies of work; data acquisition and web-based learning.

6.1 Conclusions

The following conclusions were drawn:

DAO System:

- i) A comprehensive DAQ system consisting of 108 sensors was designed, installed and commissioned to monitor a weather station, 2 solar thermal collectors, 2 ground source heat pumps and a commercial building in the Irish Maritime climate.
- ii) The sensors were scanned every 5 minutes since April 2007 generating a database of over 25
- iii) million data points without interruption, which highlights the reliability of the system.
- iv) The data has also generated experimental results which formed the basis of 4 technical papers, 4 posters and 3 PhD's to date.

Web-based learning Environment:

- i) A Sustainable Energy Online Learning Environment (SEOLE) has been created to increase awareness of sustainable energy technologies in line with government policy [<http://www.kdp1.aquaculture.ie/index.aspx>].
- ii) This environment targets a wide spectrum of users from the community, educational sector, industry and researchers.
- iii) A novel and innovative 5-step learning methodology has been incorporated into SEOLE and two case studies have been developed for the weather station and solar thermal collector.
- iv) Live system performance data has been displayed through SEOLE, demonstrating that data can be successfully acquired and logged from the sensors, stored by the data server and queried by the web-based learning environment. Now that the technology has been proven and software code established, this model can be extended to other technologies in the near future.

- v) Other projects are currently contributing and extending SEOLE including the Energy laboratory (in GMIT) and the EI capital grants scheme which includes a range of performance data from SET's.

6.2 Recommendations

The following recommendations were made:

DAQ System:

- i) Upgrade the control box in the plant room.
- ii) Place a fibre optic cable from DAQ ethernet port back to GMIT network to prevent damage from electrical storms.
- iii) Extend DAQ to include the 6 solar thermal collectors and 2 solar PV arrays during summer 2009 that were funded in 2008.

Web-based learning Environment:

- i) Place web server inside GMIT's Demilitarised Zone (DMZ) for security.
- ii) Continue to enhance graphics describing system operation.
- iii) Further develop the data analysis functionality and data download capacity
- iv) Build-up specific on-line laboratory assessments/tutorials for 3rd level students.
- v) Design specific learning modules for primary and secondary schools.
- vi) Built-in a dedicated interface to support specific industries; sustainable energy industry, construction industry, hotel industry and aquaculture industry.

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Appendix A

Data Acquisition System

- A.1 Signal Conditioning.**
- A.2 Data Acquisition System.**
- A.3 Setup of Labview Software Interface.**
- A.4 Setup and Calibration results for the Moisture Sensors.**
- A.5 Equations for the Calculation of Weather Variables in Labview.**
- A.6 Photographs of the DAQ Facility at GMIT.**

Appendix A Data Acquisition System

This appendix provides supporting information on many aspects of the DAQ system. This includes signal conditioning and DAQ cards/hardware and also a full list of sensors and the calibration details are in this section. Also included are photographs of the DAQ facility.

A.1 Signal Conditioning

As indicated in Section 2.2.2, signal conditioning takes place between the sensors and the DAQ hardware. Hence most signals require some conditioning in order to remove unwanted noise or interference from the measured signal which may involve one or more of the following operations: Filtering, amplification, isolation, excitation and multiplexing. These are defined as follows;

Filtering: employs a low pass filter that blocks the frequencies above and/or below a specific frequency range in order to get a cleaner signal. It is common for AC (Alternating Current) electrical signals (50Hz) or their harmonics (multiples of 50 Hz) to be removed by filters.

Amplification: is an electronic device or devices that boost the value of a voltage or current signal without altering the signal's basic characteristics (Elgar, 1998).

Isolation: involves isolating the measured signal from the PC/Device where there is a risk to either the equipment or the operator from high voltage transducer signals.

Excitation: involves the provision of an external voltage or current signal such as Resistive Temperature Detectors (RTD's), fluid flow meter or a strain gauge to enable the sensor to operate and hence generate an output that is proportional to the measured parameter.

Multiplexing: is a number of switching elements that route many input signals to one common output. Multiplexing is simply an electronic switching device/mechanism that allows the output from each sensor to be channelled through a single input channel to the DAQ system. This enables a DAQ system to increase the number of sensors it can monitor at any one time.

A.2 Data Acquisition System

This section outlines details of DAQ hardware and some of the factors affecting the accuracy and calibration of DAQ system.

A.2.1 Data Acquisition Cards/Hardware

DAQ hardware devices are broken down into many sub-systems with some devices providing most or all of the following features. These are known as multi-function boards and they provide the following functionality;

- a) Analog Input
- b) Analog Output
- c) Digital Input/Output
- d) Counter/Timer

a) Analog Input Hardware: Analog Input (AI) hardware converts an analog signal from a sensor into digital data as represented in Figure A.1 for processing by the PC. These are often referred to as analog input A/D (Analog-to-Digital) converters or ADC's. The important aspects when selecting AI hardware are the number of input channels, range of sampling rates and noise rejection capabilities. The accuracy of the hardware is also affected by the resolution of the ADC. The resolution is the range of digital values, expressed in bits, which the ADC can convert the analogue signal into. As the resolution of the ADC increases, the more accurate the signal becomes. An ADC with an 8-bit resolution can only scale the values between 0-255 (2^8) where as a 12 bit (2^{12}) ADC increases the resolution to 0-4095 and likewise a 16 bit to 0-65535 (2^{16}). The DAQ hardware installed in this project were 12 bit and 16 bit resolution.

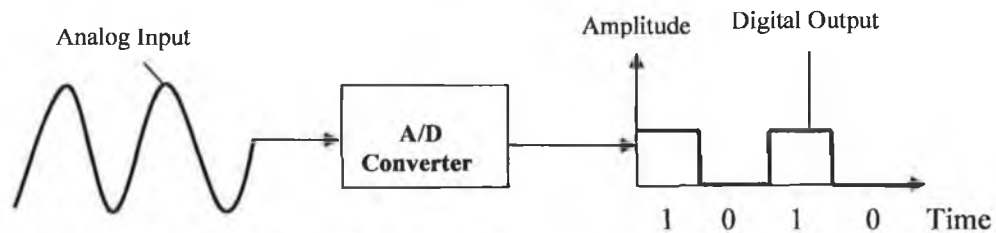


Figure A.1 Functionality of an Analog-Digital (A/D) Converter.

b) Analog Output Hardware: As represented in Figure A.2 analog output hardware converts a digital output signal from a PC to an analog signal. Smith (1998) stated that the resolution is normally no more than 12 bits with a usual signal generating an amplitude of $\pm 1V$ or $\pm 10V$. These are often known as AO (Analog Output) Devices, D/A (Digital to Analog) converters, or DAC's.

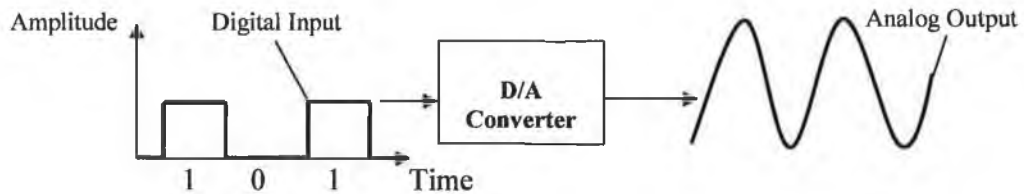


Figure A.2 Functionality of a Digital-Analog (D/A) Converter.

c) Digital Input/Output Hardware: Bishop noted that Digital Input/Output hardware is commonly incorporated into DAQ hardware for sensing contacts, controlling delays and lights and testing digital devices (Bishop, 2006a). Typical digital levels are TTL (Transistor-Transistor Logic) and TTL compatible CMOS (Complimentary Metal-Oxide Semi-Conductors).

d) Counter/Timer Hardware: Counter/timers are used for both frequency and period measurement and also for counting events. These devices are also used to measure and produce very time-critical digital pulses (Bishop, 2006a). Bishop also states that these pulses are generally TTL or TTL compatible CMOS. A fluid flow or electric power meter are examples of typical sensors that generate pulses and require a counter/timer device to record their output, and this aspect is employed in this DAQ-WBL project. A typical digital pulsed signal is illustrated in Figure A.3.

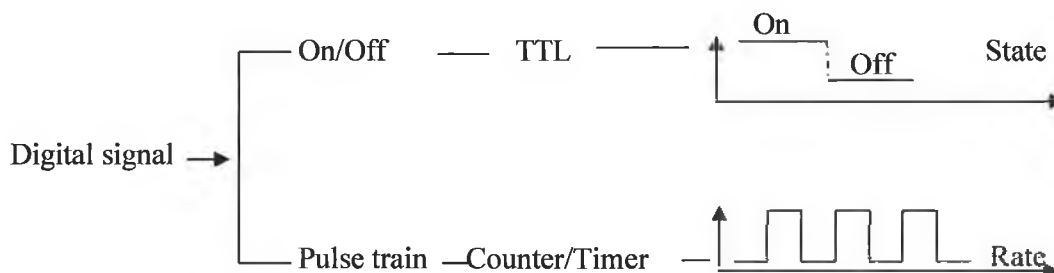


Figure A.3 Processing details of a Digital pulsed signal [Source: National Instruments (2008)].

A.2.2 Eliminating Noise

Noise can hide or swamp the true signal or often generate a false signal where the experimental data being analysed is distorted. Noise is defined as the presence of unwanted electrical signals in a circuit as a result of mains frequency, adjacent electrical components such as transmitters or transformers. It is very difficult to totally eliminate noise from a signal but measures can be taken to minimise its effect.

According to Park (2003) the main sources of electrical noise is internal noise, thermal noise, external noise, electrostatic interference, electromagnetic interference, radio frequency interference and crosstalk from other cables in close proximity. Some of the

main types of noise are thermal noise, shot noise, equipment noise and natural noise. Thermal and shot noise is classified as internal noise which is generated within the system. Shot noise (also known as schottky noise) is a current noise, due to spurts in the current through transistor junctions. Equipment and natural noise are generated from external sources outside the system. Natural noise is interference from lighting, cosmic radiation and magnetic fields, both natural and man-made.

There are numerous ways in which noise can be minimised with the first of being cable shielding. Shielding provides another path for induced noise currents to flow, so that they are not carried in the signal circuits (Park *et al.*, 2003). A shielded cable is generally a number of insulated cables surrounded by a conductive material, such as copper. It is recommended to always use shielded cable when working with a low voltage signal and an example of such a cable is presented in Figure A.4.



Figure A.4 Image of a DAQ cable which highlights the presence of Shielding [Source: www.ni.com, 2008].

The grounding of the shielded cable is also important. Park *et al.*, (2003) recommends that only one end of the shield should be grounded as grounding or earthing both ends can cause ground loops to be created as shown in Figures 2.7(a) and (b).

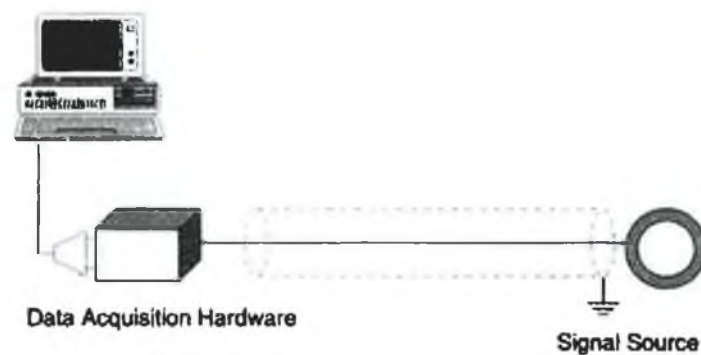


Figure A.5(a) Schematic shows the correct connecting of the grounding of the shielded cable [Source Ozkul *et al.*, 1996].

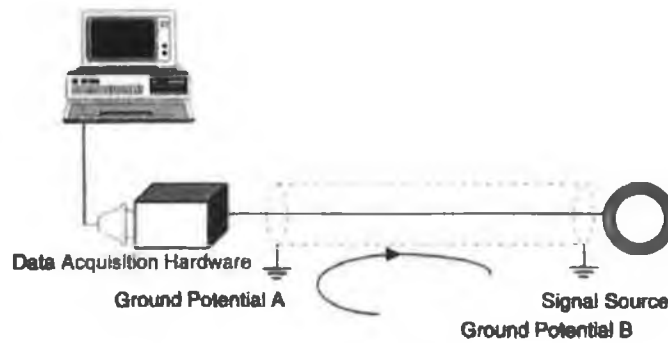


Figure A.5(b) Schematic shows the incorrect connecting of the grounding of the shielded cable. [Source Ozkul et al., 1996].

A.2.3 System and Environmental Effects

Another factor that reduces measurement accuracy is disturbance of the system behaviour due to the introduction of sensors. This is more apparent for sensors such as flow meters or internal temperature sensors. Methods of minimising the disruption to the process being monitored should be adhered to during the design and application of the fluid flow circuit. The DAQ environment should also be taken into consideration when designing the system to be monitored. Environmental variables such as temperature, water and moisture will affect the accuracy and performance of the DAQ system. Morris recognised that the “system designers are charged with the task of either reading the susceptibility of measuring instruments to environment inputs or alternatively quantifying the effect of the environment inputs and correcting them in the instrument output reading” (Morris, 2001).

A.2.4 System Wiring

Another important factor to consider during the creation of an accurate DAQ system, and one relevant to this DAQ-WBL project, is the wiring of the system. When wiring sensors it is important not to extend the sensor cabling beyond the recommended manufacturer’s lengths, as this will affect the signal accuracy. Also, when wiring sensors it is important where possible to avoid noise or environmentally unstable situations. If these situations are unavoidable, then the correct measures should be taken to prevent signal interference. Other wiring factors that need to be considered are the actual wires selected and the connectivity of the wires. Wires or cables that are poorly connected are often a source of faulty or intermittent signals, which will affect the signal consistency. The accuracy of the DAQ hardware and wiring integrity should also be taken into consideration as stated by Stum (2006).

A.2.5 Labelling

The labelling of all cable wires is another important factor that is often over looked and is very important part of the overall system, especially for troubleshooting and maintenance.

A.3 Setup of Labview Software Interface

The various steps involved in developing the Labview software control interface for this DAQ-WBL project are briefly described using the following 4 steps;

- *Step 1:* In setting up Labview to monitor and log data one must first select a FieldPoint icon from the Functions/Express/Output/ menu highlighted in Figure A.6(a) and start to configure this icon. A configuration screen shown in Figure A.6(b) will automatically appear to enable the user to select and configure the appropriate FieldPoint module.

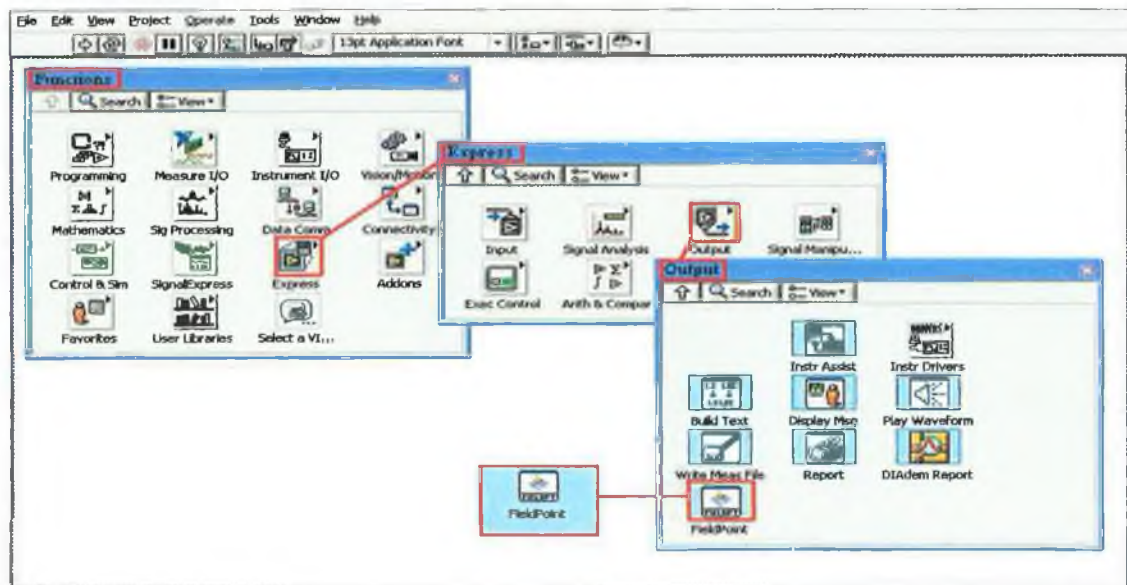


Figure A.6(a) Step 1: FieldPoint icon selected form functions menu in Labview.

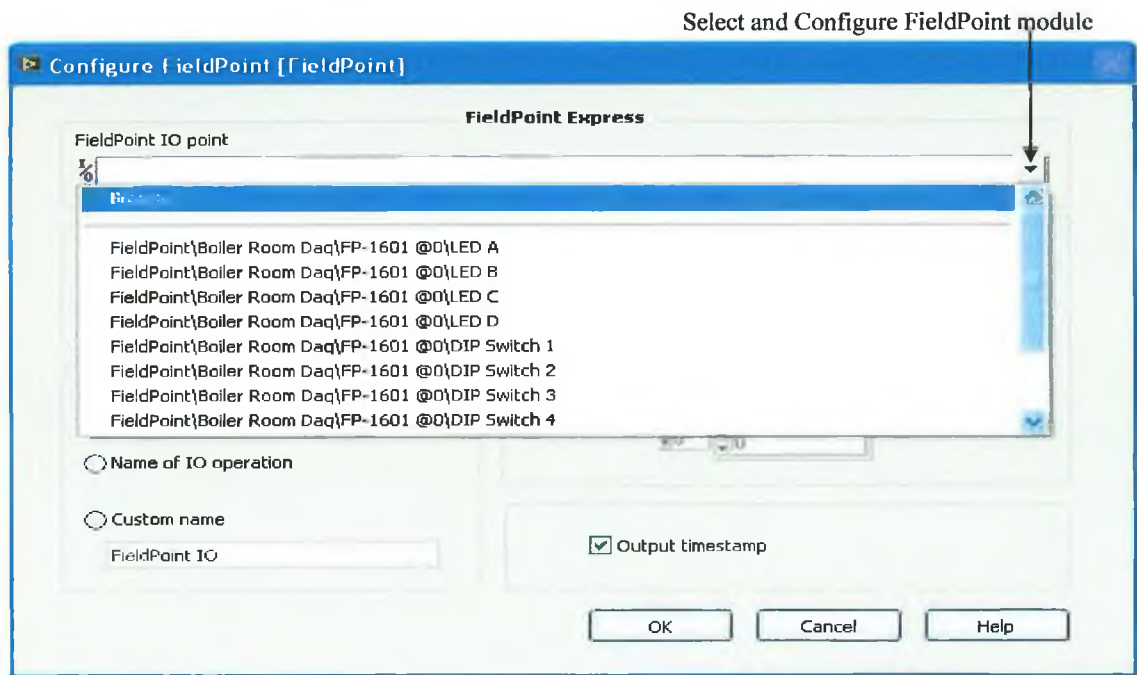


Figure A.6(b) Step 1: FieldPoint configuration menu screen.

- **Step 2:** The next step is to select the 'browse to file' shortcut within the FieldPoint I/O menu (Figure A.6(c)). Once in this screen, the .iak file must be 'browsed to' in the 'View Configurations' tab and then assign a name or 'device' to this file path such as wind vane for later reference.

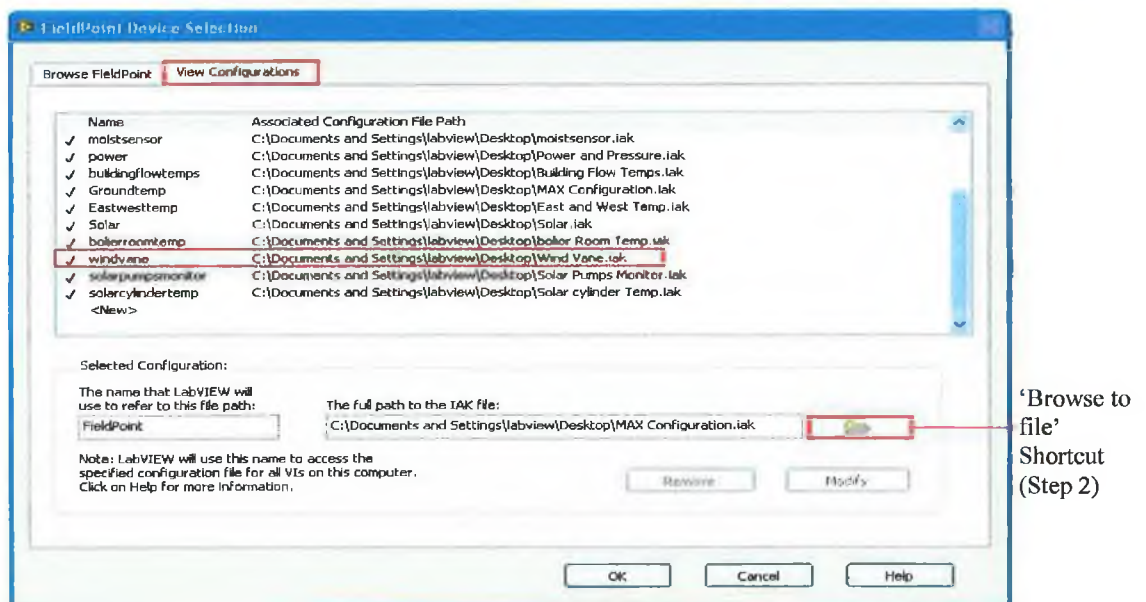


Figure A.6(c) Step 2: FieldPoint device configuration menu screen.

- **Step 3:** Now in the 'Browse FieldPoint' screen the 'wind vane' device will appear and the attached modules will appear in a sub menu. All of the labelled channels from 0-7 will also appear in the screen (Figure A.6(d)).
- **Step 4:** Selecting the channel/sensor required and exiting the screen, will establish the communication link between Labview and FieldPoint modules/sensors.

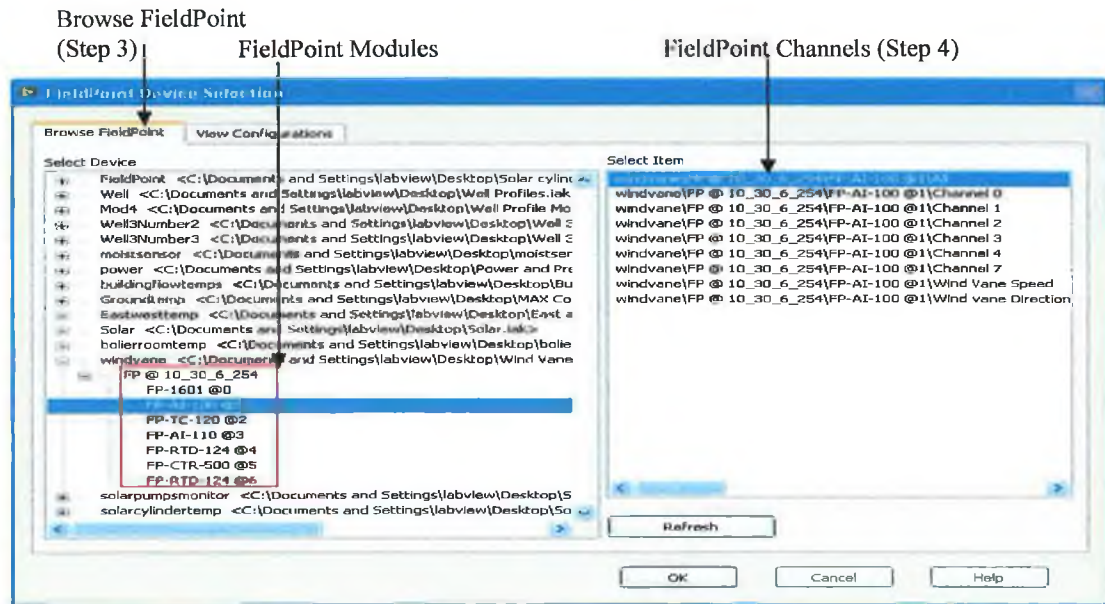


Figure A.6(d) Steps 3 and 4: FieldPoint configuration screen with in Labview.

A.4 Setup and Calibration Results for the Moisture Sensors

There were four control settings that required configuration on each VI and a screenshot of the moisture sensor VI is presented in Figure 3.17;

a) Setup of Moisture Sensors in MAX: To measure frequency with a FP-CTR-502, four channels is requires; two counter channels, one output channel and one gate input channel. *Count Input 0* generates a fixed-width positive gating pulse on *Output 0*. This gating pulse is the input for Gate 0. Count Input 1 counts the pulses of the source signal been measured, and this VI calculates the frequency of the source signal. A 10-30 VDC power supply must be connected to the V and C terminals to power the output channel.

Step 1: Setting Up the FP-CTR-502 in MAX

1. Connect the FP-CTR-502 to the system and launch MAX.
2. Find the FieldPoint bank with the FP-CTR-502 under 'Devices and Interfaces' or 'Remote Systems'.
3. Right-click the bank and select 'Find Devices'.
4. Select the FP-CTR-502, then click the 'Channel Configuration tab'.

Step 2: Setting Up Count Input 0 in MAX

1. Check the box for *Count Input 0* if it is not already checked.
2. In the 'Channel Attributes' area, select *Terminal Count* from the Attribute pull-down menu and click Create Item. This creates a data item called *Terminal Count @Count Input 0* under the FP-CTR-502 in Data Neighbourhood.
3. In the 'Channel Attributes' area, select the following attributes and values for *Count Input 0*:
Count Source = 1 kHz Reference
Gate Source = Always Enabled
Read Reset Mode = Don't Reset on Read

Step 3: Setting up Count Input 1 in MAX

1. Check the box for *Count Input 1* on the 'Channel Configuration tab'.
2. In the Channel Commands area, click 'Create Item'. This creates a data item called '*Control @Count Input 1*' under the FP-CTR-502 in Data Neighbourhood.
3. In the Channel Attributes area, select the following attributes and values for *Count Input 1*:
Terminal Count = 65535
Count Source = External Count Input
Gate Source = Gate Input 0
Read Reset Mode = Don't Reset on Read

Step 4: Setting up the Output Pin

1. On the 'Channel Configuration' tab, select Type 3: *Discrete Output* from the 'Channel Type' pull-down menu. If *Output 0* is not selected, select it now.
3. In the 'Channel Attributes' area, select the following attributes and values for *Output 0*:
Output Source = Counter Channel 0
Output Mode = Toggle, Reset On.

Step 5: Completing the Configuration

1. Close MAX.
2. When prompted to save, click 'Yes'.
3. In this VI, make sure the inputs match the location of the FP-CTR-502 in the system. The default location is position 1. If the counter module is in a different place in the bank or the *.iak* file has a different name, use the I/O controls to browse to the locations of the items created.

4. Click the 'Control tab' to control the FP-CTR-502.
5. Wire Output 0 (pin 13) to Gate 0 (pin 9) to complete the gate control.
6. Wire the signal to measure to *Count Input 1* (pin 2) to complete the external wiring.
7. Run the VI. Every time the 'new reading' Boolean flashes, a new frequency reading is displayed.

b) Setup of Moisture Sensors in Labview:

- Step 1: The first step was to browse to the '*terminal count tag*' at input 0 in the FieldPoint device selection directory on the VI's front panel as shown in Figure 3.17. This was used as a reference frequency for the input channel. Then the '*control*' input channel that corresponds with the appropriate input channel must be selected, for example *control input@input 1*.
- Step 2: The next setting was to select the input channel or '*channel count tag*' on the FieldPoint module that the sensor circuit was connected to, for example, *count input 1*.
- Step 3: Finally, the '*gating input*' must be selected. This was set to 2Hz (500ms) which doubled the frequency reading coming out of the counter FieldPoint module and returned the signal back to its original reading of between 32,258kHz and 68,027kHz (in water and air).
- Step 4: The VI could only be setup to read and log the data every second as the VI had a pulsing frequency of every second. Because of this a second VI was created to read the above logged file every five minutes, average it and then log the percentage moisture content with a time and date stamp. The frequency value was converted to a percentage using Equation 3.1.

c) Calibration results for the Moisture Sensors: Tables A.1 (a) and (b) show the results from the calibration tests carried out on the moisture sensors. The moisture sensor was connected to the FieldPoint module (FP-CTR-502) and using Labview the frequency readings were recorded. The sensors were inserted into two different samples of soil and sand and then soil only from the ground collector area. The sample was untouched until fully saturated when the frequency reading levelled out (34910kHz - soil and sand, 32396kHz - soil only). The sample was then untouched for a period of time (approximately 3 weeks) so that that the moisture could evaporate. When the moisture sensor was sending out a repetitive consistent signal (58374kHz - soil and sand, 57786kHz - soil only) the

sensor was then removed and the moisture content was measured in the soil using a soil content analysis machine.

Table A.1 (a) Moisture readings used in Equation A.2 from calibration tests.

| Soil and Sand Mix | | |
|-------------------------|-----------------------------|--|
| Frequency Reading (kHz) | Measured Moisture Content % | Moisture Sensor Number |
| 34910 | 100 | MS03-P5@0.6m MS04-P1@0.3m MS05-P1@0.9m |
| 58374 | 0.5 | MS06-P1@1.8m MS07-P7@0.3m |

Table A.1 (b) Moisture readings used in Equation A.1 from calibration test.

| Soil Only | | |
|-------------------------|-----------------------------|--|
| Frequency Reading (kHz) | Measured Moisture Content % | Moisture Sensor Number |
| 32396 | 100 | MS01-P4@1.045m MS02-P5@1.015m MS08-P7@0.3m |
| 57786 | 1.5 | MS09-P3@0.3m MS10-P3@1.15m |

This resulted in two different Equations for the calculation of the moisture content in Labview;

Equation for soil sample only;

Where; X1, Y1 = 32396 kHz (frequency output from sensor), 100% (percentage of moisture content)

X2, Y2 = 57786 kHz, (frequency output from sensor) 1.5% (percentage of moisture content)

Therefore; $m = 0.0038795 \text{ kHz}/\%$

Then; $Y2 = (X2 - 32396) * 0.0038795 + 1.5 (\%)$ (Equation A.1)

Where; Y2 = the unknown moisture content value (%)

X2 = the frequency output from sensor (kHz)

X1 = 32396 kHz

$m = 0.0038795 \text{ kHz}/\%$ (using equation. 3.1)

Y1 = 1.5%

Equation for soil and sand sample;

Where; X1, Y1 = 34,910 kHz, 100%

X2, Y2 = 58,374 kHz, 0.5%

Therefore; $m = 0.0042405 \text{ kHz}/\%$

Then; $Y2 = (X2 - 34910) * 0.0042405 + 0.5 (\%)$ (Equation A.2)

Where; Y2 = the unknown water content value (in units of Percentage)

X2 = the frequency output from sensor (kHz)

X1 = 34910 kHz

$m = 0.0042405 \text{ kHz}/\%$ (using equation. 3.1)

$$Y1 = 0.5\%$$

The moisture sensor VI front panel configuration is shown in Figure 3.17

Figure A.7 presents a photograph of the moisture sensor placed in a sample of soil only during calibration. The sensor was connected back to the FieldPoint module (FP-CTR-502) and the results were displayed in Labview.



Figure A.7 Photograph of the Moisture sensor immersed in a sample of soil only for calibration.

A.5 Equations for the Calculation of Weather Variables in Labview

Sub VI 1 Air Temperature and Humidity: The air temperature and relative humidity were setup as part of the 'DAQ system' VI. Each of these was setup to read, log and then average the data every five minutes. The sensors were reading the temperature and humidity in voltage so the output required signal conversion in labview to the appropriate output variable ($^{\circ}\text{C}$ - temperature, or % - relative humidity). This was completed using the equation for the slope of the line;

$$m = \frac{Y2 - Y1}{X2 - X1}$$

Therefore:

Air Temperature:

Where $m = 100$ (using equation. 3.1)

Therefore using Equation 3.2

$$Y2 = (X2 - 0) * 100 + (- 40) \quad (^{\circ}\text{C}) \quad \text{(Equation A.3)}$$

Where; $Y2 =$ the unknown air temperature ($^{\circ}\text{C}$)

$X2 =$ the output reading from the sensor (V)

$$X1 = 0\text{V}$$

$$m = 100 \text{ (}^\circ\text{C/V) (using equation 3.1)}$$

$$Y1 = -40 \text{ (}^\circ\text{C)}$$

Relative Humidity:

Where $m = 100$ (using Equation. 3.1)

$$Y2 = (X2 - 0) * 100 + 0 \text{ (%) (Equation A.4)}$$

Where; $Y2 =$ the unknown relative humidity (%)

$X2 =$ the output reading from the sensor (V)

$$X1 = 0\text{V}$$

$$m = 100 \text{ (%/V) (using equation 3.1)}$$

Sub VI 2 – Rainfall Level: The rainfall level sensor operates by sending a pulsed output every time the height of rainwater in the bucket reaches 0.1mm. The VI was established to count each of these pulses and had to be configured to overcome a logging error of the tipping bucket. The sensor would output a signal of 2, 4, 6, 8, 10 and so on, but sometimes the sensor would send out a second false signal such as 2, 4, 6, 9, 11, 13 and disrupt the logged values each time the bucket tipped or the sensor's state changed. The VI was configured to only read the sensor every time its state changed and log this reading in increments of 0.1mm. The rain gauge VI is shown in Figure A.8.

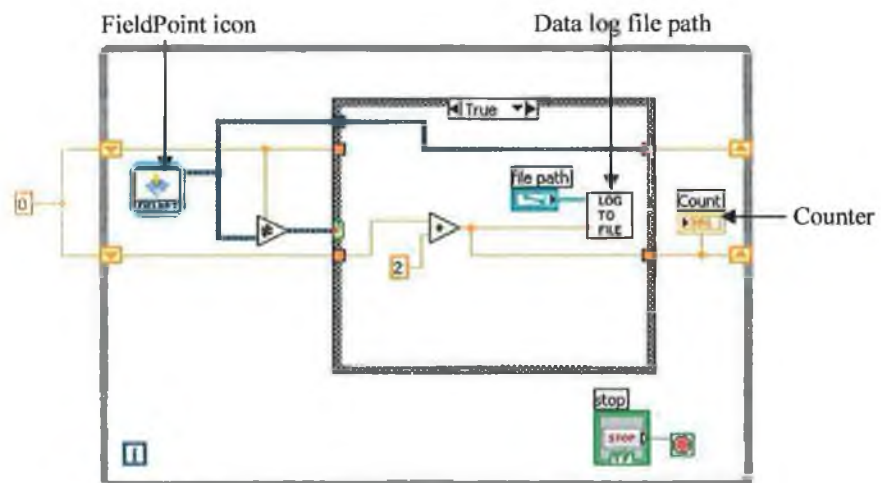


Figure A.8 Block diagram of rainfall level VI.

Sub VI 3 - Rain Temperature: The rain temperature thermocouple generates a value in degrees Celsius, so no signal manipulation was required.

Sub VI 4 - Wind Speed and Direction: The same method used for calculating the air temperature, relative humidity and barometric pressure was applied to the calculation of both the wind speed and direction. The wind speed sensor outputs a signal of between 0 - 2.5V, which is equivalent to 0 - 278.8km/hr. Therefore following the equation for the wind speed is developed;

$$Y2 = (X2 - 0) * 111.12 + 0 \quad (\text{Equation A.5, km/hr})$$

Where; $Y2 =$ the unknown wind speed value (km/hr)

$X2 =$ the output reading from the sensor (V)

$$X1 = 0V$$

$$m = 111.12 \text{ (km/hr/V) (using equation 3.1)}$$

$$Y1 = 277.8 \text{ (km/hr)}$$

A similar calculation for the wind direction was required where the output voltage is 0 – 3.249V which is proportional to 0 - 360°. Then the formula is;

$$Y2 = (X2 - 0) * 110.8 + 0 \quad (\text{Equation A.6, degrees})$$

Where; $Y2 =$ the unknown wind direction value (degrees)

$X2 =$ the output reading from the sensor (V)

$$X1 = 0V$$

$$m = 110.8 \text{ km/hr /V (using equation 3.1)}$$

$$Y1 = 360^\circ$$

Sub VI 5 - Solar Radiation (Incoming): The first calculation for the solar radiation is the incoming solar radiation and it was measured using an upward facing (towards the sky) pyranometer. The sensor outputs a voltage signal of between 0–15mV and using the equation supplied by the pyranometer manufactures, the calculation is;

$$\text{Incoming solar radiation} = \frac{U}{S} \quad (\text{Equation A.7, W/m}^2)$$

Where; $U =$ Output from sensor (mV)

$S = 13.46 \mu\text{V/W/m}^2$ (sensitivity rating of the sensor supplied by the manufacturers calibration certificate, shown in Appendix A)

The reflected solar radiation was also measured with a Pyranometer orientated downwards towards the ground. Using the Equation that the suppliers provided;

$$\text{Reflected solar radiation} = \frac{U}{S} \quad (\text{Equation A.8, W/m}^2)$$

Where; $S = 13.70 \mu\text{V/W/m}^2$ (sensitivity rating of the sensor)

These two Pyranometers, enabled both the albedo radiation (the ratio of reflected, to incoming radiation) and net solar radiation to be measured.

Sub VI 6 - Solar Radiation (Outgoing): Two pyrgeometers were used to measure the far-infrared radiation from the sky (facing upwards) and far-infrared radiation from the ground (facing downwards). The sensor outputs a voltage ranged between –4mV to +4mV and Equation A.9 was used to identify the measured value;

$$\text{Far infrared radiation} = L_{\text{net}} + 5.67 \mu\text{V/W/m}^2 \times 10^{-8} * T^4 \quad (\text{Equation A.9 W/m}^2)$$

Where; $L_{\text{net}} = \frac{U}{S}$

$U =$ Output from sensor (mV)

S = Sensitivity rating of the sensor

10.97 μ V/W/m² (Far infrared from sky)

5.56 μ V/W/m² (Far infrared from ground)

T = Air temperature (K)

A VI was used for each of the above weather sensors to manipulate the data logging so that each value was logged at user defined intervals with a corresponding time and date stamp. Table A.2 presents an example of the outputted data generated by the external air temperature sensor over an one hour timeframe with a sampling interval of 5 minutes. Further examples of the results are presented in Chapter 5.

Table A.2 Example of external air temperature data logged at intervals of every five minutes over 1 hour.

| Date/Time Stamp | Output (°C) |
|---------------------|-------------|
| 01/01/2008 01:41:27 | 10.46 |
| 01/01/2008 01:46:27 | 10.43 |
| 01/01/2008 01:51:27 | 10.40 |
| 01/01/2008 01:56:27 | 10.35 |
| 01/01/2008 02:01:27 | 10.33 |
| 01/01/2008 02:06:27 | 10.31 |
| 01/01/2008 02:11:27 | 10.37 |
| 01/01/2008 02:16:27 | 10.34 |
| 01/01/2008 02:21:27 | 10.31 |
| 01/01/2008 02:26:27 | 10.38 |
| 01/01/2008 02:31:27 | 10.35 |
| 01/01/2008 02:36:27 | 10.29 |
| 01/01/2008 02:41:27 | 10.30 |

Each weather variable was logged to its own data file and measured values can be downloaded or extracted for further analysis.

A.6 Photographs of the DAQ Facility at GMIT

Figures A.9 and A.10 shows an aerial view and a ground view of the IIBC building on which the weather station and solar collectors were installed and within which the DAQ facility was setup.



IIBC

Figure A.9 An aerial photograph of the MIT campus with the IIBC building highlighted [Source: <http://www.bing.com/maps/>, 2008].



Figure A.10 View of IIBC building from the ground (west facing side from

Figure A.11 presents a photograph of the process used to calibrate the rain gauge. A set volume of water was placed in the Pipette above the rain gauge and as the water was released the pulsed output from the rain gauge was displayed in MAX software. The actual results were then compared against the calibrated results.

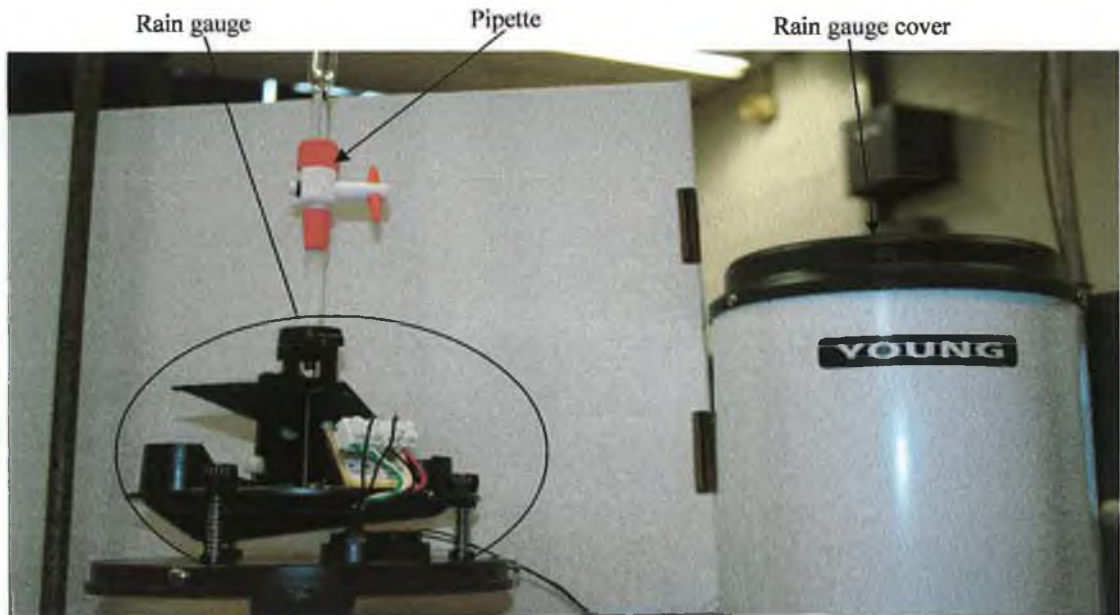


Figure A.11 Photograph of the rain gauge (with cover taken off) and pipette during calibration.

Figures A.12 (a-b) presents two views of the GSHP's collector facility during and after the installation of the collector pipes. The pipes were installed in both inline and slinky pattern.



Figure A.12(a) Photograph of the GSHP's collector pipes during installation.

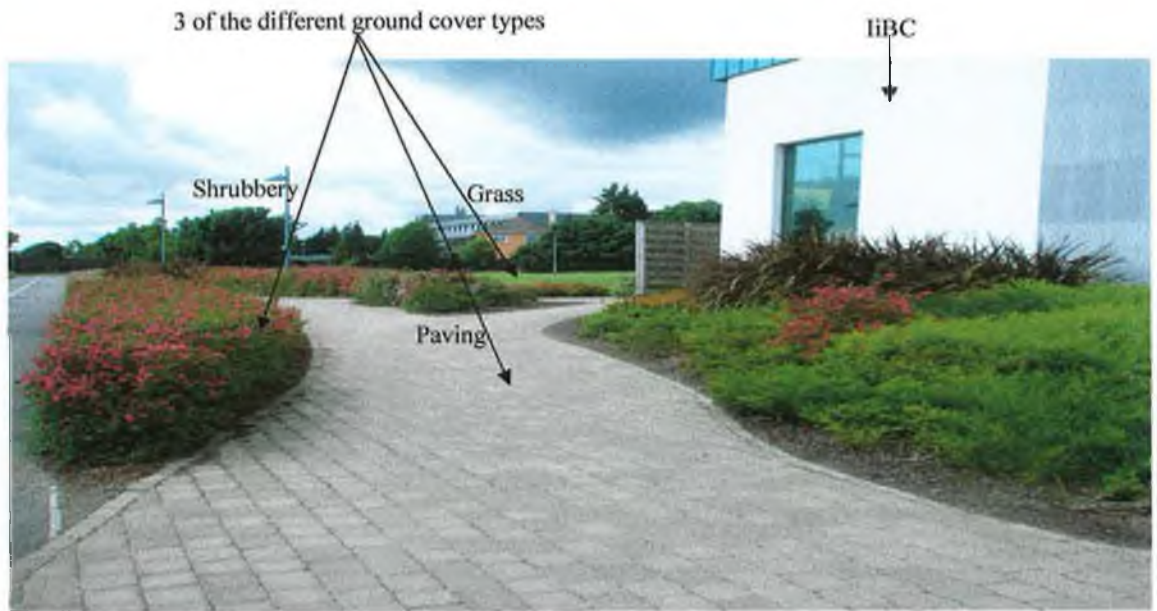


Figure A.12(b) Photograph of the GSHP's collector area after installation.

Appendix B

Sustainable Energy Online Learning Environment

- B.1 SEOLE Website Provisional Homepages**
- B.2 Learning Environments Developed Through Labview**
- B.3 SEOLE's Solar Thermal Collectors System**
- B.4 Learning Environments Similar to SEOLE**

Appendix B Sustainable Energy Online Learning Environment

Appendix B provides details of the other sites and influencing factors that contributed to the development of SEOLE.

B.1 SEOLE Provisional Homepages

As shown in Figures B.1 (a-d), a selection of different home pages and site templates were created before the final template was selected.

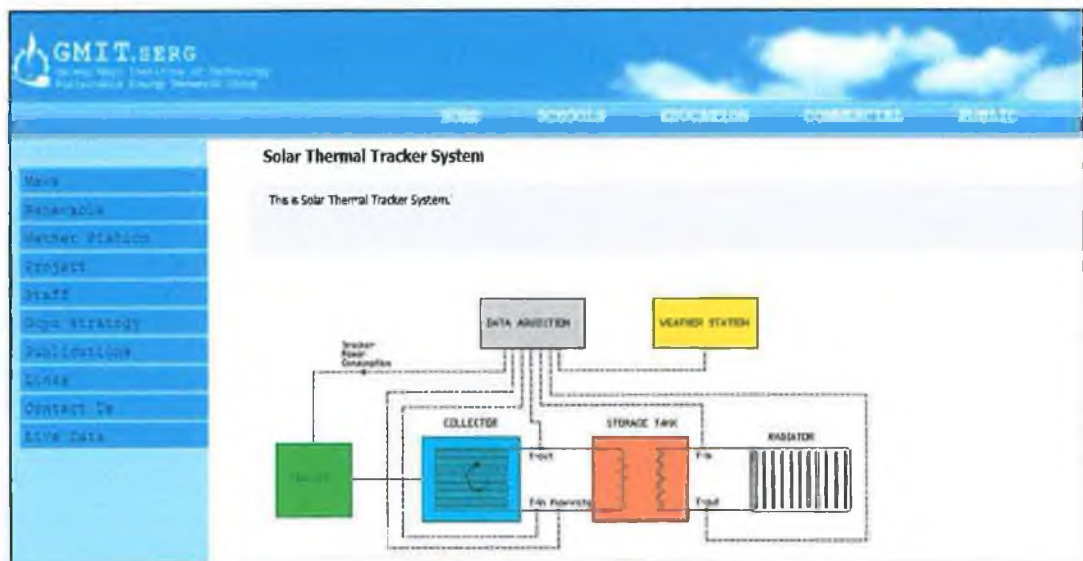


Figure B.1(a) Draft 1; Homepage designed as part of the SEOLE design stage.

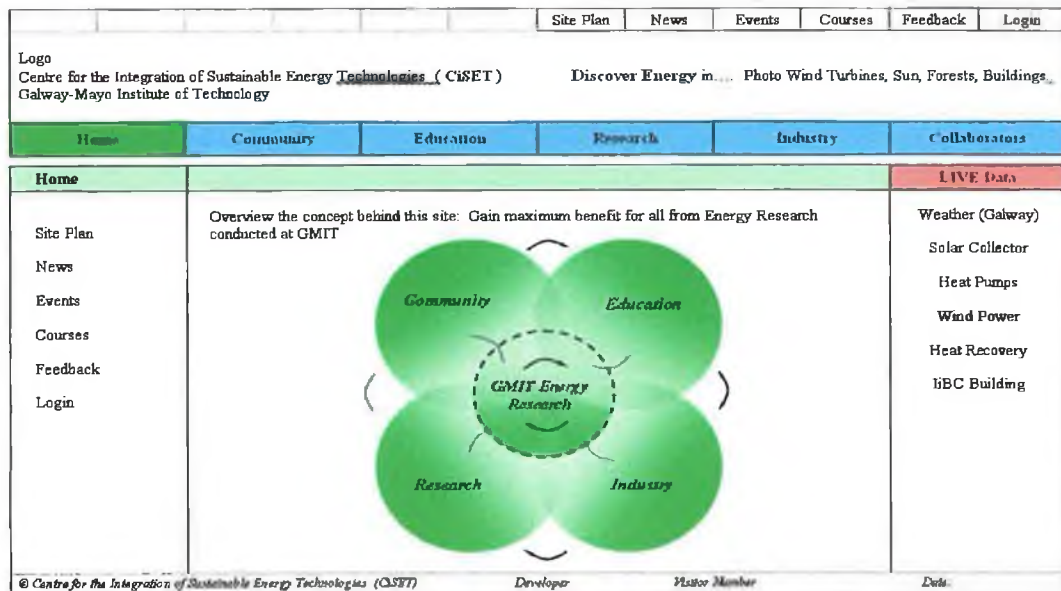


Figure B.1(b) Draft 2; Homepage designed as part of the SEOLE design stage.

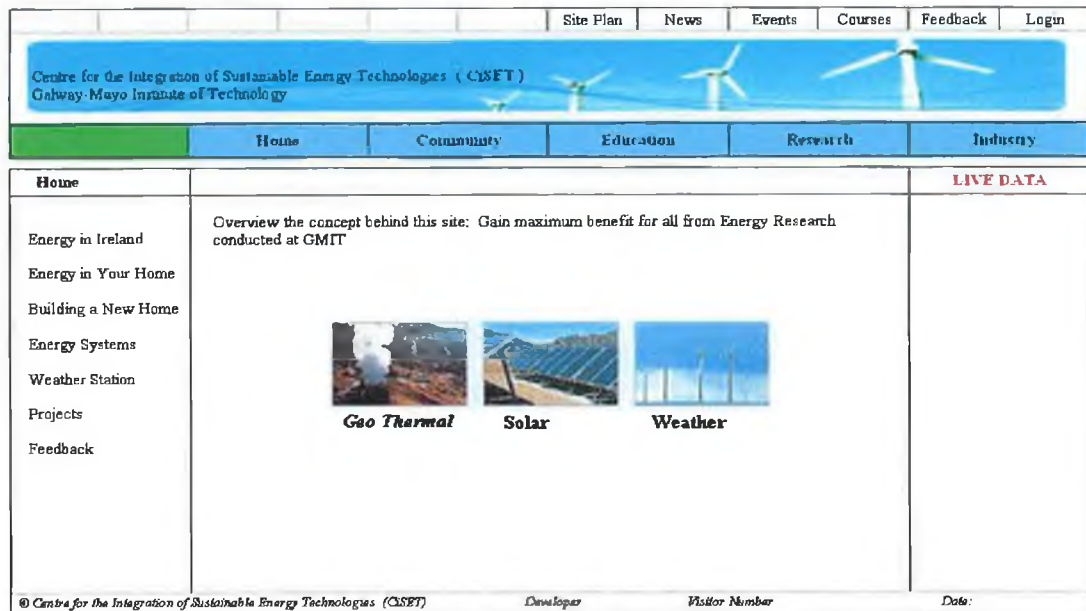


Figure B.1(c) Draft 3; Homepage designed as part of the SEOLE design stage.

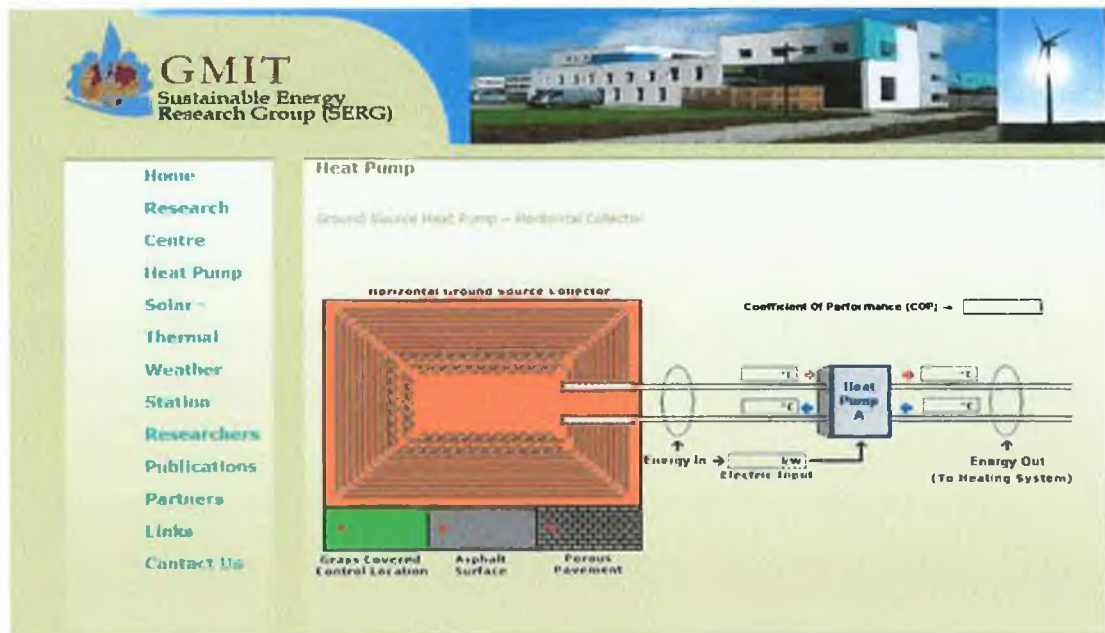


Figure B.1(d) Draft 4; Homepage designed as part of the SEOLE design stage.

B.2 Learning Environments Developed Through Labview

Figures B.2 (a-b) presents earlier versions of the learning environment developed through Labview which is also presented in Figure 3.13 and available to students within the GMT network. Figure B.2(a) presents performance data for both the horizontal and vertical collectors for the GSHP's. Figure B.2(b) live solar energy performance data from

the solar flat panel and evacuated tubes collector for the Laboratory experiments. The students used these sites to carry out experiments as part of the laboratory work.

| | | | | | | | |
|------------------------|--------------------------|------------------------|--------------------------|--------------------|----------------------|---------|---------|
| T008_P1 | T009_P1 | T010_P1 | T011_P1 | T012_P1 | T013_P1 | T014_P1 | T040_P1 |
| 16.0723 | 15.7038 | 15.3353 | 15.2392 | 14.7585 | 14.0856 | 13.5869 | 13.4287 |
| T021_P2 | T022_P2 | T023_P2 | T024_P2 | | | | |
| 16.3127 | 16.3207 | 16.2486 | 15.4955 | | | | |
| T015_P3 | T016_P3 | T017_P3 | T018_P3 | T019_P3 | | | |
| 21.696 | 19.8695 | 18.7961 | 17.7066 | 16.6972 | | | |
| T043_P4 | T044_P4 | T045_P4 | T046_P4 | | | | |
| 15.9281 | 15.7198 | 15.2712 | 15.1591 | | | | |
| T026_P5 | T027_P5 | T028_P5 | T029_P5 | T030_P5 | T031_P5 | T032_P5 | T033_P5 |
| 16.4088 | 15.3033 | 15.4475 | 15.2232 | 15.4635 | 15.1911 | 15.3994 | 15.3193 |
| T001_P6 | T002_P6 | T003_P6 | T004_P6 | T005_P6 | T006_P6 | T007_P6 | |
| 13.9414 | 13.637 | 14.1176 | 14.1337 | 14.2458 | 14.0856 | 14.0055 | |
| T034_P7 | T035_P7 | T036_P7 | T037_P7 | T038_P7 | T039_P7 | T041_P7 | T042_P7 |
| 16.0563 | 15.7359 | 15.2712 | 15.0149 | 15.3193 | 15.4314 | 15.4635 | 15.4955 |
| T101_12m (Well 1 Flow) | T102_12m (Well 1 Return) | T103_30m (Well 3 Flow) | T104_30m (Well 3 Return) | T105_22m (HC Flow) | T106_22m (HC Return) | | |
| 13.7171 | 13.8453 | 14.2618 | 14.2779 | 14.7745 | 14.7585 | | |
| Well 1 No 1 | Well 1 No 2 | Well 1 No 3 | Well 3 No 2 | Well 3 No 3 | | | |
| 11.2978 | 10.8171 | 10.9133 | 10.705 | 11.7304 | | | |

Figure B.2(a) Collector profiles performance data for both GSHP's for the Laboratory experiments.

| | | | | | |
|--|--|-------------------------------|--------------------------------|--|--|
| Stationery Tank Lower | Tracking Tank Upper | Stationery Tank Upper | | | |
| 27.5634 | 20.9949 | 23.8866 | | | |
| Stationery Collector Output Temp | Stationery Collector Input Temp | Tracking Collector Input Temp | Tracking Collector Output Temp | | |
| 20.3021 | 20.7668 | 15.127 | 26.775 | | |
| Total Radiation W/m2 | | | | | |
| -333.231 | | | | | |
| Net Solar Radiation W/m2 | | | | | |
| -15.4114 | | | | | |
| Pyranometer Shortwave Incoming (W/m2) | Pyranometer Shortwave Outgoing (W/m2) | | | | |
| 837.195 | 59.0758 | | | | |
| Net Far Infrared Radiation W/m2 | | | | | |
| 0 | | | | | |
| Pyrgometer Longwave Incoming CGR3 (W/m2) | Pyrgometer Longwave Outgoing CGR3 (W/m2) | | | | |
| 317.834 | 317.834 | | | | |
| Irradiance Incoming W/m2 | Irradiance Outgoing W/m2 | | | | |
| 0 | 0 | | | | |

Figure B.2(b) Solar energy performance data from the solar flat panel and evacuated tubes collector for the Laboratory experiments.

B.3 SEOLE's Solar Thermal Collectors System

Figures B.3 (a-c) presents screen shots for the 3rd generation solar thermal collector currently been presented as part of the learning environment process in SEOLE. Figure

B.3(a) presents the “Home Page” for the solar thermal collector system on which the viewer is shown a schematic of the solar system and the 5 step learning process. Figure B.3(b) shows “System Overview” which is step 1 of the 5 step learning process. The learner can ‘mouse’ over each of the sensor labels and the description text boxes will drop-down and explain the workings of the system which is supplemented by flash media. Figure B.3(c) shows a photograph of the GMIT solar collector facility where two solar collectors are installed.

The screenshot shows the GMIT website interface. At the top, there is a navigation bar with links for News, Events, Courses, Feedback, Site Plan, and Help. Below this is a blue header with the GMIT logo and the text 'Centre for the Integration of Sustainable Energy Technologies (CISET)'. A secondary navigation bar includes links for Home, Community, Education, Research, Industry, and Collaborations. On the left side, there is a 'Login' section with fields for 'User Name' and 'Password', and a 'Community' sidebar with a list of topics including Energy in Ireland, Energy in Your Home, Building a New Home, Energy Systems, Solar Thermal, Solar Photovoltaic, Heat Pumps: Ground, Heat Pumps: Air, Wind Power, Biofuel, Heat Recovery, Weather Station, and Projects. The main content area features a breadcrumb trail: 'Solar Thermal Collectors > 1. System Overview > 2. Principle of Operation > 3. GMIT Systems > 4. LIVE Data > 5. Further Information'. Below the breadcrumb trail, there is a heading: 'Using the above toolbar, you can discover the following information detailing a Solar Thermal Collector'. This is followed by a numbered list: 1. System Overview, 2. Principle of Operation, 3. GMIT Systems, 4. LIVE Data, and 5. Further Information. To the right of the list is a schematic diagram of a solar thermal system showing a house with solar collectors on the roof, connected to a tank and a boiler. The diagram uses colored lines (red, blue, green) to represent different parts of the system. At the bottom of the page, there is a copyright notice: 'Copyright © GMIT 2008. All right reserved'.

Figure B.3(a) Screenshot of the “Homepage” from the SEOLE.

The learner can view 9 different photographs of the facility, from an aerial shot of the IiBC building to the radiators connected to the solar collectors.

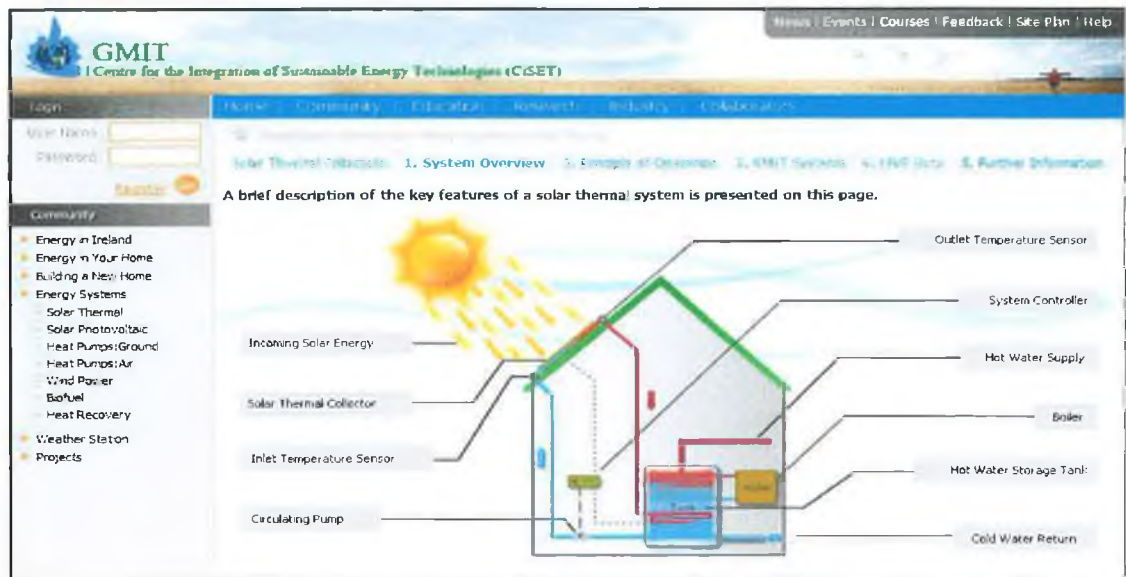


Figure B.3(b) Screenshot of the "System Overview" page from the SEOLE.



Figure B.3(c) Screenshot of the "GMIT Systems" page from the SEOLE.

B.4 Learning Environments Similar to SEOLE

As discussed in Section 4.5, a number of other website layouts were reviewed as part of the design process for the SEOLE. As shown in Figure B.4(a) Purdue University used a step-by-step process as a learning structure to guide the students through the solar energy experimental procedure. Similar to Purdue University, DECK Monitoring has also created a step-by-step process to explain the workings of their solar PV system. The learner can click on each step from 1-5, selecting each component of the system (the sun, the solar modules,

the inverter, the metering and monitoring and the utility lines) as they gain an understanding of the technology. Similar to SEOLE, the learning process is also supplemented by flash media which highlights the energy flows from the sun to the solar collectors, through the inverter and on to the utility lines to the electrical customers.

Figure B.4(a) Screenshot of 'RAEL' websites step-by-step process to their experimental procedure [Source: http://www2.tech.purdue.edu/Net/Facilities/knov427/remot/nsf/solar_proc_1.htm, 2007]

Figure B.4(b) Screenshot of 'DECK Monitoring' website's step-by-step process to their explanation on how solar PV works [Source: <http://www.live.deckmonitoring.com/>, 2008]

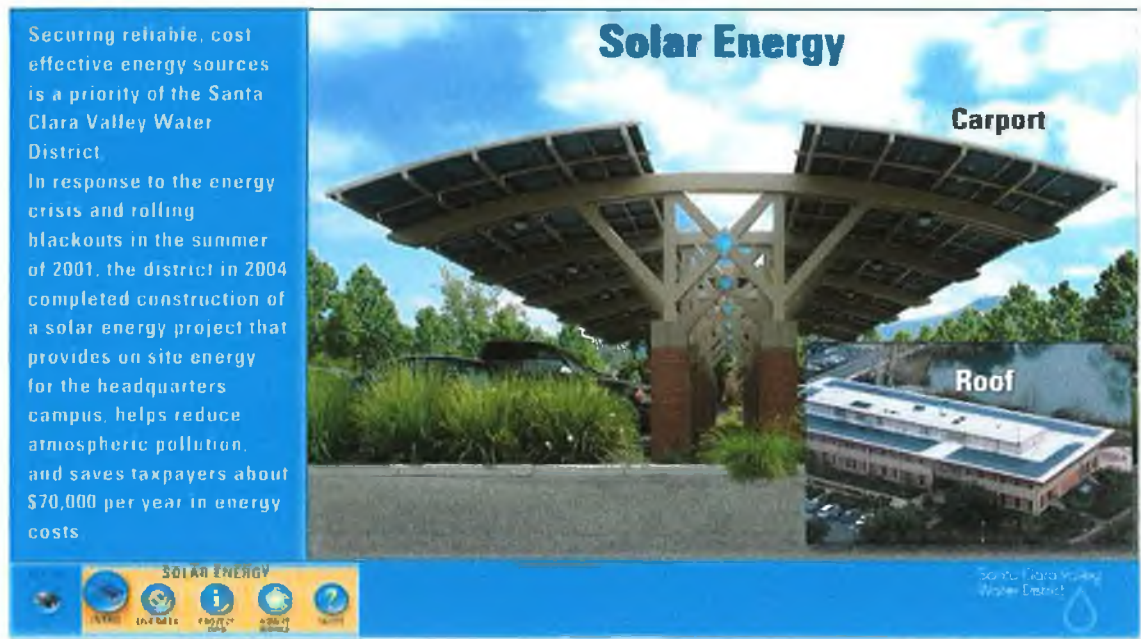


Figure B.4(c) Screenshot using 'Santa Clara Valley Water District' website for a step-by-step explanation of their sustainable project. [Source: <http://view.fatspaniel.net/SCVWD/flash/index.swf>, 2007]

Figure B.5 (a-d) presents other sites that display performance data of their sustainable energy systems and the energy savings made.

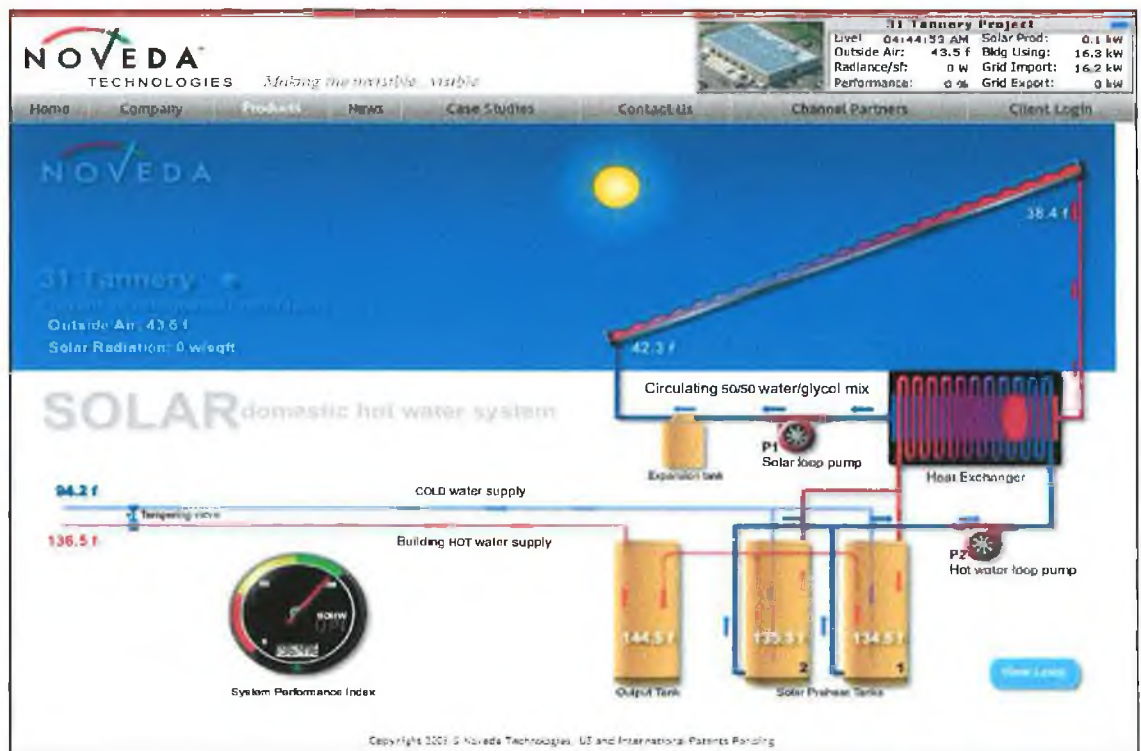


Figure B.5 (a) Screenshot from 'Noveda Technologies' website displaying the performance data for a solar thermal system. [Source: <http://www.noveda.com/en/>, 2008].

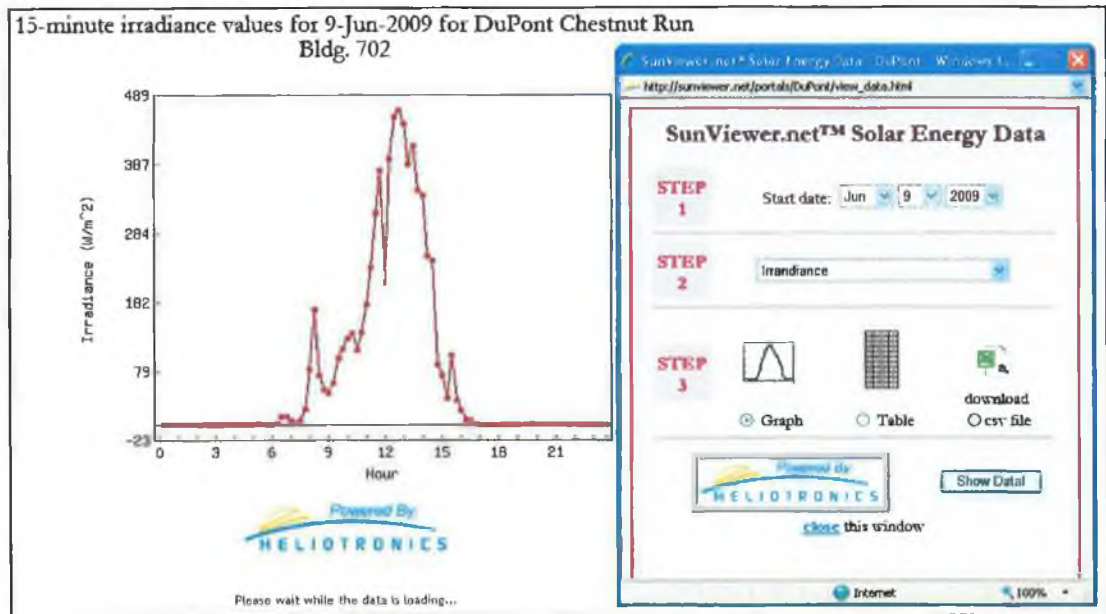


Figure B.5(b) Screenshot from Sunviewer from Heliotronics website displaying the performance data for solar radiation [Source: <http://sunviewer.net/>, 2009].

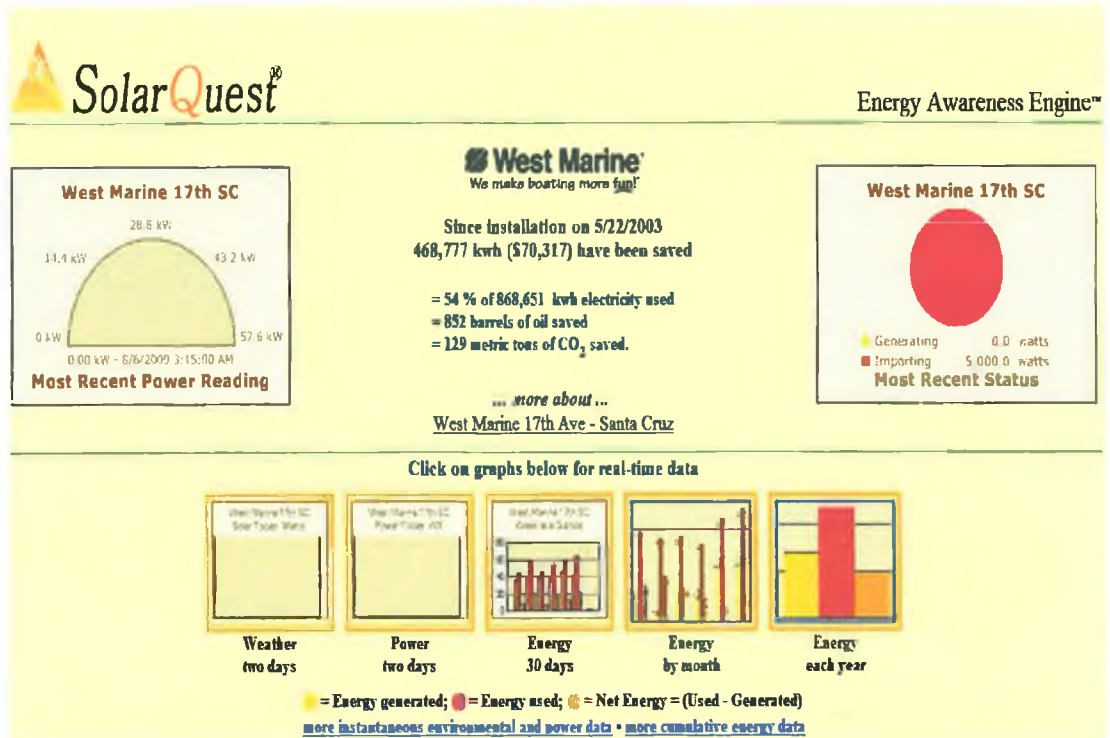


Figure B.5(c) Screenshot from SolarQuest website displaying the performance data of the energy generated and saved and weather data for the company West Marine. [Source: <http://data.solarquest.com/>, 2007].

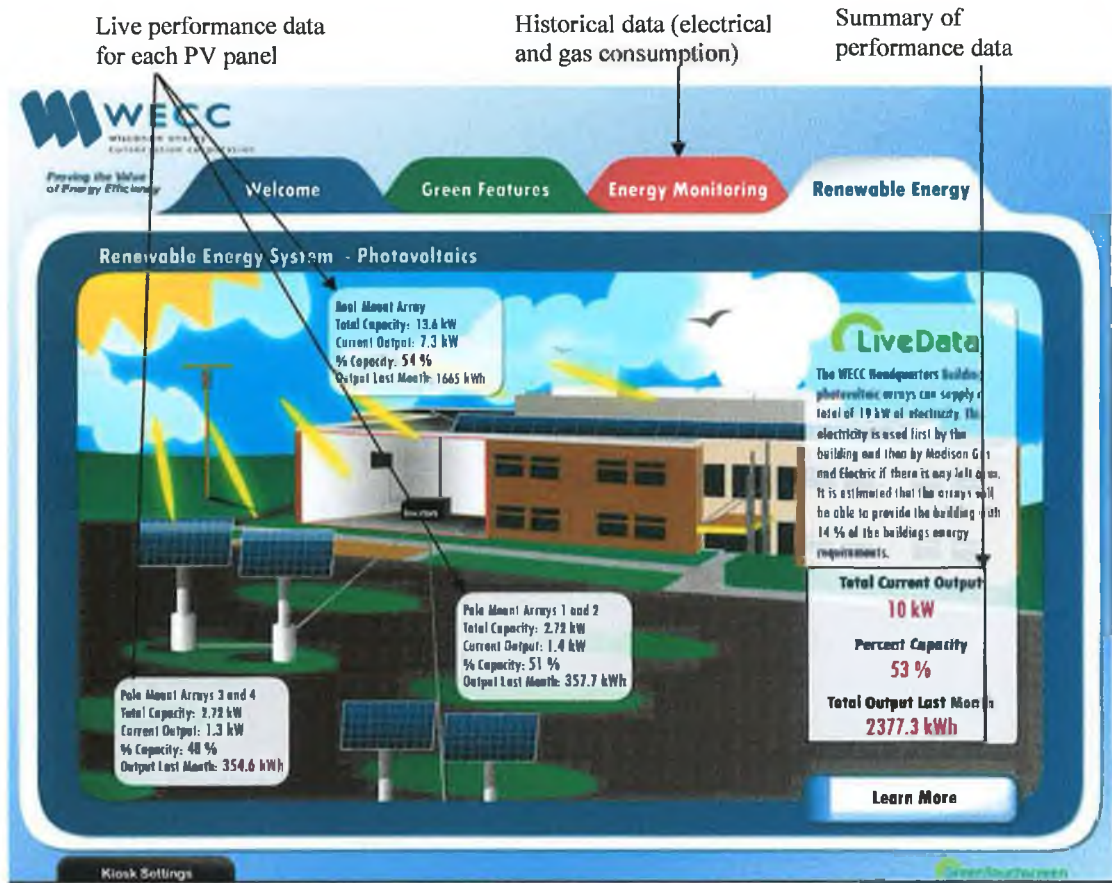


Figure B.5(d) Example of GreenTouchscreen website interface developed for WECC [Source: Wisconsin Energy Conservation Corporation, 2008].

Appendix C

Comments and Feedback about SEOLE

C.1 Feedback Questionnaire on SEOLE

C.2 Comments and Feedback from Respondents about SEOLE

Appendix C Questionnaire and Feedback about SEOLE

Section C.1 presents a list of the comments and feedback by 27 respondents from the 3rd and 4th year students from the Bachelor of Engineering in Mechanical Engineering in GMIT.

C.1 Feedback Questionnaire on SEOLE

This section presents the feedback questionnaire that the 27 students used to rate the SEOLE.

| | Excellent | | | | Very poor |
|--|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| | 5 | 4 | 3 | 2 | 1 |
| 1. Overall Impression | | | | | |
| General information/awareness, teaching? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Comment:

| | Excellent | | | | Very Poor |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| | 5 | 4 | 3 | 2 | 1 |
| 2. Content | | | | | |
| Is there sufficient information on each page? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Comment:

| | Excellent | | | | Very Poor |
|--|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| | 5 | 4 | 3 | 2 | 1 |
| 3. Web Site Design/Layout | | | | | |
| Were the pages easy to read/use? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Does the Site Design/Layout facilitate learning? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Comment:

| | Excellent | | | | Very Poor |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| | 5 | 4 | 3 | 2 | 1 |
| 4. Web Site Navigation | | | | | |
| Was it easy to get to the information you were interested in? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Comment:

| | Excellent | | | | Very Poor |
|--|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| | 5 | 4 | 3 | 2 | 1 |
| 5. System Schematics | | | | | |
| Are the schematics easy to understand/follow ? | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Comment:

6. Suggestions for Improvement of the Site:

- a. _____
- b. _____
- c. _____
- d. _____
- e. _____
- f. _____

7. Other Comments:

- a. _____
- b. _____

C.2 Comments and Feedback from Respondents about SEOLE

The following list is feedback and comments by the 27 respondent's about SEOLE;

Overall impression:

- Very good schematics
- Very good idea and very easy to understand
- Will be good when complete
- Good explanation of technologies
- Very good pages and nor cluttered
- Will be excellent when finished
- User friendly, informative
- Very good getting data from Ireland
- Good use of flash player

Is there sufficient Information on each page:

- Pop-ups an excellent idea
- Good balance between images and text
- Just enough information
- Quite clearly presented
- Very good
- Don't like pop-up boxes, they can cover the schematics

Design Layout- Were the pages easy to read:

- Well laid out
- Not cluttered, easy to read
- Very user friendly

Was the Website easy to Navigate:

At first glance missed a few links and tabs

Very easy to follow

Are the Schematics easy to understand:

Very easy and interesting

Animations are very intuitive

Very easy to follow

Very clear and good use of colour

Very easy to understand – flash media, arrows etc.

Very good schematics

Suggestions for improving the site:

Pop-ups could be bigger

Easier movement between pages- keep menus visible

Offer a detailed description of each technology

Ability to compare historical data from different weeks

Direct comparison of systems in historical graph

Introduce a forum section

Maybe the option to go into more depth

Comparison of “Green Company” performance data against SEOLE data

A search engine

Ability to download historical data

Faster updating of data

Larger area screen

Display current weather conditions on home page

Text a bit larger

More general information about renewable energies

Overall site good

Appendix D

Extracts from Schools Curriculum

Appendix D Extracts from Schools Curriculum

D.1 Extracts from the Primary and Secondary School Curriculum

Section D.1 presents a section of abstracts from the Primary and Secondary School Curriculum from different subjects relating to sustainable and renewable energy.

Primary School Curriculum:

Subject: Geography: “to foster a sense of responsibility for the long-term care of the environment and a commitment to promote the sustainable use of the Earth’s resources through his/her personal lifestyle and participation in collective environmental decision-making”

“become familiar with concept of sustainable development”

“become aware of the Earth’s renewable and non-renewable resources and recognise how the actions of people may have an impact on environments”

“come to appreciate the need to conserve the Earth’s resources”

“the prudent and rational use of natural and development human resources so as to maintain, protect and improve the quality of the environment for present and future generations”

Subject: Science: “to foster a sense of responsibility for the long-term care of the environment and a commitment to promote the sustainable use of the Earth’s resources through personal life-style and participation in collective environmental decision-making”

“to encourage the child to behave responsibly to protect, improve and cherish the environment and to become involved in the identification, discussion, resolution and avoidance of environmental problems and so promote sustainable development”

“understand the interdependence of a wide variety of living things and their environments, recognise the importance of conserving habitats and environments, and begin to understand that all life now and in the future depends on the sustainable development of the planet”

“environmental awareness and care will encourage children to become active agents in the conservation of environments and to adopt responsible attitudes and behaviour that will promote more sustainable use of the Earth’s resources”.

Secondary School: Junior Certificate Curriculum

Subject: Geography: “solar energy is the main source of heating for the earth. This energy is distributed unevenly both over the surface of the earth and within the atmosphere”.

Subject: Science: “students should study the definition and units for energy, principle of conservation of energy, forms of energy, sources of energy, renewable and non-renewable, energy sources, need for energy conservation and national energy needs”.

Subject: Technology: “energy and the need for the conservation of energy sources”.

Secondary School: Leaving Certificate Curriculum

Subject: Geography: “students should study the use of renewable and non-renewable resources in the economy and the impact of burning of fossil fuels the use of alternative energy sources”

“students should study sustainable economic development so as to control its environmental impact. Students should examine past experience, future trends and the necessity for environmental impact studies”.

Subject: Physics: “demonstrations of different energy conversions, sources of energy: renewable and non-renewable”.

Subject: Technology: “recognise the need for economic and sustainable use of energy and materials (including recycling), and take account of time and other factors”.

“students should learn about sources of energy, renewable and non-renewable Energy and Energy Conservation the principle of conservation of energy and its application, energy transformation, the cost of energy and energy efficiency”.