Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

The Glucksman Art Gallery, University College Cork, Ireland: An Innovative Space Heating Development

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Keywords: Heat pumps; Open loop system; Performance analysis; Payback time

ABSTRACT

The Lewis Glucksman Art Gallery is a cultural and educational institution promoting the visual arts at University College Cork (UCC), Ireland. Opened in October, 2004, the 2350m^2 building is serviced by a geothermal heating and cooling system, which allows heating and cooling to be provided at the same time using two water-cooled heat pumps. This enables a liquid chiller installation to serve as a full service heat source simultaneously with its refrigeration function.

Situated adjacent to the River Lee on UCC campus, and overlying a shallow gravel aquifer, groundwater at 12m depth and ~ 15°C, is fed via an open loop collector to geothermal heat pumps through plate heat exchangers. In order to ensure the preservation and safe keeping of its art collections, critical exhibition and storage space in the Glucksman requires a highly controlled environment, including humidity control by dehumidification, which demands that heating and cooling be supplied simultaneously to closed control areas. A range of climate-control technologies connected to the heat pumps optimise energy efficiency, whilst meeting the requirements of each viewing space. Two water cooled chillers at the same time generate both chilled water at 6°C and heating water at 45°C (30°C when providing cooling only). The rejected heat from the cooling process is fed directly into the heating circuits. Excess heat or cooling is transferred to the groundwater through a plate heat exchanger, and is discharged to a holding tank for use in toilet flushing and landscape irrigation. Excess water is discharged to the River Lee. The system capacity is 170kW and 200kW for cooling and heating respectively against corresponding loads of 130kW and 190kW.

In 2005 and again in mid 2008, assessments of the performance of the geothermal heating/cooling system for the Glucksman Gallery were undertaken to evaluate the operational efficiency of the geothermal system and to compare its performance to that of a conventional system. The studies also evaluated the economics and operational savings of the system relative to a conventional system and, based on fossil fuel and electricity prices over the period from commissioning of the building, estimated its payback time and future savings over the lifetime of the heat pumps. The investigations have indicated potential for considerable savings of 75% in energy consumption over that of conventionally equipped buildings. Post occupancy evaluation using recorded data from the building management system shows a remarkable correlation in energy consumed to the pre-construction design estimates. Due to significant increases in energy costs since the building was commissioned, payback time has been significantly reduced relative to pre-construction design estimates.

1. INTRODUCTION

The Lewis Glucksman Art Gallery is a cultural and educational institution in University College Cork (UCC), Ireland that promotes research, creation and exploration of the visual arts in an international context. The building, which was completed and commissioned in October 2004, has a total floor area of 2350m2, spread over 7 floors. It provides a public gallery with international curatorial standard environmental controls for University College Cork's modern art collection as well as for travelling and special exhibitions (Burgess, 2003).

The building contains four exhibition spaces, multifunction rooms, lecture facilities, a basement gallery store, a riverside restaurant and gallery shop (O'Regan, 2007). The four interlocking exhibition spaces vary in size and are staggered over three of the upper floors. The artworks are displayed in the exhibition spaces and stored in the basement store.

The Glucksman Gallery is situated on the southern bank of the South Channel of the River Lee, 10m from the river and about 1.7 km from Cork city centre. The architectural brief for the building was for an environmentally sympathetic design to complement the riverside location and its surroundings of mature trees and grassy lawns, with an emphasis on external wood and glass (Fig. 1). That it achieved these objectives is indicated by the fact that the building was short listed for the 2005 Stirling Prize for outstanding architectural achievement.

The 0.5 km wide floodplain of the River Lee, is underlain by a Pleistocene buried valley infilled by gravel deposits of variable thickness ranging up to at least 60m and possibly as much as 140m in places (Allen & Milenic, 2003), overlain by only a metre of alluvium. The south side of the building is located about 10m from the southern margin of the buried valley, which is marked by a small limestone scarp. The hydraulic conductivity of the gravels is of the order of 5 x10-3 ms-1, making them an excellent source of groundwater for a geothermal space heating/cooling system employing a heat pump with an open loop collector..

2. DESIGN SPECIFICATIONS

The Glucksman Gallery requires a highly controlled environment for the preservation and safe keeping of its art collections. This demanded exceptionally close control of temperature, humidity and natural light. Thus, in order to prevent deterioration of the artistic works, it was essential that the heating/cooling system design be capable of maintaining constant year round relative humidity (RH) of the order of 50%±5% and temperatures of 19 ± ½°C in the critical close control areas. These are represented by the exhibition spaces and the basement storage. The other areas require only temperature control.

Dehumidification is required to achieve the humidity control requirement. The dehumidification process demands that air be cooled and reheated simultaneously which is an energy intensive operation.

To maintain the design within the environmental aspiration of a low energy solution, the building-services consultant, Arup selected a range of climate-control technologies to meet the requirements of each viewing space. In view of the existence of a ready heat source in the form of the groundwater supply beneath the site, it was decided that much of the heating and cooling loads be supplied by a geothermal system. The building utilises two geothermal heat pumps (GHP's) in conjunction with air handling units (AHUs) to maintain the exhibitions and stores of art works at controlled temperature and humidity.

2.1 System Components

2.1.1 Geothermal System

Figure 1: The Glucksman Art Gallery, Ireland

The geothermal system is located below ground level in the basement of the Glucksman Gallery, and is supplied by groundwater at 15°C sourced from two 12m wells adjacent to the building. The heat pumps, which were designed, supplied and installed by Dunstar Ltd, have a lifetime of at least 20 years. System capacity for cooling and heating is 170kW and 200kW respectively against corresponding loads of 130kW and 190kW.

The system's major components are:

2 Heat Pumps; Cold and Hot Buffer Tanks; Plate Heat Exchangers and Three Way Valve

Heat Pumps:
Two York International water-cooled liquid chillers act as heat pumps. These are two stage chillers. one (YCWM75) comprising two 37.5kW compressors and the other (YCWM 120) two 60kW compressors. Actual single stage cooling capacities are 29kW and 47kW, whilst their corresponding heating capacities are 38.8kW and 64.3kW respectively (York Polaris 1999). These simultaneously generate chilled water at a temperature of 6°C and heating water at 45°C, (30°C when providing cooling only). On starting a unit, both compressors start and then one stops so that the unit runs at half capacity for part load application.

The system operates by any combination of the four compressors depending on the load requirement at that particular time. If all four compressors are running, the capacities are 152kW for cooling and 206kW for heating, whilst the power input is 55.2kW.

The refrigerant is R407C, a zeotropic mixture of three HFC's, R32, R125 and R134a in the proportions 23:25:52 by weight, which is non ozone depleting and also has high thermal characteristics since it is a mixture of three different substances.

Cold and Hot Buffer Tanks: Two buffer tanks act as energy storage. Chilled water is stored in the cold buffer tank to be circulated through the AHU cooling coils when cooling is required, whilst the hot buffer tank stores heated water for circulation through the AHU heating and reheat coils when heating and/or dehumidification is required.

Plate Heat Exchangers: There are two stainless steel brazed plate heat exchangers, one to allow excess heat to be rejected to the groundwater aquifer and the other for heat extraction from the groundwater. Plate heat exchangers were used because they are more efficient than other types of heat exchangers.

Three Way Valve: A motorized three-port valve is, depending on operational mode, used to direct the geothermal water flow to either the heating side plate exchanger or to the cooling side plate exchanger.

2.1.2 Air Handling Units

Three air handling units serve different functions and floors of the Glucksman Gallery. AHU1 provides temperature and humidity control to the basement gallery store, serving the need for close control of both temperature and humidity for the proper storage of the art works there. The unit, which consists of a carbon filter, bag and panel filter, heating coil, cooling coil, humidifier and supply fan, has fresh and return air intakes. The treated air is ducted to the room directly below (Browne, 2005).

AHU2 provides temperature control second and fourth floor galleries and to these areas. The unit consists of a bag and panel filter, heating coil, cooling coil and dual speed supply and return fans. The plant room acts as a fresh air plenum and return air is taken by duct from both rooms through a shadow gap at high level with a bell mouth in the ceiling void. The supply is provided through vertical duct drops to floor grilles (Browne, 2005). Unlike AHU1 and AHU3, this unit does not offer humidification. However it does provide dehumidification through the efficient use of the cooling and (re)heating coils both of which are fed from the evaporator and condenser sides (respectively) of the water cooled chillers.

AHU3 serves the close control gallery and multi media room, and is comprised of a return fan, mixing box, cooling coil, steam humidifier, supply fan and terminal reheat boxes. The return section is on the fifth floor consisting of fresh air mixing, a carbon filter, return fan, bag filter and panel filter whilst the supply section on the third floor consists of heating, cooling, humidification and two-speed supply fan.

2.1.3 Ancillary Plant

In addition the system includes water circulation units consisting of the borehole pumps, cold and hot loop circulating pumps, withholding tank and pipe networks.

The borehole pumps are two equally rated submersible pumps, each driven by its own variable speed drive unit, set at the bottom of the two wells at depths of 12m. The pumps, configured as a duty/standby pair, have maximum pumping rates of 10 l sec^{-1} and are used to pump groundwater to the heat pump circuit so that heat is either extracted from it or fed into it.

Geothermal hot and cold loop pump sets, each consist of two duty/standby circulating pump pairs. One is for circulating heated water between the hot buffer vessel and the geothermal hot plate exchanger, and the other for circulating chilled liquid between the chilled buffer vessel and the geothermal cold plate exchanger (Browne, 2005).

The withholding tank keeps processed geothermal water for use in flushing toilets or irrigation. The pipe network acts as a connection media between various components to transfer geothermal water from the production wells through the heat exchangers, withholding tank and discharge of excess water to the River Lee. It is also used to circulate chilled water or hot water from cold/hot buffer tanks to AHU's for cooling or heating or both in the case of dehumidification.

2.1.4 Ventilation and Air Circulation Units

Apart from the air handling units described above, there are a number of supply fans and extraction fans, which operate independently of the air handling units. Each fan operates so as to maintain the required air changes for particular floors and spaces. Of note due to its reasonable heating capacity is the kitchen ventilation (supply and exhaust) system which heats the colder winter air (0°C up to a minimum operating temperature of 15 °C) using the condenser water from the chiller sets.

2.1.5 Gas Boilers

Two 102 kW Remeha 350 model gas boilers, with a total capacity of 204 kW are located in the upper floor. One acts as a lead boiler, the other as a lag boiler to heat the LPHW water for circulation through a limited number of radiators in select areas of the building such as the trench radiators for the glazed entrance lobby and radiant panels for the tall glazing element in the entrance lobby. Their main function is to be used as a backup system for the GHP's in case of failure.

2.1.6 Underfloor Heating

Heat from the condenser side of the water cooled chillers is used to warm the flooring of the entrance lobby, toilets and cafeteria. This again maximizes the use of the low grade heating circuit that is in essence the heat rejection (condenser) side of the water cooled chiller plant.

3. SYSTEM OPERATION AND MONITORING

3.1 System Operation

The submersible pumps drive groundwater from the boreholes to the basement plant room where it is piped to the two water-cooled chillers, which act as heat pumps, generating chilled water at 6ºC and Low Gradient Hot Water (LGHW) at 45ºC (30ºC for cooling only in summer). Rejection of heat from the chillers cooling process is utilized by the heating circuit. Excess heat or cooling is transferred back to the groundwater, via a plate heat exchanger. The processed groundwater is held in a storage tank and is used for toilet flushing and irrigation, with excess water being discharged into the river.(Kennett, 2005)

There are basically four operational configurations based on modes of operation (O'Regan, 2007), which are: *Active Geothermal Cooling, Geothermal Heating Mode Passive Geothermal Cooling and Combined Geothermal Heating and Cooling*

Based on the different operating modes, the system has different coefficients of performance (COP), ranging from 3 to as high as 20 (Table 1)

Table 1. The Glucksman GSHP, COPs for Different Operating Modes (O'Regan, 2007).

Operating Mode	COP
Active Geothermal Cooling (Heat Pump Enabled)	3
Active Geothermal Heating (Heat Pump Enabled)	4
Active Geothermal Cooling and Heating (Heat Pump Enabled)	7
Passive Geothermal Cooling (Heat Pump Disabled)	20

3.2 Building Management System

A Building Management System (BMS) monitors all data for temperatures, pressures, running hours, electricity and gas consumption. The version employed for the Glucksman Gallery is BMS 963 of Trend 963 – Lite BMS supervisor software. The Trend 963 – Lite is a graphical, real-time user interface for the BMS. It enables the user to monitor the plant or building services, change the operational settings and refine control strategies with experience (Huston, 2003).

The BMS is also programmed to report all alarms in case of a problem, and to record and archive all data for future reference and plot trends using its graphical, real–time interface. However, it was found on investigating the BMS for the Glucksman that the archiving facility had not been switched on.

4. SYSTEM APPRAISAL AND PERFORMANCE

Geothermal heat pump systems are evaluated on the basis of three major performance parameters. These are: *Technical performance; financial performance* and the environmental *performance*

For all of these performance pillars, it is necessary to determine the annual cooling and heating loads and their respective annual running hours, annual cooling and heating energy consumptions and the total annual energy consumption. There is also a need to ascertain the efficiency of the conventional system and emission factors for the driving electricity for the GHP and fossil fuels for the conventional system.

The overall performance of the GHP installation is dependent on the performance of the different components that are interlinked to it within the total HVAC system.

4.1 System Appraisal

4.1.1 Technical Performance

Initial technical analysis during the design stage suggested a COP of 4 for the heating mode and a COP of 3 in the cooling mode. In the combined heating and cooling mode, as the COP for heating and cooling is the summation of the two, a COP of 7 can be achieved.

This was verified by a post occupancy assessment completed in April 2005 (Browne, 2005), which indicated that initial performance was in line with design expectations after six months of operation. Different COPs for both cooling and heating modes were determined for standard lift from an average cold inlet of 10°C and hot water outlet of 45°C. This analysis found the COPs to be 2.98 and 3.93 for YCWM 120 and 3.05 and 4.02 for YCWM 75. These also give averages of 3 for cooling, 4 for heating and a total COP of 7 for combined heating and cooling (Browne, 2005).

4.1.2 Financial Performance

During the design phase, a comparison of the estimated energy usage and running costs for the conversional system and geothermal heating and cooling system was undertaken. The comparison in capital cost showed the conventional system to be cheaper by €175,000 (Burgess, 2007). The comparison in running costs and cost savings are shown in Table 2.

Table 2. Energy Use and Running Cost Comparison – Design Phase (Burgess, 2007).

System Type	Energy Usage in kWh	Unit Price	Annual Cost
Conventional System			
Chiller	61,512	€ 0.07410	€ 4,558.04
Boiler	1,690,758	€ 0.01775	€ 30,010.95
	Total Annual Running Cost		€ 34,568.99
GSHP System			
GSHP	268,644	€ 0.07410	€ 19,906.52
Boiler	176,779	€ 0.01775	€ 3,137.83
	Total Annual Running Cost		€ 23,044.35
Annual Cost Saving = Difference in Running Costs			€11,524.64

Using a simple pay back period calculation:

Payback Period = Difference in Capital Cost ÷ Annual Cost Saving

Payback Period = € 175,000.00 ÷ €11,524.64 = **15.2 years.**

In the 9 month period after commissioning, Browne (2005) found that energy usage by the GHP system was considerably less than initially calculated, indicating that it was operating more efficiently than anticipated (Table 3). This allowed him to revise down the payback period to 11 years, although changes in fuel and electricity prices over this period were not factored into his calculations.

Table 3. Energy Use and Running Cost Comparison – One Year of Operation (Browne, 2007).

System Type	Energy Usage in kWh	Unit Price	Annual Cost
Conventional System			
Chiller	61,512	€ 0.07410	€ 4,558.04
Boiler	1,690,758	€ 0.01775	€ 30,010.95
	Total Annual Running Cost		€ 34,568.99
GSHP System			
GSHP	230,000	€ 0.07410	€ 17,043.00
Boiler	100,000	€ 0.01775	€ 1,775.00
	Total Annual Running Cost		€ 18,818.00
Annual Cost Saving = Difference in Running Costs			€15,750.99

Simple Pay Back = Difference in Capital Cost ÷ Difference in Operational Cost

Simple Pay Back = €175,000 ÷ €15,750.9 = **11.1 years**

4.1.3 Environmental Performance

The design consultants, ARUP also undertook an evaluation of CO_2 emissions generated by the Glucksman Gallery resulting from utilisation of different sources of electrical power. It was estimated that the GHG system would bring about a reduction of 256,249 Kg CO_2 compared to the conventional system, if the electricity was supplied by the UCC Combined Heat and Power (CHP) plant. This gave an environmental pay back of 10 years (Burgess, 2007).

4.2 Current Performance Analysis

Since commissioning of the geothermal system in the Glucksman Gallery in October 2004, fuel and electricity prices have risen sharply in response to various market factors, together with uncertainty of supply due both to political events and peak oil concerns. Consequently there was a need to re-examine the performance of the system and to recalculate its economics. This was undertaken in August-September 2008 (Gondwe, 2008), enabling financial savings for the four years of operation to be established in order to assess their effect on the payback period and also to assess the system in terms of its continuing performance relative to design specifications and expectations.

A number of system performance assessment models were investigated (Gondwe, 2008). Those most applicable to the Glucksman Gallery heating and cooling system were the RETScreen – Open Loop System Model, the Exergy System Analysis Model and a model entitled 'The Glucksman Heating and Cooling Assessment Model' developed by Browne (2005), which has subsequently been upgraded to incorporate special financial and technical analysis tools (Gondwe, 2008). It has the capability of carrying out Exergy System Analysis and also Life Cycle cost analysis and payback period with uneven cash flows. In addition the RETScreen and the Exergy Analysis Models were compared.

4.2.1 Annual Load Profile

Based on modelling with RETScreen 4, it is found that the system is basically running in two modes per year at 0% non weather dependent load and in a single mode per year with 15% non weather dependent loads as shown in Figs. 2 and 3[1]

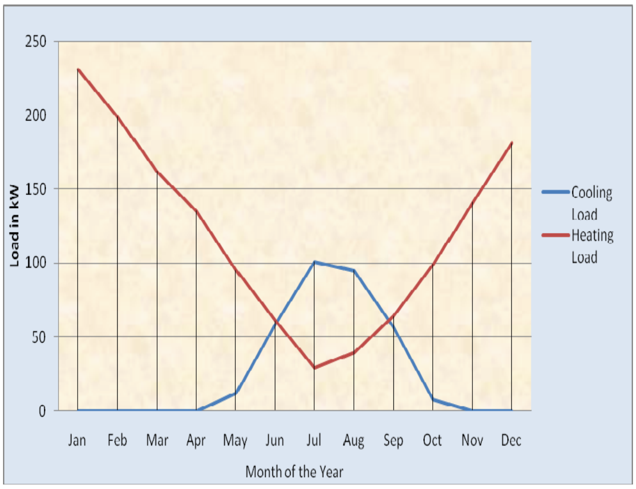

Figure 2: Annual Load Profile with 0% Non Weather Dependent Load

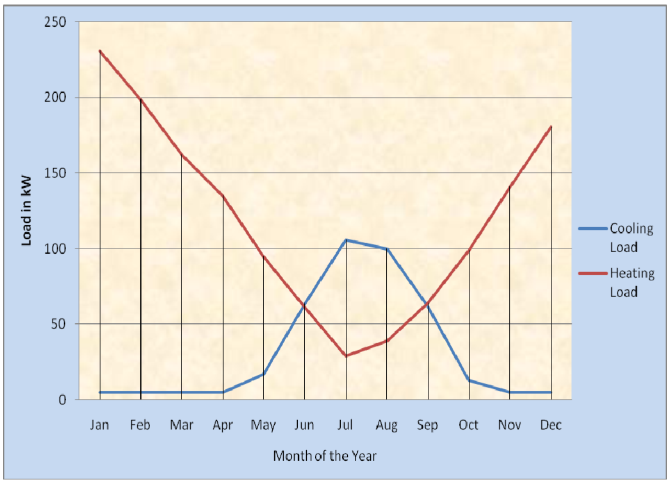

Figure 3: Annual Load Profile with 15% Non Weather Dependent Load

Fig. 2 indicates that the system runs in heating mode from November to April and then in heating and cooling mode from April to November, whilst Fig. 3 shows that the system runs in heating and cooling mode throughout the year. The latter case applies when dehumidification is required for humidity control throughout the year. In both cases heating loads are at peak in December and January and minimum in July and August. The reverse applies for the cooling loads. The two figures represent the base case only.

4.2.1 Annual Heating and Cooling Hours

Since no historical data on compressor run times and operation mode was archived on the BMS, RETScreen 4 was used to determine the load profiles and the corresponding heating and cooling hours.

From Fig. 2, it is established that Annual Heating Hours (AHH) are 8760 hrs whilst Annual Cooling Hours (ACH) are 5856 hrs, whereas Fig. 3 indicates that both are 8670 hr

The final performance analysis including projections through the project life time was done using the performance model developed. This has been outlined in section 5 below.

5. THE PERFORMANCE MODEL

5.1 Model Description

The Glucksman Heating and Cooling System – Performance Model is an MS Excel model used to calculate and predict the system performance factors, financial savings and emission savings (Gondwe, 2008). The model has three major sections:

5.1.1 Input Section

The model operates with two sets of inputs. The inputs are grouped into System Inputs and User Inputs.

System Inputs: These are default inputs specifying the system data including the initial design cost of the system. This set of inputs acts as a data storage. In addition the system data input provides a list on natural gas and electricity price projections.

User Inputs: This section consists of two sheets, "Input Data" and "Valid Data Values". The user enters the data in the Input Data Sheet and the model tests its validity in the Valid Data Values Sheet. The model uses the "Accepted Values" in the Valid Data Values as its input.

There are four entry tables for entering past energy consumption, efficiencies and emission factors for the grid, prices for electricity and natural gas, power connection times for the CHP and the grid. The entry tables are numbered 1 to 4 with corresponding tables in the Valid Data Values.

5.1.2 Computation Section

This section consists of three sheets in which performance calculations are undertaken. System technical performance is determined in the "Technical Performance Sheet", whilst financial performance is established in the "Financial Calculation Sheet" and the environmental performance is determined in the "Emission Calculation Sheet".

5.1.3 Output Section

Although most of the performance information can be obtained from the computation section, a special output section has been set in the "Summary Graphs Sheet". This is a simplified graphical presentation of all the findings and results.

5.2 Electricity and Natural Gas Prices

5.2.1 Available Price Data

Based on data from UCC Buildings and Estates Office, Bord Gais Energy Supply and Sustainable Energy Ireland, Natural Gas prices rose from €0.033/kWh in 2004 to €0.057/kWh in 2008. This gives an overall growth of 72.26% with an average annual growth of 19.9%.

Over the same period electricity from the campus CHP rose from €0.101/kWh to €0.117 giving an overall growth of 15.29% and an average annual growth of 4.86% whereas grid electricity rose from €0.131/kWh to €0.159/kWh giving an overall growth of 21.37% with an average annual growth of 6.67%

5.2.2 Price Projection – 2005 to 2029

The model was used to compute price projections and their relative variation from 2005 to 2029. These are demonstrated in Figs. 4 and 5.

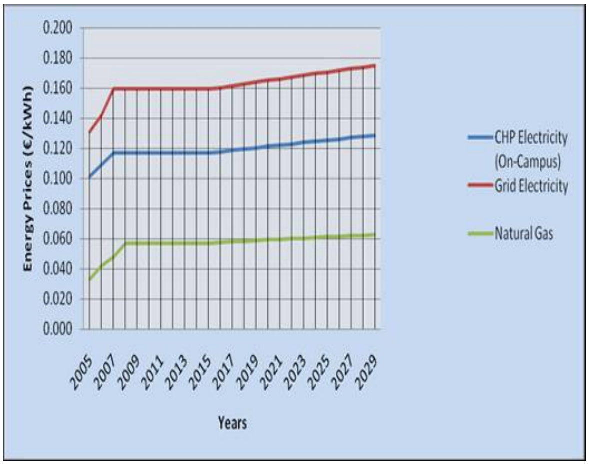

Figure 4: Natural Gas and Electricity Price Projection in Ireland (2005 – 2029)

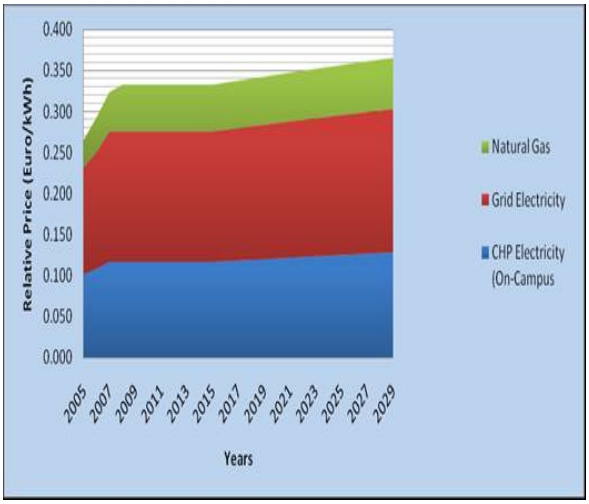

Figure 5: Relative Price Growth for Natural Gas and Electricity in Ireland (2005 -2029)

Fig. 4 shows the projected variation in prices, whereas Fig. 5 shows the relative price growth for each of the three energy sources. Applying projected growth rates supplied by Sustainable Energy Ireland, price deflators in the system and the fuel data sheet of the model, it was found that there will be a huge price rise in Natural Gas from €0.033/kWh in 2005 to €0.063/kWh in 2029 giving an overall rise of 91% compared to 33% for grid electricity and 27% for CHP electricity as shown in Fig. 5. Prices for electricity per kWh will rise from 10.1 cents and 13.1 cents in 2005 to 12.8 cents and 17.5 cents in 2029 for CHP and grid supply respectively as shown in Fig. 4.

5.3 Performance Results and Discussions

Based on the available BMS data, Chillers' Design Specifications and the price projections, the model produced the following results:

5.3.1 Technical Analysis

Since no flow rates were available, COPs were calculated using interpolation on the design specification and the calculated COPs from the model. Results are:

From August to September 2008

Chiller Leaving Temperature (Mean) - 7.94^{o}C

Evaporator Leaving Temperature (Mean) – 48.53^{o}C

By interpolation, COP_c = 2.63

COP_h = 3.59

$COP_{(h+c)}$ = 6.21

From November 2007 to September 2008

Chiller Leaving Temperature (Mean) – 6.67^{o}C

Evaporator Leaving Temperature (Mean) – 42.98^{o}C

By interpolation, COPc = 2.88

COP_h = 3.93

$COP_{(h+c)}$ = 6.89

COPs for the period October 2007 – September 2008 are shown in Fig. 6. These have been calculated based on CHW and LGHW flow temperatures shown in Fig. 7.

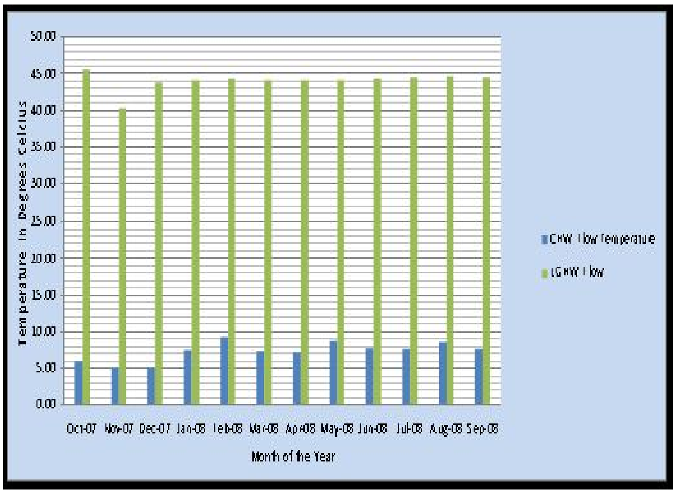

Figure 6: CHW and LGHW Flow Temperatures (Oct 2007 – Sept. 2008)

Figure 7: COPs Based on CHW and LGHW Temperatures (Oct 2007 – Sept. 2008)

From Figs. 6 and 7, the mean COP_h is 3.9 whilst that of COP_c is 2.93. Mean CHW flow temperature is 7.36^{o}C whilst that for LGHW flow temperature is 44.07^{o}C.

5.3.2 Financial Analysis

5.3.2.1 Financial Cost Savings

Based on energy consumption data obtained from UCC Buildings and Estates and both past and projected prices, model results obtained were:

Actual Cost Savings: The model showed that there have been cost savings of €28,808.22 in 2005, €48,258.47 in 2006, €56,911.21 in 2007 and €71,402.96 for 2008. This gives a total saving of €205,380.85 for the four years of operation. These are shown in Fig. 8. The figure shows actual savings and its resulting cumulative value for that year. The graph can be updated in the model for future years.

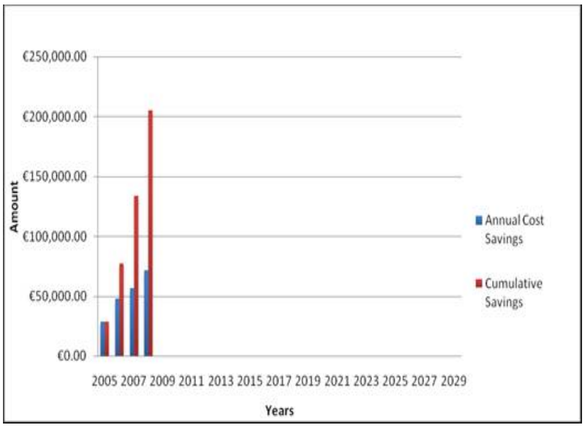

Figure 8: Life Cycle Cost Analysis (LCCA)

Using the projected natural gas and electricity prices, a modelled Life Cycle Cost Analysis was carried out to determine the cost savings and the break even point. The results from the model were:

Break - even Point: Break even point is the point at which the balance on capital cost becomes zero. LCCA modeling resulted in a break even point of 3.57 years after installation. This is presented in Fig. 9:

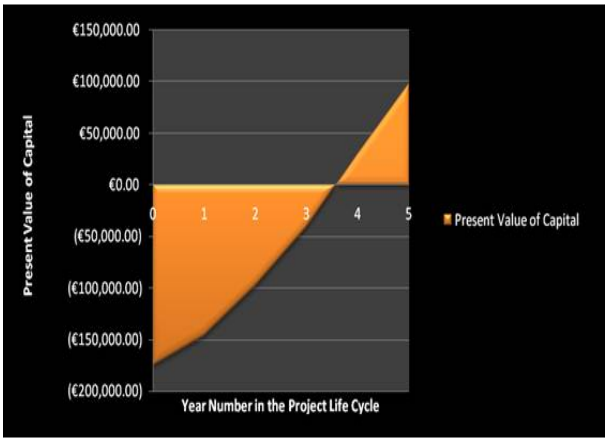

Figure 9: Break – even Point with LCCA

5.3.2.2 Project Payback Period

The model also evaluates the systems payback period based on the designer's method – simple payback method. It further computes the payback period with actual savings (uneven cost savings). The results of the modelling are:

Simple Payback Method: Model results were, 14.6 year for Arup design case, 11.1 years for the Browne assessment and 6.1 years based on actual energy consumption and prices for the first year of operation (2005).

Fig. 10 shows all three lines of constant savings. Where they intersect the line of capital cost is the payback for each of them.

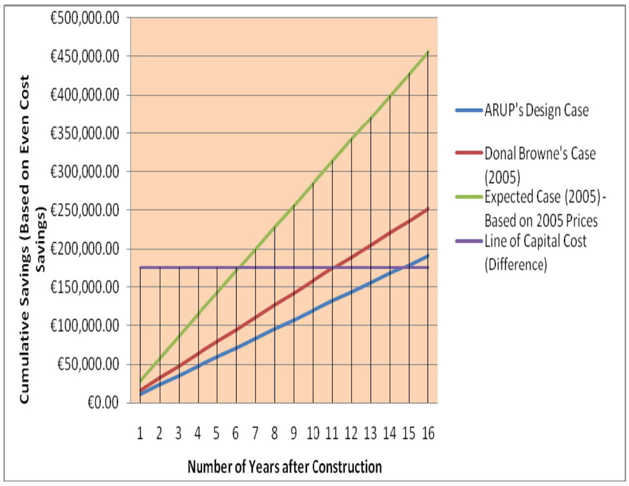

Figure 10: Simple Payback with Even Cost Savings

Payback Period with Uneven Cost Savings

Payback period with uneven cost savings was found to be 3.57 years. This is shown graphically in Fig.11.

Comparison between Simple Payback Method and Payback with Uneven Cost Savings

Comparing the two approaches in determining the payback period it was found that the payback period dropped from 14.6 years to 3.57 years (11 years) when comparing the uneven approach with the simple payback approach – Arup's design case. On the other hand, there was a drop from 6.1years to 3.57 years (2.5 years) when compared with the 2005 expected case. This comparison is shown in Fig. 12.

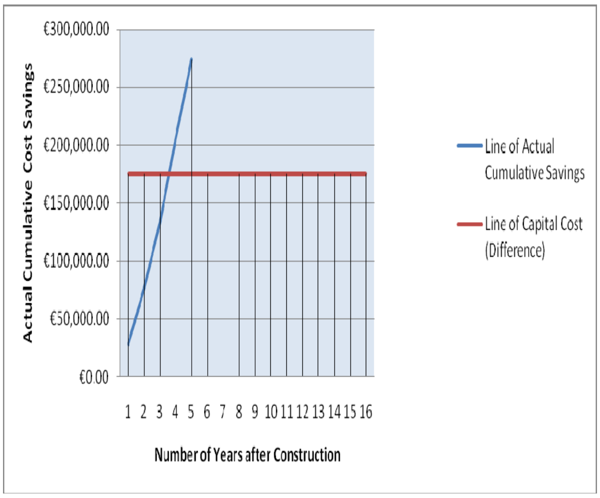

Figure 11: Payback Period with Uneven Cost Savings

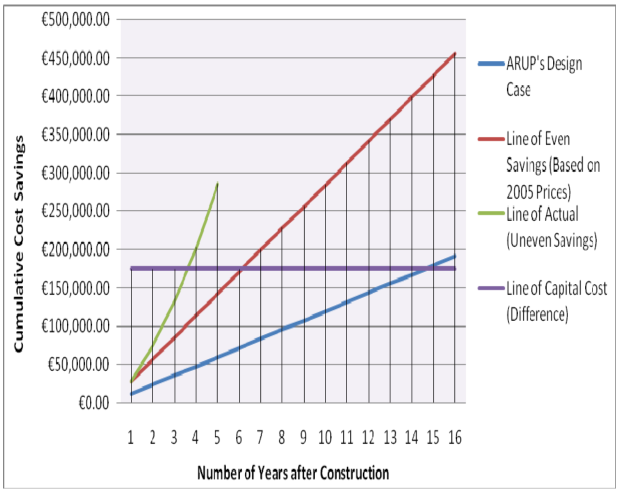

Figure 12: Comparison between Simple Payback Method and Payback with Uneven Cost Saving

5.3.3 Environmental Analysis

Modelling of environmental impacts was undertaken to determine the actual CO_2 savings and the environmental payback.

5.3.3.1 Emission Savings

The emission savings were calculated using both the TEWI and the yearly emission savings projections.

Yearly Calculations: Yearly calculations were used to determine the actual emission savings and the environmental life cycle analysis.

The model results on computing the emission savings were, 92.59 tCO_2 in 2005, 149.26 tCO_2 for 2006, 141.01 tCO_2 for 2007 and 139.66 tCO_2 for 2008. This gives a cumulative saving of 522.51 tCO_2 for the four operational years. These are illustrated in Fig. 13, whilst environmental life cycle analysis results are shown in Table 5.

Applying the TEWI approach, emission savings for the four years of operation were found to be 824.7 tCO2 and for 25 years mechanical life were 4,947.8 tCO_2.

Environmental Payback Time

Results for environmental payback time also referred to as CO_2 payback time (CPT) are shown in Fig. 14.)

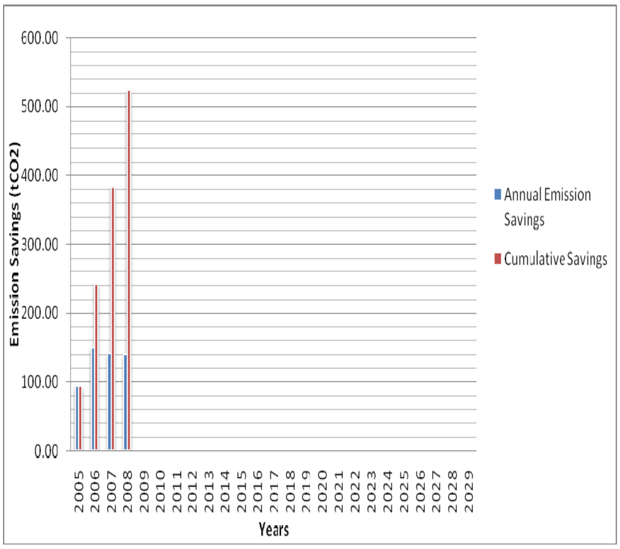

Figure 13: Actual emission savings for the four operational years

Table 5. Environmental Life Cycle Analysis.

Value at:	Cumulative Savings (tCO_2)	Balance on the Emissions during construction (tCO_2)
4 years operational period	523	- 2,037
End of Design Life (20yrs)	2,642	+ 82
End of Mechanical Life (25yrs)	3,304	+ 744

Total Equivalent Warming Impact (TEWI) Approach

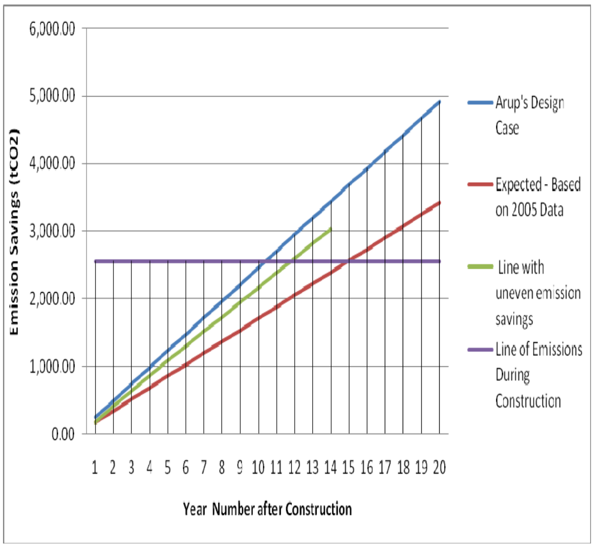

Figure 14: CO_2 Payback Time

The CO_2 payback times were found to be 10.4 years for the Arup design case, 15 years for the expected case (based on 2005 data) and 11.9 years for the actual line with uneven CO_2 savings.

6. DISCUSSION

6.1 Technical Performance

Due to unavailability of data for the flow rates and the VSD frequencies, an interpolation method was employed. According to York International, interpolation is done in two stages. The first is to determine the COP's for the actual evaporator leaving temperature for the standard CHW flow temperature, whilst the second is used to determine the COP's for the actual CHW flow temperature at the actual evaporator leaving temperature.

The results obtained are not much different from the design assumptions for COPs of 3 for cooling, 4 for heating and 7 for heating and cooling.

The small internal close control gallery AUH (3) and basement archival store AHU (1) successfully achieve low room temperatures of 19°C at 50% RH. The main wrap around galleries on 2^{nd} and 4^{th} floors can and do provide dehuimidifcation in the summer without the need for fossil fuel fired reheating. The large gallery exhibition spaces are able to achieve straight-line control during the shoulder and summer seasons when active humidification is not required.

6.2 Financial Performance

It is noted from the results the simple payback period dropped by 8 years from 14.6 years for the design case to 6.1 years for the actual case (based on 2005 data). A 5 year drop is also noted when compared to the Browne (2005) case, which gave a payback period of 11.1 years. This has been principally due to the rise in natural gas prices from 2002 to 2005. For simplicity of comparison Browne (2005) used 2002 prices instead of 2005 prices.

In Fig.12, a comparison between payback with uneven cost savings and that from simple payback is made. Payback with uneven cost savings is found to be 3.57 years. This has been mainly due to the rise in natural gas prices from 2005 to 2008.

In Fig. 8 and Table 4, it is noted that savings to date are €205,380.85 and will reach as high as €2,886,724.07 by the end of the heat pumps mechanical life. The huge projection in cost savings is due to the fact that natural gas is projected to rise by up to 52.4% from €0.033/kWh in 2005 to €0.063/kWh in 2029.

6.3 Environmental Performance

In Fig.13, the actual CO_2 savings are shown to be considerably lower than the design prediction of 256t CO_2/year. This is also depicted in Fig. 14 where the CO_2 payback time has increased from 10 years for the design case to 19.38 years for the actual case with uneven emission savings.

This has been contributed by two main factors; firstly the designer assumed that electricity would be sourced from the on-campus CHP only, at an efficiency of 89%, against the actual situation where supply comes from both the grid and the CHP, with the CHP's actual electrical efficiency reaching only 39.9%. Secondly the improved fuel mix in the Irish electricity generation increased the ratio of emissions of the CHP compared to those for the grid.

Table 5 shows that the emission savings as at present are at 522.5 tCO_2 and are expected to rise to 3,304.5 tCO_2 by the end of the heat pumps mechanical life. This will lead to a net emission saving of 744 tCO_2.

Emission savings using TEWI are higher than those obtained by the yearly approach because it assumes average consumption applies to all years and uses average grid efficiency and emission factors.

CONCLUSION

The highly sophisticated GHP heating and cooling system installed in the Lewis Glucksman Art Gallery provides precise and constant year round temperature and relative humidity to critical close control areas for the preservation and safe keeping of its art collections.

A performance analysis has shown that a well designed, correctly installed geothermal system can generate significant savings in heating and cooling costs for buildings. The ongoing monitoring and use of the BMS for data collection is critical to fine-tuning and optimization of the GHP systems.The energy consumption over the 4 years of operation of the GHP system of the Glucksman Gallery to September 2008, is remarkably close to the design estimates used for the original life cycle cost and sensitivity analysis undertaken in 2001.

Although the Glucksman is only a medium sized building with modest heating and cooling loads (190 kW and 130 kW respectively), the €200,000 savings generated in only 4 years of operation are quite spectacular. Much of these savings have resulted from steep rises in natural gas and electricity prices in Ireland over the period 2004-2008, due to global political instability and market volatility, and future projections of oil and gas prices envisage much more subdued markets. However, the projected rise in gas and electricity prices over the next 20 years is quite conservative, and should political events lead to future instability in world energy markets over this period, the projected savings of nearly €3 million by the Glucksman geothermal system over the lifetime of the installation may be significantly enhanced.

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