A Concept for IT-Supported Carbon Neutral Renovation

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ABSTRACT: Building renovation supports excellent opportunities to reduce energy consumption in buildings or reduce their CO_2 emissions by making smart energy-saving choices to achieve carbon neutrality of buildings. The challenge is to achieve 'zero energy' and carbon neutral buildings by focusing not only on new designs but also primarily on old structures. However, to achieve effective carbon-neutral building renovation substantial financial investments are required. Therefore, it is important to provide a detailed decision support which informs the selection process which building elements should be considered in the renovation process. In this paper we present a simple energy simulation model used for the analysis of energy consumption and carbon dioxide emissions. The model was used to produce an energy consumption report to assist us in the initial phases of a renovation project to evaluate the impact of design alternatives on energy conservation, investment, running costs, reduced CO_2 emissions and further environmental impacts.

1 INTRODUCTION

Currently, climate change is recognised as the most important and threatening global environmental problem. In 2007 energy use in Ireland increased by 1.4% and energy-related CO_2 emissions increased by 0.8%. Over the period since 1990, energy-related CO_2 emissions grew by 2.5% per annum, while the economy grew by 6.5% per annum. Table 1 tabulates the growth rates for the economy (GDP), primary energy (TPER) and energy-related CO_2 emissions for the period 1990 – 2007 using five yearly intervals (Howley et al. 2008).

Table 1. GDP, TPER and CO_2 Growth Rates

	Growth %	Average annual growth rates %					
	1990-2007	90-07	90-95	95-00	00-05	05-07	2007
GDP	190.4	6.5	4.6	9.6	5.6	5.9	6.0
TPER	69.8	3.2	2.2	5.5	2.7	1.1	1.4
Energy CO_2	51.2	2.5	1.6	4.6	2.3	-0.1	0.8
Energy CO_2 (excl. international aviation)	46.6	2.3	1.6	4.4	2.1	-0.7	0.5

Fossil fuels are a limited resource. Furthermore, the usage of fossil fuels as a primary energy source for electricity generation to support buildings' operation increases greenhouse gas (GHG) emissions and contributes to global warming. Therefore, smart and more efficient solutions for energy-savings in buildings will help us to reduce GHG emissions and achieve Carbon Neutrality of buildings.

2 CARBON NEUTRALITY

In both developed and developing countries, most of the energy sources used to heat, cool and light buildings are currently using fossil fuels. The burning of fossil fuels connected with operating a building is responsible for approximately 70% to 80% of the CO_2 footprint of the building. Carbon neutrality with respect to building operation means to drastically reduce the amount of GHG emitting energy required to support heating, ventilation, air-conditioning, lighting, and additionally the carbon emissions associated with the commercial, institutional or residential use of the building by the occupants. These targets may be accomplished by implementing innovative sustainable design strategies, generating on-site renewable power and/or purchasing (20% maximum) renewable energy and/or certified renewable energy credits. (CND Project, 2009).

However, holistic carbon neutral design is aiming to reduce carbon emissions associated with all phases of the building life-cycle. This would include the energy used to operate a building, but also the so called embodied energy used for the manufacturing process of building materials and energy used to support the construction and maintenance processes. Embodied energy has two components: Firstly, the initial embodied energy in buildings represents the (non-renewable) energy consumed in the acquisition of raw materials, their processing, the manufacturing and transportation of building materials, and energy used to support the construction processes.

Secondly, the recurring embodied energy in buildings represents the (non-renewable) energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life-cycle of the building. Materials themselves are able to make differing contributions to the overall energy efficiency of a building, particularly where energy reduction is the primary goal of designing for carbon neutrality. This is most clear when comparing materials on the basis of either their ability to retain heat (act as thermal mass) or resist heat flow (act as insulation). (CND Project, 2009)

Current sustainable design and operation strategies for buildings are already addressing some aspects of carbon reductions. However, the area of holistic energy management during building operation needs further improvements.

2.1 *Concept Development*

Numerous authors published concepts for the maintenance, upgrade, and renovation of large stocks of buildings and infrastructural systems. A holistic approach was taken by the Enqete Kommission of the German Parliament (1994 to 1998). The work of this commission focused on three aspects of sustainable development (cf. Deutscher Bundestag, 1997):

(1) to define the main features of resource, energy, and material flow management,
(2) to identify stakeholders and their responsibilities for resource, energy, and material flow management with an emphasis on the commercial sector,
(3) to specify the main features of resource, energy, and materials flow management policy.

The work of this commission stimulated multiple research projects and publications analysing the potentials and constraints for the future development of housing, infrastructural developments and their impacts to society and the economy (Hassler et al. 1999). A major finding of these research activities is that there is a need to use and better understand the existing building stock as a major resource in our society. Kohler et al. argue that it is inefficient to either 'downcycle' or deposit building materials after demolition of buildings. Models developed by Kohler can prove that it is more efficient to redesign, renovate, and maintain the 'shell and core' of existing buildings. (Hassler et al. 1999).

Furthermore, there is clear evidence that a well balanced mix of 'passive' and 'active' technologies for building operation is the optimum solution for the development of sustainable, long-term oriented concepts for building operation (Hassler et al. 1999).

Finally, Richter et al. argue that there is a need for improved understanding and more transparency of operational impacts and costs of buildings. Only the full understanding of the 'Total Cost of Ownership' will lead to a paradigm change in the construction sector from 'Planning of new Buildings' to the 'Development of Life-Cycle Oriented Building Concepts'.

2.2 *Carbon Neutral Renovation*

The next chapter presents the initial version of a concept for carbon neutral renovations which is currently under development at University College Cork, Ireland, as part of the Carbon Neutral Building Project. The emphasis of our research is to develop a holistic methodology describing how information technology can be used:

(1) to document the current status of an existing building – emphasizing on factors of building performance,

(2) to explore and identify all existing 'development potentials' in terms of sustainable building operation of an existing building that is embedded in a specific 'neighbourhood',

(3) to generate and evaluate alternative design proposals for renovation and provide decision support to stakeholders,

(4) to support the planning and design process for the optimal renovation strategy.

An important part of the concept development is to fully explore the development potential of the existing building. Work in this area must emphasize on the following aspects:

(1) to optimise the usage of 'embodied energy' of the existing building by maintaining major parts of the 'shell and core',

(2) to optimise the 'embodied energy' added to the building and ensure a maximum usage period for added systems and components,

(3) to optimise the usage of energy for building operation by using new control technologies with an appropriate installation density,

(4) to optimise the exploitation of renewable energy sources for building operation.

(5) to optimise the 'energy export capabilities' of the existing building by integrating the building's renewable energy sources into so called 'Neighbourhood Management Systems'.

Carbon Neutrality can only be achieved if the 'energy export capabilities' of the building are optimally exploited, since the exported energy from renewable sources can compensate for the 'embodied energy' which was required to manufacture and transport the building materials.

Therefore, the expansion of the usage time of major building elements is an essential part of the development of concepts for carbon neutral renovation since the amount of 'embodied energy used per annum' could be substantially decreased by expanding the overall life-cycle of a building. Finally, it is essential to carefully balance the amount of 'embodied energy' that is added as part of the renovation.

2.3 *Energy simulation to achieve Carbon Neutrality*

As explained earlier, there are particular ways to transform an existing building into a 'Carbon Neutral' building. One important part is to maintain substantial parts of the old construction since re-use does not add further embodied energy to the overall energy balance. Secondly, materials with a low carbon footprint must be used for required refurbishment activities.

Another important part of carbon neutral renovation activities is the development and installation of modern solutions to support heating, ventilation, air-conditioning, and lighting to decrease the consumption of 'non-renewable' energy. This includes the optimization of total energy usage and the implementation of innovative building control strategies within a facility.

Therefore, Computer Aided Energy Simulations are beneficial to contribute to the development of Carbon Neutral design strategies since they assist us in identifying potential energy-savings. For new buildings, design simulations allow to forecast the energy consumption of design alternatives, support the comparative analyses of design elements, such as mechanical systems, and lead finally to the optimization of building design alternatives. These design alternatives will minimize energy use by combining best available mechanical and electrical systems with advanced control technologies and novel design and construction practices. This will contribute to minimal energy consumption so that residual energy requirements can be easily mitigated with reliable carbon neutrality.

However, building simulations can also be used to evaluate the energy consumption of existing buildings and to demonstrate potential energy and carbon savings. They are used as a basis to plan renovation activities aiming to optimize operational and maintenance systems and to improve the energy efficiency of devices, components and other equipment.

2.4 *Purpose and methodology of this study*

The purpose of this paper is to report about the development of an energy simulation model for an existing university building. The model has been used to inform the decision process for future renovations. The energy simulation is complemented by an initial study about related renovation costs (cf. Chapter 4).

The following sections explain the development of the energy simulation model based on the example of the building of the Department of Civil and Environmental Engineering (CEE) at University College Cork. The building is a traditional structure built in 1910 and in need for substantial renovation. A detailed description of the building can be found in Chapter 3. The objective of this energy simulation was to better understand the energy utilisation profiles of the existing building and to understand how the elements and systems of the building impact the energy use.

Simulating a building's energy flow requires not only a model of the building and the materials that make it up (including insulation, windows, foundation, etc.) but also a model of the building's location, with the path of the sun through the year and weather data that is accurate and detailed, including humidity, wind, simple daytime - night-time temperatures, and a host of other information. The following diagram clearly shows the structure of the model.

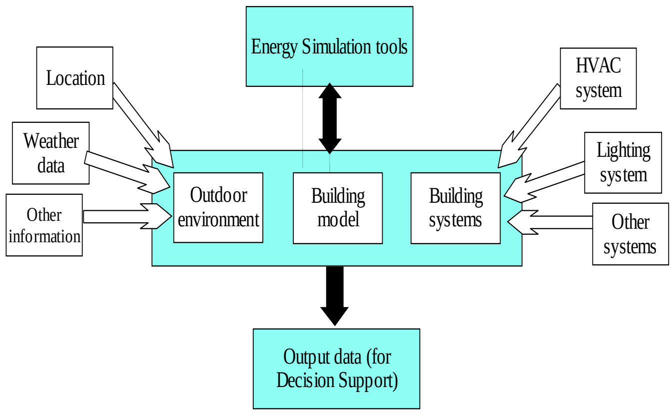

Figure 1. The structure of modelling and simulation.

In the first step we focused on developing a 3D model of the building. In our case we used Revit Architecture for the 3D-modelling of the building. In a second step we developed a computerised building energy model using Revit MEP. The energy simulation was performed by using the IES plug–in of Revit MEP. The overall development process included:

- Collect data to create the CEE-building models, including design documentation, site visits, users and other information.
- Create a 3D model of the CEE-building.
- Set up for simulation.
- Run energy simulations.

By running the energy simulations we developed an understanding of how and where energy is used in the building with respect to its location, building function, space types and hours of use. By applying building energy simulation software we identified key building elements in terms of CO_2 emissions and energy consumption.

In a next step we used modelling and energy simulations for the development of sustainable renovation strategies. Design and quality of construction are key and integral to the energy performance of a building when it is in use. The condition of the main architectural elements has a big influence on the energy performance and the related CO_2 emissions. The improvement of external walls, insulation and the replacement of the old windows, can contribute to huge savings of energy and a decrease in CO_2

emissions. Therefore, IT- supported building energy management is an efficient way to reduce energy wastage.

Finally, a further analysis of the financial aspects of changes to major building elements would be made. For instance, the replacement of single glazing to double glazing using information from the building models will show not only the energy but also the financial savings. This will be true for all elements.

3 CASE STUDY

The presented research has focused on the Building of the Department of Civil Environmental Engineering of University College Cork (UCC). The building was inaugurated in 1910 originally providing space for Chemical and Physical Laboratories. It is placed on the main campus area. The building is North-South-facing with a total length of almost 41 meters, 22 metres wide and a height of almost 14 meters. The total area is $1854m^2$ and the total volume of $9300m^3$. Its traditional structure and old fittings give a broad field for research. The CEE-building is a three storey structure made of 550mm red brick walls covered externally with roughcast, old, single glazed windows and a very spacious timber roof, being a mix of sloped and flat shape with two skylights in the middle section. Rooms and lecture theatres are over 4 meters high.

The building has no mechanical ventilation system. However, laboratories were ventilated using a system of ventilation shafts running within the brick walls to the roof, where three mechanical fans were mounted in metal turrets. An additional source of fresh air is provided using shafts underneath each window. Next to existing electricity and fire safety systems there is a low pressure water central heating system. The system is fed by a natural gas powered boiler provided to the building and its iron radiators. Figure 2 presents the 3D model of the CEE-building. Figures 3 and 4 present how much details can be considered in the model.

Figure 2. Civil Environmental Engineering Building model created with use of Revit Architecture.

Figure 3 presents a computer laboratory in the CEE building, showing details of all furniture like chairs, tables and radiators but more importantly all lights, computer and computer monitors as additional heat sources.

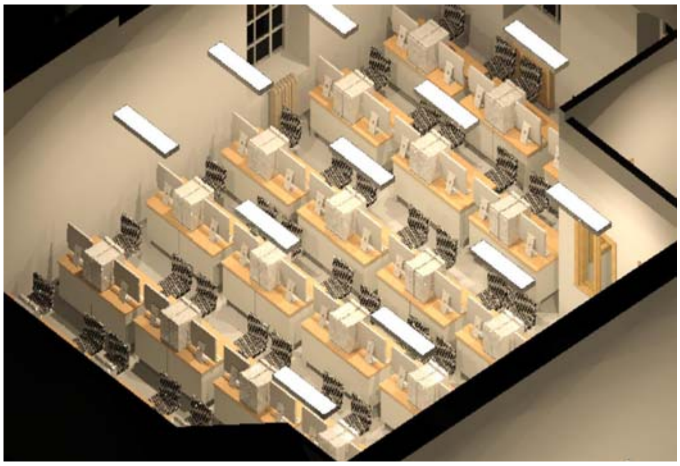
Figure 3. CE 109 - computer laboratory.

Figure 4 presents one section through the eastern wing of the building including the natural ventilation system.

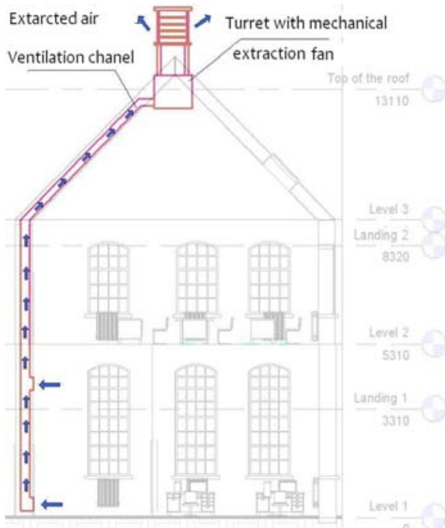

Figure 4. Section through the eastern wing, showing ventilation system.

3.1 *Applying the concept*

The first part of our applied research activities focused on the structural/materials selection process. Four scenarios of renovation were taken under consideration:

- Walls renovation by adding additional layers of external insulation.
- Roof renovation by adding insulation.
- Replacement of the old windows with high quality and high resistance double glazed windows.
- Analysis of a combination of all of the above scenarios.

In case of wall renovation we propose to improve the u-value of the existing brick wall (1.232 W/m^{2}K) by adding a 14 cm thick insulation layer, i.e. the new u-value is 0.22 W/m^{2}K (Pistohl, 2007, p. H16).

The estimated embodied energy of the existing brick is 1040 kWh/m^3 (cf. Schulze Darup 1996, p. 171). We have chosen to use mineral wool as insulation material with an average embodied energy of 60 to 395 kWh/m^3. The total values for the embodied energy of the walls and the added insulation layer are given in Table 2 below.

Table 2. Embodied Energy of Walls and Insulation

Material	embodied energy	volume	total
unit	*kWh/m^3*	*m^3*	*kWh*
brick	1040	454	472,160
mineral wool	225	115.57	26,003

In case of the roof we propose to improve the u-value of the non-insulated roof (3.3775 W/m^{2}K) by adding additional mineral wool insulation. The new u-value is 0.1589 W/m^{2}K.

Finally, we propose to replace the single glazed windows with high-performance, double glazed windows with 9.5 mm glass / 12mm Krypton gas / 4mm glass. The old (estimated) u-value of 5.5617 W/m^{2}K could be decreased to u_w 1.6 W/m^{2}K.

In case of the Skylights we propose to improve the u-value from 5.7361 W/m^{2}K to 2.103 W/m^{2}K. The values for the estimation of the embodied energy are again taken from the literature (cf. Schulze Darup 1996, p. 176) and the total embodied energy for the replacement of the windows is given in Table 3.

Table 3. Embodied Energy for new windows

Material	embodied energy	volume	total
unit	*kWh/m^3*	*m^3*	*kWh*
glass	15,175	3.429	52,035

The additional embodied energy added to the total energy balance of the building distributed over an estimated usage period of 20 years is marginal compared to the simulated energy savings. The energy simulations used to estimate the potential energy savings are explained in the next chapter.

3.2 *Model generation and simulation process*

As described above, the first step of an energy simulation is to create the simulation model. The development of the three dimensional (3D) geometric model is the initial step. Based on data compiled at previous surveys and further information about the building materials and existing building systems the 3D-model was generated using a parametric CAD-system. The advantage of using a parametric CAD-system is that this application supports the creation of any 3D object within so called families of objects, such as structural objects, façade objects, electrical components, HVAC-objects, or furniture objects. All of these geometric object representations have an option to create additional sets of properties further specifying the objects by using alphanumerical data.

Since the energy simulation package (limited IES VE Integrated Environmental Solutions) is available as “plug-in” to the parametric CAD-system we could exchange the geometrical model between the parametric modeller and the energy simulation package efficiently.

In the next step, the 3D model was imported to another module of the parametric CAD system, namely the MEP component. Additional information about the HVAC system, lighting systems and further electrical appliances were edited as required input for the IES simulation package. Properties of the building such as geographical coordinates to specify weather data, its function, main elements of the building (U – values) were specified. Furthermore, the type of HVAC systems and the type of ventilation principles of the building had to be specified. Finally, we added properties of each room and zone, such as its functions, occupancy patterns, lighting and power loads. After the complete acquisition of all relevant data the energy simulation was performed. The simulation is based on algorithms defined in the European Building Performance Directive. After the first simulation a report was produced about existing heating and cooling loads.

For further iterations we changed the technical values of the building elements proposed for renovation or replacement, like roofs, walls and windows. Alternative U-values, as specified in chapter 3.1 were assigned to the relevant building elements. For each design alternative we performed an individual simulation. After each simulation the report being produced gave an idea about the differences between heating and cooling loads for each scenario. The produced simulation reports were used to inform the decision process how the renovation activities should be prioritized.

3.3 *Results of the case study*

The simulation results are summarised in Figure 5 below. One can see that the improved insulation of the external walls will reduce the CO_2 emissions by 19% (using heating load figures for calculation as explained below).

Further figures are given in Figure 5, illustrate that the improved roof insulation will lead to 33% savings, the replacement of windows leads to 11% savings and finally, for the ‘holistic’ scenario, the reduction will reach almost 65% of savings.

Within the next paragraphs we will give an interpretation and evaluation of this initial energy simulation.

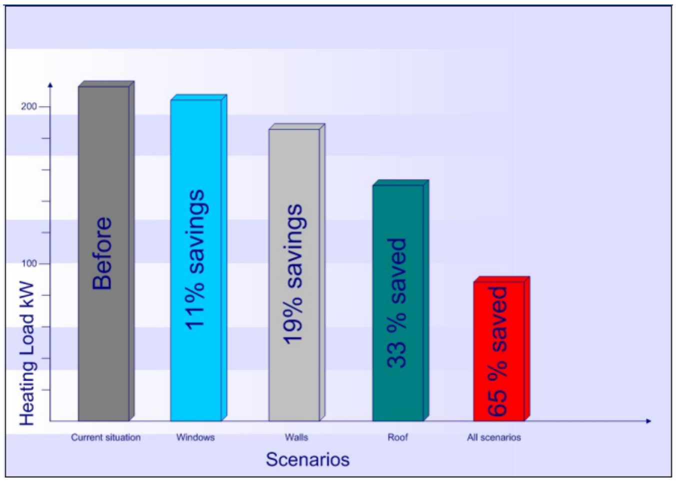

Figure 5. Representation of savings for each scenario.

Unfortunately, we could only estimate the energy consumption of the heating system. Currently, there is no metering for the heating system installed in the building. The building is connected to a central heating system. This central heating system is provides hot water to many buildings of various functions on UCC's campus. Since the system is owned and operated by the University there is no need to install meters in the individual buildings.

However, based on measurements for the overall hot water production and the accessibility of the 'distribution pattern' we could estimate that the CEE-building's heating system consumes approximately 228 kW for heating (i.e. simulated total heating load).

As a result of the holistic renovation scenario the estimated heating load will decrease to 80kW. The operation hours are estimated as 2096h, and the boiler efficiency is approximately 80%. The total energy used for heating purposes is given in Table 4 below.

Table 4. Energy Consumption Heating

	heat load	usage	eff. -factor	total
	kW	*h*		*kWh*
existing bldg.	228	2096	0.8	597,360
after renovation	80	2096	0.8	209,600
savings				387,760

According to Sustainable Energy Ireland (SEI) green gas conversion factors for natural gas were 1kWh – 0.2045kg CO_2 (Emission Factors, 2006), leading to the following CO_2 emissions:

Table 5. Related CO_2 Emissions for Heating

	energy heating	CO_2 equivalent	CO_2
	kWh	*kg/kWh*	*t*
existing bldg.	597,360	0.2045	122.10
after renovation	209,600	0.2045	42.86
savings	387,760	0.2045	79.24

Furthermore, the electricity consumption of the building and its influence on CO_2 emissions must be taken into consideration. In case of electricity consumption we could access metered data. The average daily electricity load of the CEE-building is 20KW according to the monthly reports provided by UCC's Office of Buildings and Estates (UCC, 2009). SEI states that 1kWh of grid electricity has a CO_2 equivalent of 0.6365 kg CO_2/kWh (Emission Factors, 2006).

Table 6. Electricity Consumption & CO_2 output

elec.consump.	usage	total	CO_2equivalent	CO_2emissions
kW	*h*	*kWh*	*kg/kWh*	*t/years*
20	2096	41,920	0.6365	26.7

The total CO_2 emissions of the CEE-building from heating and electricity before renovation and after renovation and the related CO_2 emissions per area are summarised in table 7 below. Finally, table 7 also gives some benchmarking criteria provided by Sustainable Energy Ireland (SEI). According to the building type and its function the SEI-benchmarking criteria is 32.2 kg of CO_2/m^2 for Good Practice of energy use and 56.8 kg of CO_2/m^2 for Typical Use (Carbon Trust, 2003).

Table 7. Electricity Consumption & CO_2 output

	before renovation	after renovation
CO_2 emissions	148.8 *t/years*	69.56 *t/years*
bldg. area	1854 m^2	1854 m^2
CO_2 per area	80.26 $kgCO_2/m^2$	37.52 $kgCO_2/m^2$

Benchmark		
SEI typical use	56.80 $kgCO_2/m^2$	
SEI good practice		32.20 $kgCO_2/m^2$

A comparison of the above results with benchmarks taken from Sustainable Energy Ireland standards is presented in graph below:

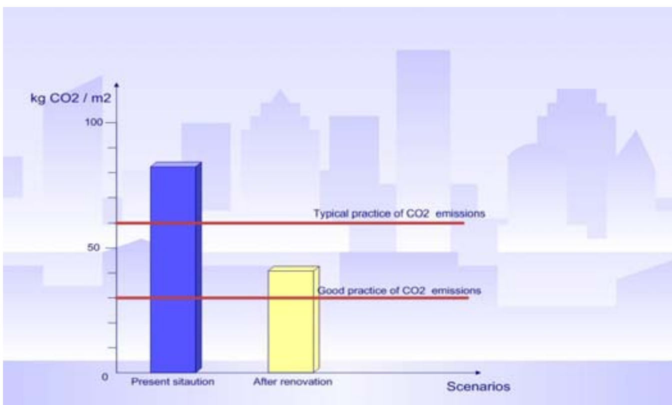

Figure 6. Graph presenting scenarios over SEI benchmarks.

4 FINANCIAL ANALYSIS

Commercial buildings such as the CEE-building contribute significantly to the total energy consumed in the building sector. In general both heating and lighting account for most of the energy used and thus provide key areas for improvement. In light of the current world recession and a downturn in economies generally the opportunity exists to enhance the future of the CEE-building due to the consequent reduction in the costs of materials and labour. However the only real alternative from a cost point of view is refurbishment. The investment risks and associated demolition and rebuild costs associated with redevelopment are not optional given the current budgetary climate. There is however a number of advantages in taking the refurbishment route. These are (Rawlinson et al. 2008):

- Speed to market – fast construction, minimised planning together with opportunities to phase construction works if necessary to manage cash flow or work around existing users.
- Retention of the advantages of the existing building – character, development density and massing.
- Cost Avoidance of total demolition and the reconstruction of major elements of the building fabric should result in capital cost savings of at least 20%, even on major projects.
- Flexibility – opportunities to tailor the extent or the timing of the refurbishment to market conditions, reducing funding costs and maximising occupancy.
- Sustainability – refurbishments use fewer resources and create less waste (the shell and core are retained) than new building projects, and contribute to sustainability by improving the performance of the existing building stock.

In order to take advantage of the opportunity to change the buildings behaviour as an energy system in terms of reducing energy and building maintenance bills, increasing safety and market value and improving user comfort the EU Construction Products Directive 89/106/CE requires all structures to comply with six essential requirements:

(1) mechanical resistance and stability;
(2) safety in case of fire;
(3) hygiene, health and the environment;
(4) safety in use;
(5) protection against noise and
(6) energy economy and heat retention.

These aspects would have to be taken into consideration in relation to the refurbishment of the CEE-building and the Energy in Buildings Performance and the Energy Services Directives.

Financially viable are a number of energy efficiency measures that would not only reduce energy consumption but also improve the building structure generally. Some of these measures are upgrading the heating radiator system, replacing single with double glazing, roof insulation and possible wall insulation.

There will be a subsequent reduction in the running, operational and maintenance costs as for example replacing timber wooden window frames with uPVC double glazed units will give a longer working and relatively maintenance free life.

Likewise modern heating systems, such as solar hot water panels, wall heating and under floor heating would not only allow for energy efficiency and reduction but also allow for greater user comfort. Whilst generally accepted that improvement will be of benefit it is argued (Martinaitisa et al. 2007) that there is probably no comprehensive review of appraisal methodologies for renovation projects.

In financial terms the most recognised means for measuring or quantifying the benefits of energy upgrading of buildings are calculations that show simple payback time, net present value (NPV), and internal rate of return (IRR) of the investment or cost of conserved energy (CCE). Mostly only energy savings are included in an economic analysis whilst the other benefits of building renovation are neglected (Martinaitisa et al. 2007). Another method claimed to be the most straightforward and easy-to-interpret (Fuller, 2008) is Life-cycle Cost Analysis (LCCA). Its purpose is to estimate the overall costs of project alternatives that will provide the lowest overall cost of ownership.

4.1 *Investments Glazing and Improved Insulation*

An example for the CEE-building can be given using the replacement of glazing. Taking an average cost of 337 €/m^2 means that the average replacement cost of glazing will be 254m^2 × 337 € = €85,598. However the college will not need to spend as much money on heating bills - approximately 11% less – once double glazing has been introduced. Payback time is expected to be from 5 to 6 years if double glazed.

By insulating the external walls the costs on average are 1854m^2 × €133/m^2 = €246,582. Payback time is expected to be from 10 to 20 years. To complete insulation of the building envelope the roof space is also insulated. The average cost to insulate the roof will be 1572m^2 × €6.34/m^2 = €9966. Payback time is expected to be from 3 to 6 years.

4.2 *Savings Achieved by Reduced Heating Load*

From Revit MEP/IES energy simulation as described in the previous section it can be determined that before refurbishment the total heating load per annum amounted to 597,360 kWh. The cost of natural gas is 0.06 €/kWh leading to a total cost per annum €35,842. With refurbishment the total heating load per annum dropped to 209,600 kWh. At €0.06/KWhr the total heating cost became €12,576. The total estimated saving per annum is €23,266.

Table 8 summarizes the overall required investment costs to €342,146 and the potential savings to €23,266. Therefore, the overall payback time could be calculated of €342,146 / €23,266 = 14.7 years.

Table 8. Summary Financial Analysis

Investments	unit cost	units	total cost
Glazing	337 €/m^2	254 m^2	85,598 €
Ins. Walls	133 €/m^2	1854 m^2	246,582 €
Ins. Roof	6.34 €/m^2	1572m^2	9966 €
Savings			
Gas per annum	0.06 €/kWh	387,760 kWh	23,266 €

5 CONCLUSIONS

This paper has represented a range of IT applications that support Carbon Neutrality in building renovation. The research concentrates on existing building performance analysis based a 3D simulation models and a financial analysis in the building lifecycle. We used the CEE-building at UCC as a demonstrator.

From the energy analysis of the case study, it is clear that the CEE-building energy reduction will be almost 65% if the external walls, roof and single – glazing windows are changed into insulation with good quality walls and roof and double – glazed windows, whilst at the same time, saving 42.16 kg CO_2 per square meter.

Finally, the financial analysis illustrates the total saving per annum is € 23,266 therefore giving an overall payback of 14.7 years.

Given the nature and condition of the CEE-building, its location and position in the college market, the current economic conditions and the investment timescale of the office of Buildings and Estates will determine the extent of possible refurbishment. Since this building has an inherent long term value related to location, character, future planning constraints and possible listed building status this could justify significant investment in refurbishment. The risk profile of refurbishing the CEE-building could be high as it would mean working within an existing building with the constrained budgets and programmes required to deliver a commercially viable scheme.

It is the belief of this group that refurbishment of the CEE-building will not only be cost effective and energy saving but will also help towards achieving carbon neutral renovation.

6 FURTHER WORK

Further steps of research will focus on getting actual data for heating consumption and more scenarios for renovation of the heating system and the associated advantages. Another aspect to be considered is the use of thermal imaging and the state of the actual physical condition of the building to point out all invisible heat leaks in order to adjust energy simulation results more, in keeping with the existing situation. It is also important to drill down the problem of operation aspects of building heating system control by mounting a network of sensors and meters to give a better idea about its impact on energy consumption and CO_2 emissions. To complete the range of ideas for the subject, research will be under take to consider and simulate sustainable solutions and the impact on CO_2 emissions.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

Carbon Trust. 2003. Energy use in offices. http://www.carbon trust.co.uk/Publications/publicationdetail.htm?productid=ECG019&metaNoCache=1.

CND Project. 2009. What is Carbon Neutral Design? http://www.architecture.uwaterloo.ca/faculty_projects/terri/carbon-aia/carbon_definition.html.

Deutscher Bundestag. 1997. Zwischenbericht der Enquete Kommission ‘Schutz des Menschen und der Umwelt - Ziele und Rahmenbedingungen einer nachhaltig zukunftsverträglichen Entwicklung’ http://dip21.bundestag.de/ dip21/btd/ 13/074/1307400.pdf (last accessed 3-June-2009).

Emission Factors. 2006. http://www.sei.ie/Publications/Statistics_Publications/Emission_Factors.

Fuller, S. 2008. Life-Cycle Cost Analysis (LCCA). http://www.wbdg.org/resources/lcca.php.

Hassler, U. & Kohler, N. & Wanig, W. 1999. Umbau – uber die Zukunft des Baubestandes. Ersnt Wachsmuth Verlag. Tuebingen & Berlin, Germany.

Howley, M. & Ó Gallachóir, B. & Dennehy, E. 2008. Energy in Ireland 1990 – 2007.

Martinaitisa, V. & Kazakevicius, E. & Vitkauskasb, A. 2007. A two-factor method for appraising building renovation and energy efficiency improvement projects. *Energy Policy* 35 (2007): 192 – 201.

Pistohl, Wolfram. 2007. Handbuch der Gebäudetechnik. (Handbook Building Services) Werner Verlag, Köln, Germany.

Rawlinson, S. & Wilkes, M. & Langdon, D. 2008. Cost model: Office refurbishment. *PPA Subscription Magazine*.

Schulze Darup, Burkhard. 1996. Bauökologie (building ecologie). Bauverlag GmbH Wiesbaden und Berlin, Germany.

University College Cork. 2009. University College Cork Official Gazette.