Energy profiling in the life-cycle assessment of buildings

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Few would deny the centrality of environmental issues to the sustainability agenda. Even a cursory investigation of the existing building environmental assessment methods shows that a building's energy performance is usually a key element in the evaluation process and will constitute a significant portion of the overall assessment result. Thus, increased lifecycle energy efficiency in buildings lies at the heart of most approaches to sustainable urban design, development and assessment. Advances in information and communication technologies [ICTs] offer the opportunity to increase energy efficiency in the built environment by improving the way energy profiling tools and techniques are used to measure and inform the energy performance of buildings throughout their lifecycle. The exploitation of this potential is one of the goals of a current EU FP7 funded project, entitled 'intUBE - Intelligent Use of Buildings' Energy Information. This paper illustrates how the intUBE project will contribute to improving the measurement and evaluation of building energy performance. The paper also highlights the potential offered by the energy profiling tools and techniques being developed as part of the intUBE project to contribute to the assessment of sustainable urban development.

Keywords: assessment, buildings, energy, life-cycle, profiling

1 Introduction

There is much disagreement over the definition of sustainable development. Although there is agreement that sustainable development involves a process which enables the continuing resolution of conflicting priorities – with the ultimate aim of balancing the economic, environmental and social attributes of a particular situation. As no two situations can ever be exactly the same, this process needs to be repeated time and time again and which conflicting priorities are given preference is dependent upon the development context. However, few would deny the centrality of environmental issues to the sustainability agenda and even a cursory investigation of the existing building environmental assessment methods "*shows that a building's energy performance is usually the key element in the evaluation process and will constitute a significant portion of the overall assessment results*" (Hui 2002). Therefore lifecycle energy efficiency in buildings lies at the heart of most approaches to sustainable urban design, development and assessment. Consequently it is unsurprising that there are numerous studies which attempt to assess current and developing benchmarking criteria and buildings codes with reference to how they contribute to sustainable urban development (see for example Hui 2002, 2003; Olgyay and Herdt 2004; Zimmermann et al. 2005; Lee and Burnett 2008). One of the conclusions of this work is that the prescriptive nature of many current approaches to benchmarking criteria and sustainability assessments stultifies innovative approaches to sustainable building design. It is argued that *"[t]o provide greater design flexibility and encourage innovative design, it is important to move towards performance-based approaches and consider the integrated whole building performance in design and evaluation"*(Hui 2002).

Performance-based building energy codes set maximum allowable energy consumption levels without specifying the methods, materials and processes employed to achieve that that level. This approach can be used to allow trade-offs among different aspects of an assessment enabling a combination of measures that yield the best possible performance within certain budgetary constraints to be adopted (Hui 2003). However, performance based approaches to measuring sustainability require a life cycle assessment of the energy demand of buildings which accounts for embodied and operational energy consumption (Erlandsson and Borg 2003; Olgyay and Herdt 2004; Pushkar et al. 2005). In turn, this will demand improvements in the energy profiling tools and techniques used to measure the operational energy performance of buildings and the embodied energy within the materials and methods used in the construction and renovation of buildings.

Advances in information and communication technologies [ICTs] offer the opportunity to improve the way energy profiling tools and techniques are used to measure and inform the energy performance of buildings throughout their lifecycle. The exploitation of this potential is one of the goals of a current EU FP7 funded project, entitled *"intUBE - Intelligent Use of Buildings' Energy Information.* The overall aim of the project is to improve the energy performance of new and existing buildings via the intelligent use of buildings' energy information. It is vital that the tools and techniques developed by this project are not restricted to use in new building projects; as given current demolition rates, it will be necessary to improve the energy efficiency of existing buildings if we are to improve the sustainability of the built environment with any kind of propinquity.

Redeveloping rundown buildings can be more sustainable than demolishing them, as reuse reduces both the amount of embodied energy wasted through demolishing a building, and the (potential) energy used in constructing new ones.

Nonetheless, the energy used in running a building throughout its life cycle is much greater than that used in its construction. Therefore, if building redevelopment is to be thought of as a sustainable practice, renovation and refurbishment programmes must seek to bring about ever more energy efficient buildings.

The reminder of this paper illustrates the potential of the intUBE project to contribute to improving the measurement and evaluation of building energy performance during the whole lifecycle of buildings. To do so the main body of the paper is divided into three sections. The first introduces the reader to how energy profiling is used within the built environment and the potential provided by new ICTs for improving the lifecycle assessment of buildings. The second section outlines the approaches to energy profiling adopted within the intUBE project. By way of conclusion the final section of the paper highlights the potential offered by the energy profiling tools and techniques being developed within the intUBE project to contribute to the assessment of sustainable urban development.

2 Energy profiling in the lifecycle assessment of buildings

2.1 What is energy profiling?

Energy profiling, in the built environment, involves an analysis of the actual or predicted energy performance of buildings and/or an analysis of the embodied energy within the materials and methods used to construct buildings. The ultimate aim of this analysis is to improve the energy performance of buildings. Energy profiling usually involves comparisons between actual or predicted energy use and some type of benchmark or model intended to indicate regulatory requirements, average energy consumption or best practice. The focus of energy profiling can be individual buildings (Doukas et al. 2007), building types (Huang et al. 1991; Gaglia et al. 2007; Räsänen et al. 2008), organisations (Levermore 2000; Ó Gallachóir et al. 2007) or localities (Jaccard et al. 1997; Yao and Steemers 2005; Yamaguchi et al. 2007; Heiple and Sailor 2008). Energy profiling often involves calculations of both energy consumption and related carbon dioxide (CO2) emissions (Jaccard et al. 1997; Myer and Chaffee 1997). This approach is related to increasing environmental concerns which have brought about new government regulations associated with the assessment of the energy performance of buildings in many countries (Levine et al. 2007). This new regulatory environment combined with rising energy prices is stimulating a new interest in the role of energy profiling in measuring and optimising energy performance during the whole life cycle of domestic and commercial buildings (O'Donnell et al. 2004).

2.2 How is energy profiling applied?

2.2.1 The traditional approach

Traditionally two types of energy profiling are used in different phases of a buildings lifecycle. These can be thought of as design-phase energy profiling and operational-phase energy profiling. The former usually involves building energy simulations. It is conducted by design professionals (project team members, assisted by energy consultants) using building design and energy analysis software tools to analyse the energy performance of their designs. For example, the energy performance feedback provided by whole building energy analysis tools allows designers to assure equipment is properly sized for the design conditions of a given building and that the part-load performance of the building subsystems are optimised to provide a comfortable environment with the lowest possible energy costs (Jacobs and Henderson 2002). Design phase energy profiling could also include calculations of the embodied energy within the products and methods used in the construction of buildings, although this type of energy profiling in buildings is very poorly represented in current preconstruction energy analysis (Hellingsworth 2002).

Ideally operational-phase energy profiling is based on the actual energy consumption of the building or buildings under examination. It is used to analyse buildings energy demand and illustrate measures that building managers, owners or occupiers can use to improve energy efficiency within the running of those buildings on a daily basis. However much energy analysis for the operational phase of a buildings life cycle has been sporadic, typically working from historical metered data and focusing on bulk energy assessment (O'Donnell et al. 2004). This level of information leaves many possibilities for the reduction of heavily energy intensive energy consuming practices in both commercial and domestic buildings unknown. It also means that much of the information which is used to assess building energy performance is based on 'rules of thumb' rather than the measurement of that performance (Hand et al. 2008).

2.3 New technologies and new possibilities

Advances in the sophistication of computing technologies and real-time monitoring and metering technologies, combined with a reduction in their cost, offer the possibility of improving the information used in assessments of building energy performance. These technologies are enabling a rapid growth in the sophistication of energy profiling and encouraging an expansion of the use of building management systems (BMS) to manage the energy consumption of buildings. BMS are control systems for individual buildings or groups of buildings that use computers and microprocessors for monitoring, data storage and communication (Levermore 2000). BMS can be centrally located and communicate over telephone or Internet, with remote buildings having 'outstations' so that one energy manager can manage many buildings remotely. With energy meters and temperature, occupancy and lighting sensors connected to a BMS, faults can be detected manually or automated fault detection software can be used to avoid energy waste (Levine et al. 2007). With the advent of inexpensive, wireless sensors and advances in information technology, extensive monitoring via the Internet is possible (Clarke et al. 2004).

Advances in computing technologies are also facilitating improved techniques within design phase energy profiling. For example, new building information modelling software tools and techniques are enabling the creation and use of coordinated, internally consistent, computable information about a building. However the building information models [BIMs] produced are criticised for not explicitly incorporating feedback to the design phase of buildings or accounting for any changes made to buildings layout or fabric during construction(O'Donnell et al. 2004). In the absence of accurate data obtained from actual buildings in operation, designers need to rely on estimate values to feed in the data about loads, air flows, or heat transfer in order to carry out energy simulations (Hand et al. 2008). It is therefore suggested that BMS can be integrated with the building energy analysis software tools traditionally used in the design phase of buildings to enable BIMs to act as a data source which can be compared against actual building energy performance (O'Donnell et al. 2004). This would represent a dramatic move forward within energy profiling as it would enable architects, planners, building managers, consumers and owners to accurately visualise both the measured and predicted energy performance of a building. Interoperable performance analysis software tools capable of integrating the information stored in BMS with whole building energy simulation tools capable of emulating the building dynamic behaviour are under development (O'Donnell et al. 2004). There is also progress in this area in software tools designed for the domestic environment (Mills 2004; CSIRO 2008) which ultimately could enable 'smart neighbourhoods' that utilise design-phase and operational phase energy profiling to enable optimum energy use across a given community or local.

3 IntUBE and the future of energy profiling

3.1.1 The vision and the challenges

The intUBE project is developing new methods of integrating the ICTs used in the design and operation of buildings with the aim of facilitating improvements in the energy performance of buildings and the measurement of that performance. To do so, the project will develop new methods and tools which integrate design phase and operational phase energy profiling. The potential of this approach for supporting performance based energy assessments is great, as it could significantly improve the way in which the energy performance of buildings is assessed. However research has shown that there are many barriers to the adoption of the energy profiling software tools designed for professional use. This is problematic because a more generalised uptake of these tools is essential to improving the measurement and evaluation of building energy performance.

Barriers to the adoption of energy profiling software tools include the steep learning curve required to enable the use of energy simulation tools and the extensive data input required by those tools (Jacobs and Henderson 2002). The amount of time necessary for data entry when using energy analysis programs is repeatedly mentioned by researchers as one of the main obstacles to the generalised use of these tools (Bazjanac 2003, Neuberg et al. 2003, Hand et al. 2008, Laine et al. 2007, Klein et al. 2008). Poor interoperability between building information models and energy simulation tools also hinders a generalized use of energy analysis (Krygiel and Nies, 2008). Currently, the time required to process the geometry generated with a BIM authoring tool to conform to the format required by an energy analysis software amounts to up to 50% of the time a project team dedicates to performing energy simulations (Krygiel and Nies, 2008). The lack of accurate real-time consumption information on which to base energy simulations is also a barrier to the use of energy profiling in both the operational phase and design phase of buildings (O' Donnell 2004). While the level of expertise necessary to interpret the results of energy simulations is a further obstacle to the use of energy profiling in the design and operation of buildings (Schlueter and Thesseling 2008).

3.1.2 The way forward

The problems outlined above have lead to the infrequent application of comprehensive energy profiling in the design and/ or operation of buildings (Jacobs and Henderson 2002). Therefore it is important that the energy profiling tools and techniques developed within the intUBE project ameliorate as many of these issues as possible. To do so new approaches to the following are being developed:

- The integration of BIM authoring software and energy simulation software;
- The integration of simulation and real-time data capturing sensors;
- Evaluating and selecting amongst the design alternatives offered by energy simulation software.

In this way techniques and tools developed as part of the intUBE project should overcome many of the barriers to the generalised use of energy profiling as earlier research suggests that:

- By integrating BIM authoring software with energy simulation software much of the time taken to enter data into energy simulation software could be eliminated (Krygiel and Nies, 2008).
- By integrating simulation tools and real-time data capturing sensors within buildings the data on which energy simulations are based could be greatly improved, as could the accuracy of the energy profiles used to inform building operation (O' Donnell 2004). This approach also offers the opportunity to use real-time information about buildings to optimise building operation (Packham et al 2008).
- By providing a method of evaluating and choosing between the design alternatives offered by energy simulation tools the uptake of their use could be greatly improved (Schlueter and Thesseling 2008).

3.1.3 The philosophy of the intUBE approach

The first stage in producing simulated energy models or profiles of any given building is the development of a building information model [BIM] for that building. Essentially a BIM is coordinated, consistent, computable information about a building stored in a single data repository. A BIM can represent an existing building or a building which is at the design stage. However, standard BIMs do not contain all of the data necessary for simulating energy use in a building. Therefore it will be necessary to combine the data from a buildings' BIM with additional information, such as building use, HVAC system details, building spaces and occupancy levels, to create an Energy BIM. This process will enable the production of detailed simulated energy profiles for a building. These simulations of a buildings' energy performance will then be analysed to identify design strategies and/ or building control strategies. This information will then be stored in a relational database creating a reference model of simulated building and systems performance (See figure 1).

In process A 1 the BIM is developed and the data necessary for conducting energy simulations is added to create an Energy BIM. In process A2 the energy simulations are conducted based on historical weather data. In process A3 the energy simulations are analysed to identify optimum building design/building control strategies which are then used to create the reference model in process A4

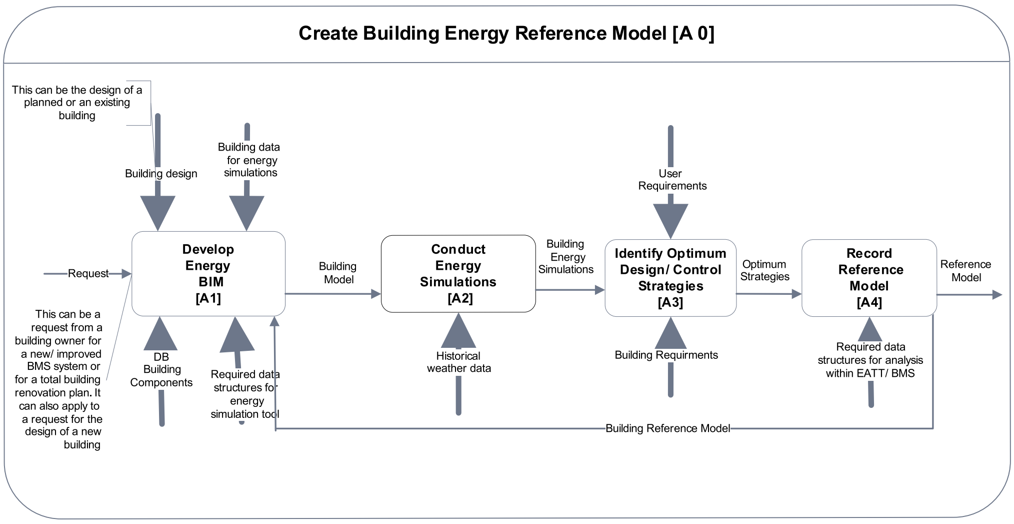

Figure 1 Create building energy reference model

At the design stage of a buildings lifecycle [or at the redesign stage in the case of building renovation] the reference model will be used to draw comparisons between different design alternatives. The system will include an environmental assessment trade-off tool [EATT] which will enable the choices necessary to the optimisation of building energy performance to be made at the early stages of the design process (See figure 2). This is highly advantageous because it is at the early stages of design that the greatest opportunity for cost-effective energy measures occurs (Schlueter and Thesseling 2008). The EATT tool will use a lifecycle cost assessment, a lifecycle assessment of the embodied energy used within building construction /renovation and an assessment of the energy performance of the building. Multi-criteria decision analysis (MCDA) theory, also known as multi-criteria decision making (MCDM), will be used to explore the trade-offs between different variables and to address their impact on the overall design of the building (See figure 2 and Loh et al 2008 and Loh et al forthcoming). The output of this stage will be a building model which illustrates the most energy efficient building design or renovation plan possible within given constraints. This building model will form the basis of a building reference model which can then be extended to inform building operation once the construction/ renovation process is complete.

The Lifecycle Assessment [LCA] will be conducted by a software tool, such as SimaPro (See SimaPro 2008), which enables the measurement of the energy embodied within the life cycle of the construction materials to be measured, as well as the energy embodied within the construction methods.

The Environmental Impact Analysis [EIA] and the Lifecycle Cost Assessment (LCCA) will be conducted by a tool such as Integrated Environmental Solutions (IES) VE-WARE (See IES 2008). The LCCA will include capital build cost and annual maintenance and running costs, while the EIA will include energy use and CO_2 emissions.

The results from EIA, LCA and LCCA assessments will be input into the Environmental Assessment Trade-off Tool (EATT) which will enable design decisions to be made with full comprehension of both the upside and downside of a particular choice with regard to CO_2 emissions, energy consumption, build costs and running costs.

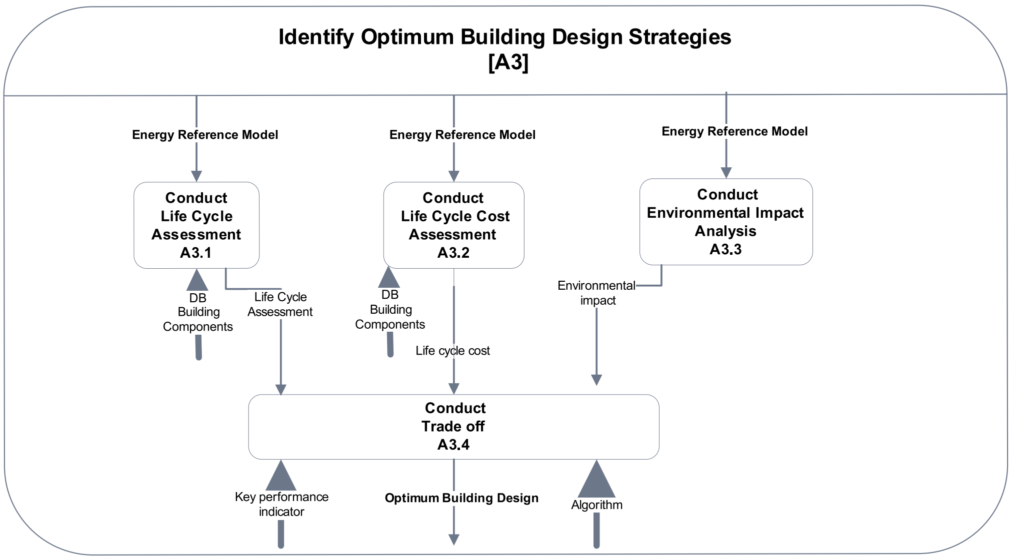

Figure 2 Identify Optimum Building Design Strategies

The reference model used to inform building operation will be more detailed than that used during design stage energy profiling. This is because it will be necessary to model the buildings control system in much more detail than is the case during the design phase of buildings. Therefore in the case of buildings which were modelled during their design further building information will have to be added to the reference model. In the case of existing building which are being renovated the reference model will have to be developed from scratch. During the operational phase of a building the reference model will provide a data resource which will be used to support the intelligent control of a buildings' management system (See figure 3). The intelligent control of a buildings' management system will be achieved by using the optimum building control strategies within the reference model to inform building control. It will also be possible, to further tailor building control. This will be achieved by using the information concerning a buildings simulated thermodynamics and simulated response to HVAC etc, to train various computationally intelligent algorithms and send control decisions back via the BMS that take into account ambient weather conditions and building occupancy. In this way the energy profiling system developed will enable the building management system to optimise building energy performance while maintaining the thermal comfort of the buildings occupants.

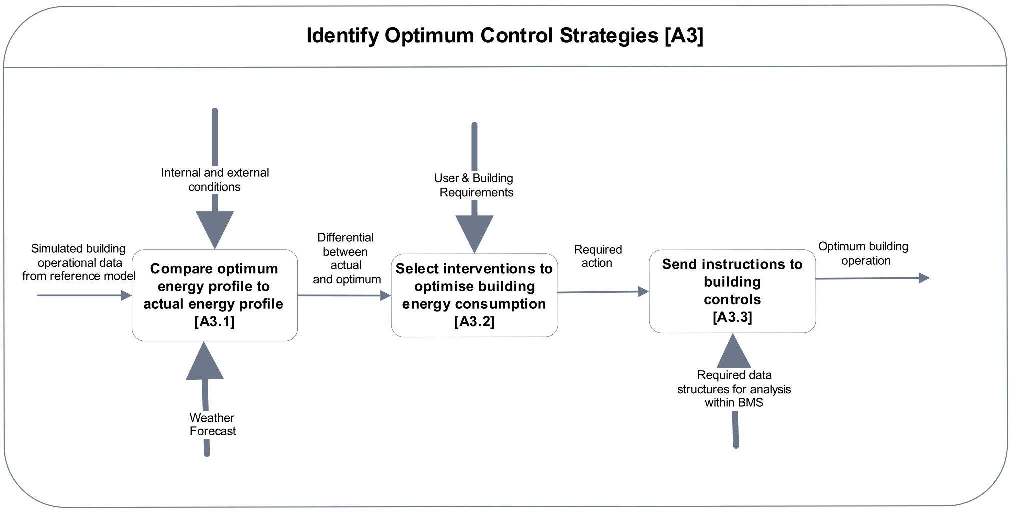

Figure 3 Identify Optimum Control Strategies

Conclusions

The intUBE project will contribute to *"[t]he long-term vision held by many in the building science community: virtual (collaborative) 'life-cycle' building tools that simulate actual buildings and their construction coupled with intelligent systems that monitor and archive design intent and performance and feed the results back to the simulation tools, which, in turn, grow more refined through integrating better empirical data"*(Mills 2004). The potential offered by this approach to contribute to the assessment of sustainable urban development is great. Firstly the tools and techniques described in this paper will enable those involved in the design of buildings, or developing renovation plans to accurately measure the energy performance of their designs and renovation proposals. In doing so the necessary information for adhering to performance based energy codes will be provided. Secondly the approach adopted also offers the opportunity to inform performance based energy codes by improving the building energy performance data on which they are based. Thirdly the tools and techniques described in this paper provide a method of evaluating and choosing between the design alternatives offered by energy simulation tools which could be used to simplify the compliance process once performance based energy codes have been developed and implemented.

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