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BUILDINGPI: A FUTURE TOOL FOR BUILDING LIFE CYCLE ANALYSIS

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ABSTRACT

Traditionally building simulation models are used at the design phase of a building project. These models are used to optimise various design alternatives, reduce energy consumption and cost. Building performance assessment for the operational phase of a buildings life cycle is sporadic, typically working from historical metered data and focusing on bulk energy assessment. Building Management Systems (BMS) do not explicitly incorporate feedback to the design phase or account for any changes, which have been made to building layout or fabric during construction. This paper discuses a proposal to develop an Industry Foundation Classes (IFC) compliant data visualisation tool Building Performance Indicator (BuildingPI) for performance metric and performance effectiveness ratio evaluation.

INTRODUCTION

In response to the Kyoto protocol, the European Union (EU) introduced new legislation (directive 2002/91/EC). This directive necessitates individual member states implement sets of measures for the reduction of CO_2 emissions by 2006. Predominant focus is on building energy consumption and it is envisioned that the legislation will dramatically alter building operation leading to improved performance and a reduction in energy usage. The Irish government propose a large building/facility based annual threshold for total CO_2 production with financial penalties for buildings or industries that are found to be exceeding this predefined limit (directive 2003/87/EC). However, if the building is found to be operating efficiently, it will be below its permitted threshold and will be allowed to sell credits to less efficient buildings. Thus the directive may become a source of income for many efficiently operating businesses.

With the impending threat of financial penalties for inefficient buildings or a potential new source of income for exceedingly efficient buildings, performance of buildings must become a priority. In order to successfully improve the building's performance, a sustainable approach to analysis must be undertaken. The future of sustainable buildings lies with the incorporation of a building life cycle performance monitoring and assessment methodology. The current nature of building life cycle assessment is fragmented with little or no feedback from the design stage. Goals set down by the AEC community tend to get lost as the building evolves through its many life cycle stages. There are a plethora of performance assessment methodologies on both sides of the Atlantic, however each methodology has associated limitations and much future work is required to amend these inadequacies (Hitchcock 2003).

Interoperability offered by Industry Foundation Classes (IFC) based Building Information Model (BIM) provides a framework to store information, across the entire project life cycle. Presently IFC, developed by the International Alliance for Interoperability (IAI 2002), are the only non-proprietary intelligent, comprehensive and universal data model of buildings (Bazjanac 2003). They are a set of rules regulations/protocols that describe and store building information. A BIM is a static instantiation of IFC data model that describes a building at a particular instance in time.

The latest version, IFC2*x*2 incorporate model extensions that specifically facilitate interoperability among post CAD applications (Bazjanac 2003), e.g. performance analysis, building simulation or Computational Fluid Dynamics (CFD) programs.

Using IFC as a standard for data storage, building geometric data can be seamlessly transferred among various IFC-compliant software packages. The IFC HVAC interface (Bazjanac and Maile 2004) facilitates seamless transfer of EnergyPlus™ HVAC component information to the BIM. Morrissey et al (2004) describes in detail a performance assessment methodology through which performance related information for a particular HVAC component is referenced in a BIM but stored independently.

The Building Energy Monitoring Analysing and Controlling (BEMAC) framework offers the required

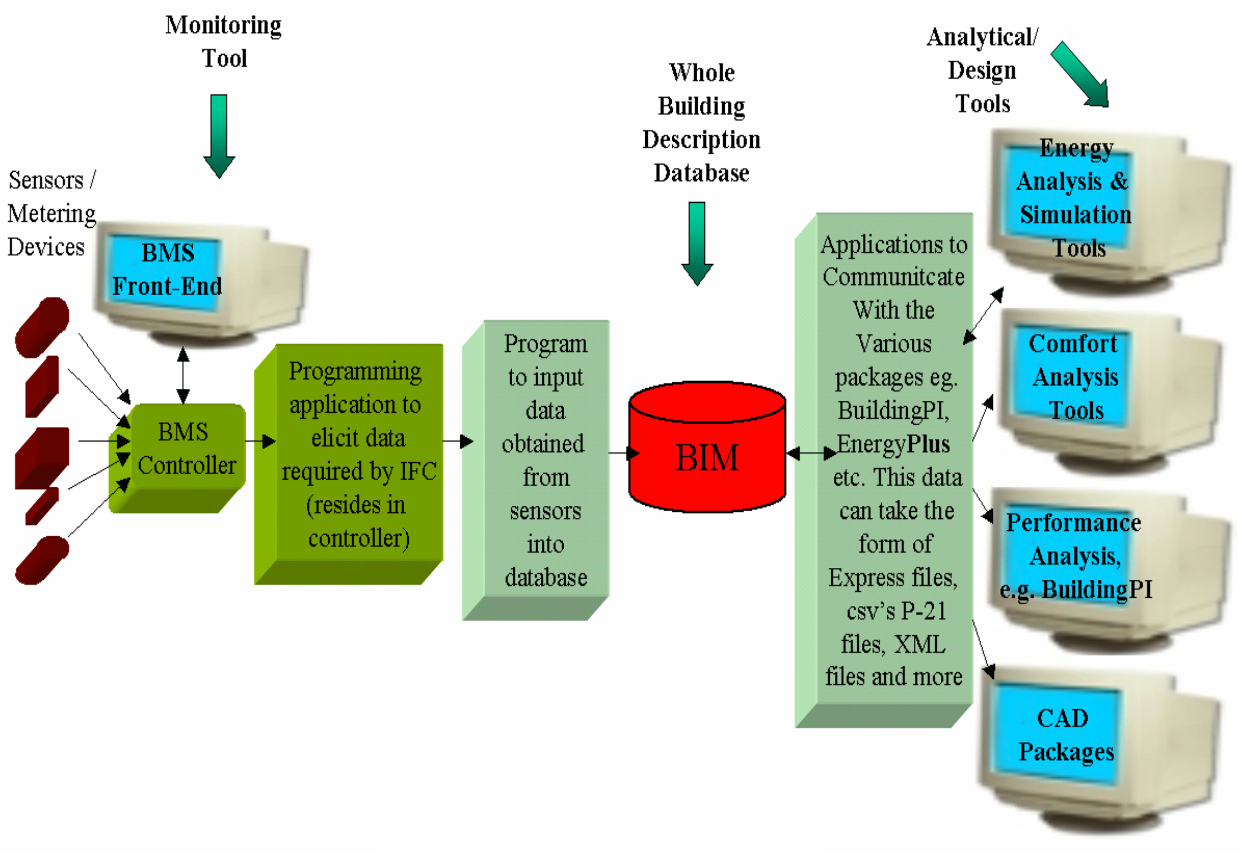


Figure1: The BEMAC Framework

environment for building lifecycle performance assessment (Figure 1).

It was developed as an integrated environment for obtaining, formatting, storing, retrieving and controlling data (O'Sullivan et al. 2003). One of its objectives was to be extensible and applicable to other future buildings; thus it was essential that it comply with the principals of standardisation and open systems. Among such standards employed were the Standard for the Exchange of Product Model Data (STEP 2002) and IFC for the transfer and storage of data between various analysis and design tools and the BIM. The hub of the BEMAC framework is the BIM, which is an instantiation of the IFC data model. IFC was chosen as the environment in which to store all relevant building related information.

BEMAC is primarily associated with building energy usage and is employed through standard industry software Building Management Systems (BMS) and emerging interoperable software tools such as BuildingPI. Programs have been written to convert data to the necessary formats for end user software, e.g. programme required to instantiate reference to sensor data in the BIM. A means of building performance analysis is now required within the context of the BEMAC framework.

BUILDING PERFORMANCE METRICS

Hitchcock (2003) defines building performance metrics as a methodology for explicit representation of quantitative criteria in a dynamic and structured format. A performance metric should fundamentally measure, reflect or significantly influence a particular performance objective. Each metric must be capable of being predicted or measured at each stage of the building life cycle so its objective can be evaluated. Performance objectives and their constituent metrics may vary over time. Objectives can be modified or elaborated as a project progresses. A data model for tracking performance metrics must therefore be capable of archiving a history of these changes across the life cycle of a building (Figure 2). For any given project, numerous design alternatives require evaluation, i.e. numerous BIM's are initially created, each necessitating performance metric programming for the specification and design phases. At design phase BuildingPI can be used as an evaluation tool to enhance estimation of building life cycle cost.

To differentiate between a particular performance metric for the various stages of the building life cycle, "views" of the BIM are instantiated, e.g. predicted simulated metric at design phase will differ dramatically from the predicted calibrated metric at operational phase. Figure 2 highlights how each view will represent performance metrics for a particular stage of the building life cycle. The following steps explain the context of the various BuildingPI accessible views with relation to the entire building life cycle.

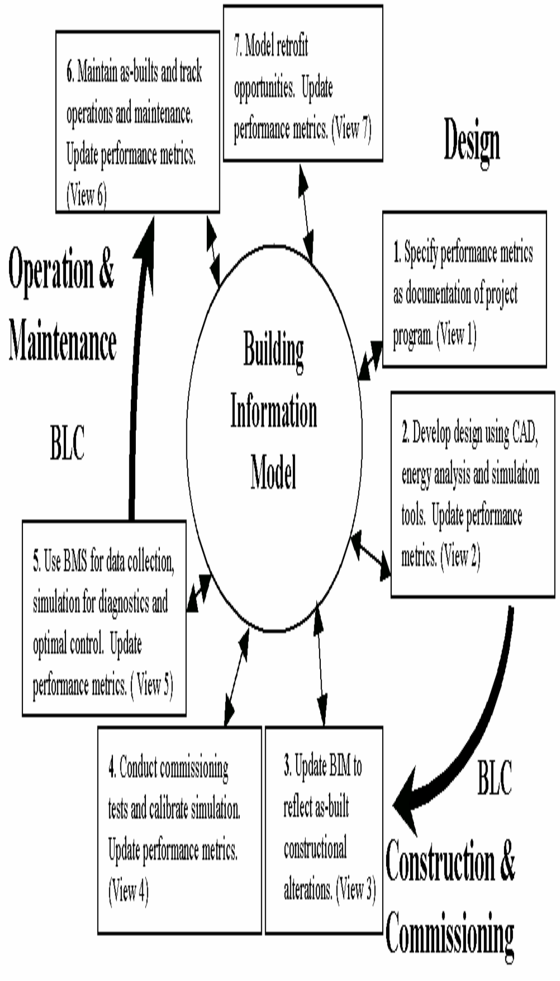


Figure 2: The Building Life Cycle

1. Key performance metrics are selected and recorded in the BIM to represent desired building performance objectives;
2. Results from the final design simulations are summarised in an updated set of performance metrics, which establish a set of benchmarks for use in commissioning. BIM is updated. Along with the design stage information model, these metrics more clearly document design intent;
3. BIM is updated to reflect as-built constructional changes. Through energy simulation the impacts of these changes can be quickly and comprehensively evaluated if performance data is referenced in the BIM;
4. Commissioning tests are conducted to determine if the design intent was met (Step 3). Also at this stage, in-situ test results are used to re-calibrate simulation models and to update the appropriate performance metrics;
5. The BMS is used to continuously monitor the building and provide data for calibration of the simulation model;
6. BuildingPI will analyse actual operation against current performance benchmarks to track operations and maintenance (O&M) actions. BIM is updated to include a reference to BMS data;
7. The BIM can also be linked to a retrofit simulation tool that would allow the facility manager to explore the energy savings from possible major or minor system changes.

Metracker (Hitchcock 2002) is a prototype performance metric tracking tool based on IFC2.0. This pilot tool successfully views performance metrics from each phase of the building life cycle. Displaying appropriate performance metrics for a particular building is of paramount importance. Therefore the initial metric selection at preliminary design phase is crucial for periodic analysis. Hindering this process is the absence of a complete standardised set of building performance metrics. Most recent and appropriate efforts to standardise performance metrics are included as an intricate part of the Laboratories for the 21st Century Program (A-Team, 2001). These standardised metrics were developed specifically for buildings with laboratory spaces, but can be adapted to all building types. BuildingPI will display a project relevant subset of these standardised performance metrics through graphing simulated, measured and benchmark performance metrics for a specific building or component.

BUILDINGPI TOOL

BuildingPI will be a software tool that utilises a Graphical User Interface (GUI) to facilitate visualisation of performance metrics and building/component performance effectiveness ratios across the entire building life cycle. These performance metrics and performance effectiveness ratios may be compared by facilities managers and building owners. BuildingPI is currently under development; an operational prototype is expected for autumn 2004.

Need for such tool

BMS seldom if ever incorporate feedback to the building's design objectives. Sizable amounts of performance data are available from various sources such as Comma Separated Variable (CSV) files from a BMS and building energy simulation tools such as DOE2 or EnergyPlus^{TM}. Individually these sets of data offer limited information to facilities managers or building owners. Sets of standardised performance metrics offer a quantitative means for more prudent building appraisal. A means to scrutinise these performance metrics is required. Communicating these results effectively, efficiently and flexibly to users such as designers, energy managers and policy maker is the key (Prazeres et al. 2003). Information must be communicated in a manner that addresses the needs of the possible user types. Facilities managers are often left to interpret sensor data without a quantitative basis for how a building should perform. A tool that incorporates comparative analysis through data visualisation for each stage of the building life cycle through benchmarking techniques would be of significant benefit.

Currently, there is an absence of an IFC2*x*2 based data visualisation tool for performance related information generated for each stage of the building life cycle. "Metracker" is presently the only IFC compatible performance analysis tool cognisant of objective and metric data. It is however limited to IFC2.0. Unlike IFC2*x*2, IFC2.0 uses building element proxies to represent HVAC components in a BIM. This requires time-consuming manual entry of the individual HVAC components and is difficult to maintain. "Metracker" only displays metric values on a primary axis and does not display effectiveness ratios. It also lacks recommendations to the end user, which would be useful for improving certain metrics.

Goals

BuildingPI is being developed to address this void. It will provide explicit visualisation of performance metric data for all stages of the building life cycle (e.g. design, commissioning, operation, retrofit etc). It is also envisaged that BuildingPI will output building performance effectiveness ratios (Morrissey et al. 2004). This is a significant improvement on graphs of building management system output depicting energy use intensity (EUI) and Metracker's single axis graphs. On completion of graphical analysis, BuildingPI will also facilitate storage of end user comments on performance analysis conducted in the IFC2*x*2 BIM.

Benefits

BuildingPI will highlight poorly performing HVAC systems through visualisation of performance metrics and performance effectiveness ratios. It will be the responsibility of the building operator to react appropriately to the results presented. It will enable end users scrutinise performance metrics with the assistance of building/component performance effectiveness ratios, thus offering more detailed energy analysis for a building or HVAC component (Morrissey et al 2004).

National University of Ireland, Cork (NUIC) is a large campus facility that has already quantified its annual emissions in terms of tonnes of CO_2 (Howley 2003). A non-negotiable goal of the NUIC energy committee is that the campus becomes a trader of emission credits. BuildingPI will assist meeting this goal through displaying building/component performance in the "Mardyke Arena" sports centre (test building for BuildingPI tool). The tool will also provide recommendations to facilities managers and others, based on its perception of how systems and components are performing.

IMPLEMENTATION

The tool will require performance data from various sources (i.e. initial benchmark estimates) for building /component energy consumption, sensor values and optimal simulated performance from an energy simulation package. Figure 3 highlights the process by which BuildingPI will display performance metrics and effectiveness ratios. The following steps (1-8) describe the required data flow for BuildingPI output.

1) Benchmark performance metrics will be computed from Building codes and catalogue data. Hand calculations or preliminary energy simulation will be recorded in standard CSV format;
2) BMS will record output (e.g. sensor values, damper position) in standard CSV format;
3) Energy simulation package will generate output (node properties, damper position) in standard CSV format;
4) Using steps 1, 2 and 3 performance metrics will be calculated and stored in eXtensible Markup Language (XML version 1.0) files for each time step as outlined by Morrissey et al. (2004). The XML schema adopted is for one metric

value to be stored per time step complying with one performance metric per file;

5) User will select performance metric and time period from the BuildingPI GUI;
6) BuildingPI will extract performance metric XML file names and locations from the BIM;
7) XML files will be processed through BuildingPI;
8) Performance metric data and performance effectiveness ratios will be displayed to the user.

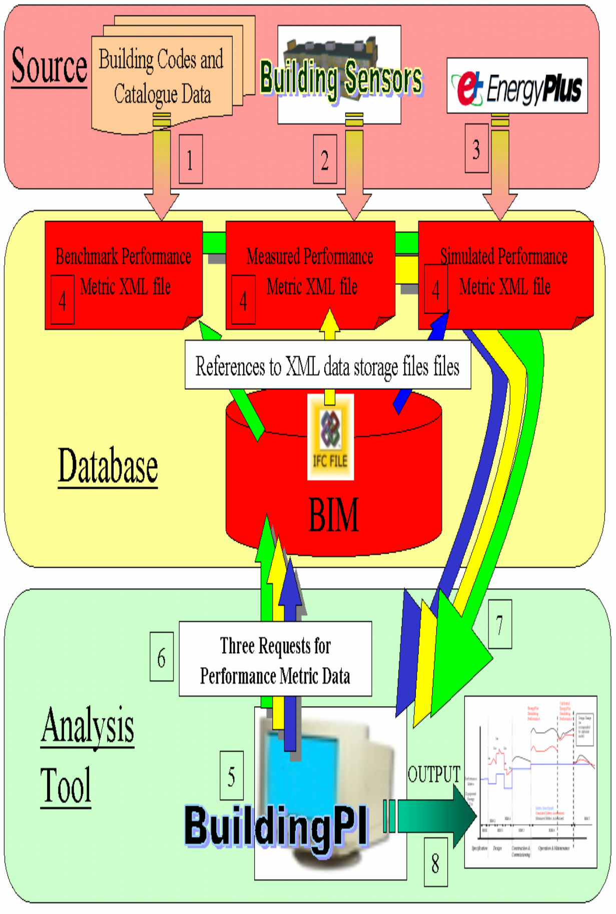
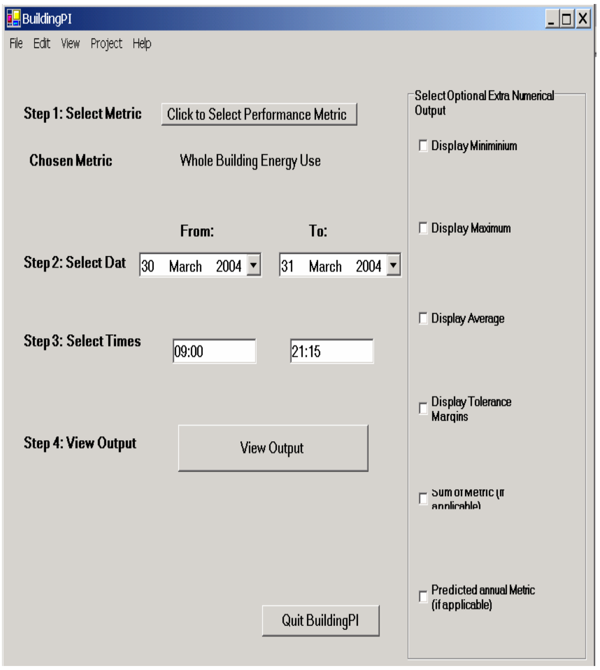


Figure 3: Data flow chart for generation of BuildingPI output

Functionality of the tool

The purpose of the BuildingPI tool will be to present performance metric data in a practical and useful manner. The tool's GUI (Figure 4) will be a windows style program to ensure ease of use for facilities managers and building owners.

A set of performance metrics has been developed in accordance with the laboratories for the 21st centaury programme (A-Team 2001). The metrics to be used are a subset of whole building performance metrics. Theoretically many of the same quantitative performance metrics could be categorised under many different performance objectives (qualitative); e.g. boiler efficiency metric could by available under "minimise building energy use" and "minimise heating systems energy consumption" objectives.



Step 1: Select Metric

Chosen Metric Whole Building Energy Use

Step 2: Select Dat From: 30 March 2004 To: 31 March 2004

Step 3: Select Times 09:00 21:15

Step 4: View Output

Select Optional Extra Numerical Output

☐ Display Minimium

☐ Display Maximum

☐ Display Average

☐ Display Tolerance Margins

☐ Sum of Metric (if applicable)

☐ Predicted annual Metric (if applicable)

Figure 4: BuildingPI GUI

For ease of use and to avoid end user confusion, a convention of one metric per objective will be adopted. To circumvent possible ambiguity with regard to viewing output, BuildingPI metrics will only be viewed individually. The time period for analysis along with a selection of tick boxes will also be available for selection depending on the focus and quantity of output required by the user.

Output will be in user selectable 2-D graph form (Vector, 2D XY, Time Series) as shown in Figure 5, with the graph type dependant on the metric selected. For each metric, a set of tabbed graphs will be produced to facilitate varying degrees of analysis. The primary graph will solely display the metric in question. Subsequent graphs will include relevant temperatures, flow rates, energy transfer rates, effectiveness ratios, etc. that assist understanding building/component operation. A project "save" option will facilitate project storage for referral and update at a later time. A facility that allows comments, based upon performance metric analysis to be stored in the BIM will also be incorporated into the tool.

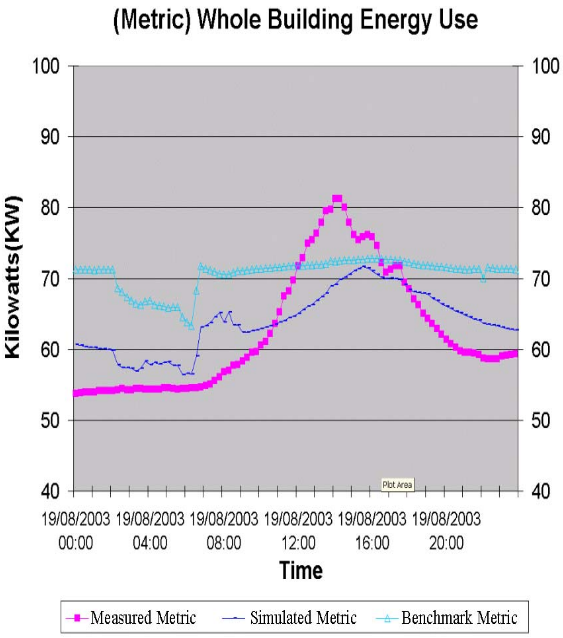


Figure 5: Sample BulidingPI output

Example of BuildingPI use

The Mardyke Arena was selected as the demonstration facility for the BuildingPI tool. This €18.5 million sports centre located in University College Cork, Ireland was only recently opened. The 6511m^2 indoor sports complex consists of a 6 lane, 25 meter swimming pool, a 1400m^2 sports hall, a 425m^2 main fitness suite, along with offices, meeting rooms, performance laboratories, dance studios, catering facilities and a second newly created overflow fitness suite. The focus of this demonstration is the Pools Zone. It contains one multipurpose 12.5 x 25 meter pool and a smaller children's 7 x 6 meter pool both of which have a constant temperature set point of 27^{o}C. It is serviced by a VAV full fresh air system consisting of an Air-to-Air Flat plate heat exchanger, a heating coil and a Variable Air Volume fan. The zone air set point is 28^{o}C with a relative humidity dead band of 40-60%. Hot water is supplied to the heating circuit from central gas fired boilers.

BIM Creation

The geometric representation of the building was created in Archicad^{TM}. The generated BIM was validated in Solibri Model Checker^{TM} and stored. An EnergyPlus^{TM} input data file was created from the BIM by the process outlined by Bazjanac (2001).

Description of Energy Simulation Model

Swimming pools, both indoor and outdoor are notoriously difficult to simulate. Two approaches were investigated 1) Rate of water evaporation from a pool surface (Jones 1997) and 2) DOE sponsored Energy Smart Pools Software model (2002). The Energy Smart Pools Software model was not applicable, as it would not run on a modern version of Windows^{TM} (2000 or XP). Jones method, though not easy to adapt for EnergyPlus^{TM} accounted for a latent load that was dependant directly on the number of pool occupants and activity level. Zone occupancy profiles were obtained from the BMS. Scheduled latent loads were based on occupancy and on averaged activity level per methodology outlined by Jones. An area equal to that of the pools surfaces was modelled as a slab of uniform temperature (27^{o}C) to represent the pools sensible load.

Table 1: Objectives and metrics for the primary AHU in Mardyke Arena

HVAC Component	Performance Objective	Metric
Boiler	Minimise Energy use	EUI (KW) Efficiency
Air-to-Air Heat Recovery	Maximise Energy Transfer	Energy Transfer Rate (KW)
	Efficiency	Efficiency (%)
Pumps	Minimise Energy Use	EUI (KW)
Heat Exchangers	Maximise Efficiency	Effectiveness (ratio)
	Rate of Energy Transfer	Energy Transfer (KW)
Fans (Supply and Return)	Minimise Energy Use	EUI (KW)
	Fan Efficiency	Efficiency V Air Flow

All performance data for HVAC equipment was obtained from 'operation and maintenance' manuals. Through comparison of BMS data and initial energy simulation output, the model will be calibrated to more accurately emulate the building (BuildingPI requires a calibrated simulation model for accurate performance metric and performance effectiveness ratio analysis).

The buildings HVAC components were instantiated in the BIM with the IFC HVAC Interface to EnergyPlus™ (Bazjanac et al. 2004). Performance metrics for the prototype pool system are shown in Table 1. References to building performance metrics will be added to the BIM (Morrissey et al. 2004).

BuildingPI will query the BIM and elicit the performance metric data file locations. BuildingPI will extract the data and display relevant performance metrics to the user. Figure 6 illustrates the process through which a BIM evolves and the role of BuildingPI in the context of an interoperable environment.

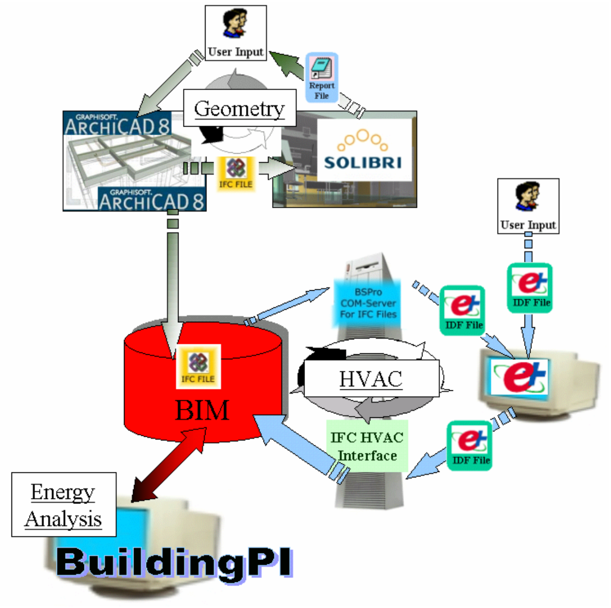


Figure 6: Example of data transfer through IFC Compliant Packages

WORK IN PROGRESS

To date the methodology behind the BuildingPI tool has been established. This includes the framework in which BuildingPI will reside (BEMAC), the programming language through which the tool will be developed and performance metrics have been programmed for the operational phase of the test building. The style of the end user interface has also been finalised.

The Future version of the tool will include extended functionality to encapsulate whole building life cycle analysis for a second building prototype.

CONCLUSION

Implementation of EU directive 2003/87/EC necessitates a reduction of building energy consumption. The concept of building life cycle performance analysis through the IFC based BEMAC framework will enhance the prospects of achieving the required reduction in building energy usage.

Energy simulation models act as a data source for simulated performance metric generation. A theoretical level of building performance will be displayed against which actual building operation can be compared. BuildingPI (a future interoperable performance analysis software tool currently in development) will display building performance metrics and performance effectiveness ratios to assist building energy analysis.

Efficient use of BuildingPI will be reliant on vigilant building operators to act accordingly, when results displayed indicate an unacceptable level of building energy performance.

ACKNOWLEDGMENT

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