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Specification of an Information Delivery Tool to Support Optimal Holistic Environmental and Energy Management in Buildings

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ABSTRACT

Building performance assessment for the operational phase of a building's life cycle is heuristic, typically working from available historical metered data and focusing on bulk energy assessment. Building Management Systems are used in the operational phase of the building to control the building's internal environment according to the design criteria outlined during the design phase.

Recent developments in mechanisms that communicate building performance such as standardised building performance objectives and metrics enable the use of the output from whole building energy simulation tools by non-technical personnel and all project stakeholders. This paper proposes to specify and demonstrate the utilisation of an Information Delivery Tool that supports optimum holistic environmental and energy analysis aimed at an established profile of building managers utilising standardised performance objectives and metrics.

INTRODUCTION

Building managers do not have the data, information and tools needed to provide optimal results with respect to building performance management (Piette, Kinney, and Haves 2001). Maintenance records, energy and efficiency reports and trend analysis should be accessible to building managers but in many cases are not (Piette, Kinney, and Haves 2001). If used correctly measured HVAC time-series data are descriptive of building performance but are wholly dependent on strict boundary conditions such as weather and control strategies.

Present proprietary Building Management Systems (BMS), Energy Management Systems (EMS) and Monitoring and Targeting (M&T) systems are ineffective because the respective user interfaces do not account for changes that occur across the Building life Cycle (BLC). A fundamental requirement exists for a qualitative and quantitative description of building performance that is easily understood by all life cycle stakeholders (Augenbroe and Park 2005). At operation this requirement enables an explicit coupling of updated design intent with actual building performance.

Most building managers track how energy is used solely on the monthly utility bill (Piette, Kinney, and Haves 2001). Monthly consumption values can be benchmarked against previous monthly values or against energy consumption for an identical time period from a previous year. When evaluating annual gross energy consumption of a building common practice has been to compare a building's Energy Use Intensity (EUI measured in kWh/m^2/yr) with previous performance or with a statistical set of other similar buildings. Normative comparison methods include CIBSE Guide F, Energy Star, Dutch NEN 2916 (EnergyStar 1992; CIBSE 2004; NEN 1999). The GSA Building Performance Toolkit offers normative and objective performance indicators which in turn enable dialogue between different project stakeholders (Augenbroe and Park 2005). However each and every building is unique and what if all the buildings in the sample set are inefficient? (Federspiel, Zhang, and Arens 2002).

Building performance, building thermo-physical conditions and energy flows are a complicated series of heat transfers and energy balances. In the context of building management an 'ideal' may be considered an up to date virtual representation or benchmark of a building's energy performance for comparison with measured data. Whole building energy simulation models are capable of providing 'ideal' quantitative performance data at all phases of the BLC. In practice whole building energy simulation is seldom used across the BLC especially during operation (Papamichael and Pal 2002). Research initiatives have shown the merits of utilising whole building energy simulation at operation. However significant energy simulation expertise in is required.

Systematic procedures to address inefficient building operation are beginning to emerge (Mills et al. 2004; Hampton 2003; Claridge et al. 1994). A 'continuous commissioning' monitoring process is applied to tune building systems for optimal comfort and peak efficiency based on current operational requirements. These methods have saved an average of over 20% of the total energy cost and over 30 % of the heating and cooling cost in over eighty buildings (Claridge et al. 1994). (Mills et al. 2004) deduced a saving of $18 billion or more could be achieved annually if systematic commissioning was applied to the entire U.S. commercial building stock. Buildings are an asset and it is imperative that clients demand more effectively operated assets. Researchers have demonstrated success by bringing in experts who use their knowledge, experience and resources to 'fix' building systems (Baumann 2005; Baumann 2004). Few tools are available to the on-site building manager to conduct such improvements (Piette, Kinney, and Haves 2001). The knowledge, experience, and role of building managers must be considered (O'Donnell 2008). Performance optimisation is replaced by benchmarking against previously established performance.

A customised information delivery tool must support:

- The ability to compare 'ideal' performance with measured data and account for the inherent complexity of building performance (O'Donnell 2008);
- User profile of the end user (building manager);
- A technique capable of capturing the interconnected complexity of the different aspects of building performance, Scenario modelling (O'Donnell 2008);
- A technique that describes all Performance Objects, hierarchies of Standardised Performance Objectives and Metrics (Hitchcock 2003).

USER INTERFACE SPECIFICATIONS

"There is a definite challenge ahead for the building industry to develop and deliver graphical displays that can convey complex interactions to operators with limited technical training - all of which can be easily run on readily available desktop computers with only a few keystrokes or mouse clicks" (Haberl, Sparks, and Culp 1996)

A current void exists with respect to communication of simulation results to non technical stakeholders. Two types of software tool offer the potential to assist the building manager; a visualisation tool or a data mining tool (Shneiderman 2002). A hybrid approach has not yet been developed for the AEC/FM industry. The tool's user interface must be developed specifically for the established profile of the building manager (O'Donnell 2008). Extensive domain knowledge is required to effectively data mine, therefore a visualisation approach is preferred. Only necessary functionality is to be included in a user interface and unnecessary functionality can be inhibitive to some building managers (Agarwal, Prasad, and Zanino 1996). User selections should be minimised and data processing techniques should be automated (Morrissey 2006).

Information Delivery Tool specifications are underpinned by established building manager profiles (RPS 2007; Geoghegan and Fenner 2007; Ahern 2006). Figure 1 depicts the identified sequence of actions as an building manager navigates the user interface. The building manager selects the building and analysis time period, for example today or July 1 to July 31 of this year. The default view is real-time. Based on these selections the building manager is presented with three different performance views from which a specific aspect of performance. For example select AHU 1 or Heating Coil 1. Subsequently, view specific performance objectives and metrics or the metric combinations from a selection of relevant operational scenarios. Based on observed performance a report can be generated and the analysis session saved.

Requirements deemed essential during the profiling exercise of building managers identified that unambiguous guidance is necessary when making a selection. The established user profile also stated a preference for diagrammatic navigation, where possible selections should be assisted by appropriate interactive schematics for the following Performance Objects; *site layout, building floor, floor plan, HVAC systems etc.* These interactive schematics should have clearly labelled, well defined boundaries and incorporate active links e.g. each zone should be clearly defined on a floor plan, clicking on the zone should activate selection.

Reliance on end user memory load should be reduced by the intuitive and repetitive nature of tool navigation. Consistency would be provided by the master tree of building objects. It is intended to be used as both a frame of navigational reference and also for experienced users who may wish to investigate specific aspects of building or HVAC system performance.

The center (navigation) portion of Figure 1 depicts three *views* of building performance. Views A and B, the *Zone Performance Table* (Table 1) and the *System Performance Table* (Table 2), are specified to guide the building manager toward improper indoor environmental conditions and inefficient system operation respectively. Table 1 illustrates the specified layout of the Zone Performance Table. The table includes a complete list of conditioned zones in the building, ordered according to greatest discrepancy from a predefined critical zone environmental metric, for example temperature in a chilled store or thermal comfort for an occupied space (Geoghegan and Fenner 2007). Zone names are listed in accordance with the format specified in (Gillespie et al. 2006), for example Z1-2:Hall. 'Z1-2' denotes zone two on floor one and the end use description 'Hall' is included to remove any additional ambiguity. The indicator type is predefined for each metric and is an average over the time period or percentage of time it lies outside a certain tolerance range. The Actual, Ideal and Error columns quantify the variation between benchmarked (source, whole building energy simulation) and measured (source, sensor data) performance.

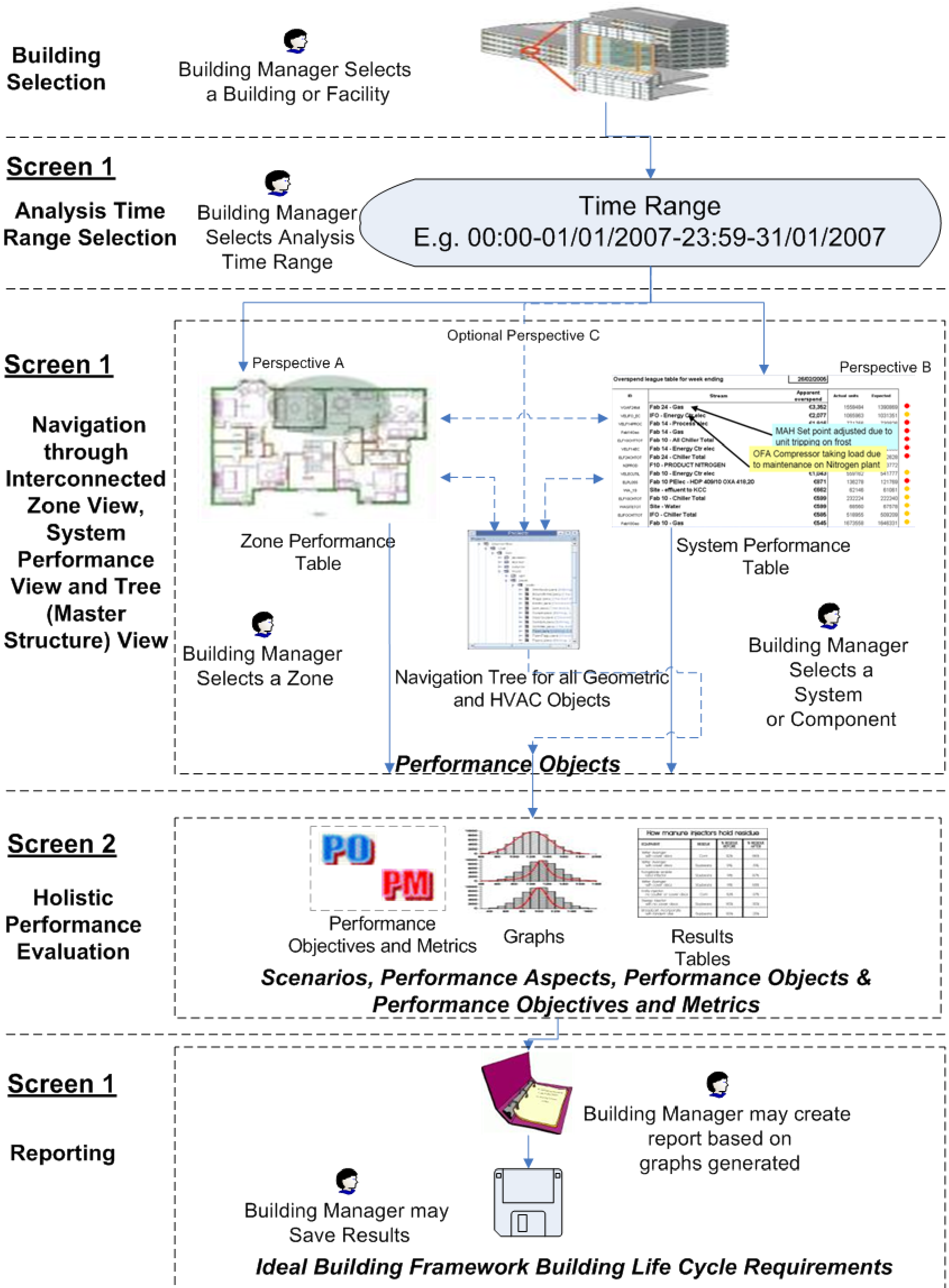

Figure 1: Proposed Logical Sequence for Navigating the Information Delivery Tool

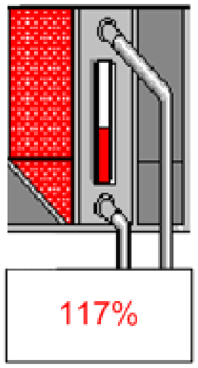

Figure 2: Heating Coil Example Icon illustrating a 17% excess when compared with 'ideal' energy consumption

A similar philosophy applies to the specification of the System Performance Table illustrated in Table 2.

Building managers can learn from, improve and optimise building operation by analysing archived performance metrics. An Information Delivery Tool should focus the building manager's attention on anomalies in operation. A visualisation approach should incorporate an unambiguous consistent mechanism for highlighting inefficiencies. Figure 2 illustrates how actual energy consumption relates to benchmarked (ideal/simulated) energy consumption for a heating coil. These percentage readings are displayed on all objects (site layout, building floor, floor plan, HVAC Systems schematics) and would significantly reduce navigation time (RPS 2007). Colour coding of percentages also highlights discrepancies and illustrates magnitudes of excessive energy consumption i.e. 0% green, 0 - 5% yellow, 5 - 10% orange and greater than 10% red. An Information Delivery Tool offers building managers the flexibility to determine acceptable or unacceptable patterns of energy consumption or system operation at their desired level of resolution. This flexibility directs an building manager towards the greatest sources of energy waste and not just the most inefficient components. For example a 150 kW heating coil using 110% of intended consumption (15kW excess) should take precedence over a 30 kW heating coil consuming 120% of intended energy use (6kW excess).

USER INTERFACE LAYOUT

Default computer screen resolutions do not adequately display the data that the Ideal Building Framework has the potential to generate. (May 2005) stated the default screen display resolution of 800*600 pixels is typical for operators within the General Services Administration (GSA).

Research initiatives that have expanded the domain of building performance analysis have been undertaken by (Haberl, Sparks, and Culp 1996) and (Prazeres and Clarke 2003). Certain HVAC faults can be identified using time sequenced graphics for visualising differences between specific data at selected time intervals (Haberl, Sparks, and Culp 1996). The latter (I^2PV) is a web-enabled program to assist in the interpretation of the performance trends inherent in large data sets as produced by simulation programs. (Prazeres and Clarke 2003) also observe that humans respond best to more than one stimulus and investigate the use of techniques not conventionally associated with building performance analysis.

The iRoom framework consists of a general, extensible common data model for the central storage the distributed (among participants) project data. iRoom is used for the interdisciplinary tasks discussed in project meetings (Schreyer et al. 2002).

Virtual reality has the potential to bring alive a particular domain by providing the user a means for interaction with domain objects. Its usefulness in building simulation is self-evident: the domain is inherently 3D, tactile and dynamic. It gives rise to the prospect of a direct model enquiry approach whereby the model itself is used to initiate user requests for information on material properties, occupancy schedules, performance variables, system states and the like (Prazeres and Clarke 2003).

The above tools, each with their own techniques and functionality are useful for the purpose for which they were designed to varying degrees. With the exception of the BMS, the limitations of which are clearly documented in (O'Donnell 2008), were not designed for an building manager. For example the Universal Translator (UT) was designed as a commissioning assistance tool which can augment existing data and interpolate for missing values but requires an expert end user (TaylorEngineering 2006).

- Many of the tools listed could with minor modifications display sensor and simulated output simultaneously with some minor modifications. Organising the data to be displayed would be a time consuming process and beyond the ability of the majority of building managers.
- The disconnect between design intent and actual operation is not addressed by any of these tools. Techniques such as 3-D animation, IRoom and virtual reality were dismissed for use by building managers due to the perceived complexity, training time, computer power required and cost (RPS 2007; Geoghegan and Fenner 2007; Ahern 2006).

The chosen user interface design considers the use of two physical screens to support the scenario modelling, benchmarking with ideal performance and while incorporating afore mentioned best practice user interface design. Physical Screen 1 contains the user interface as depicted in Screen 1 of Figure 3. Physical Screen 2 contains the user interface as depicted in Screen 2 of Figure 3. Both

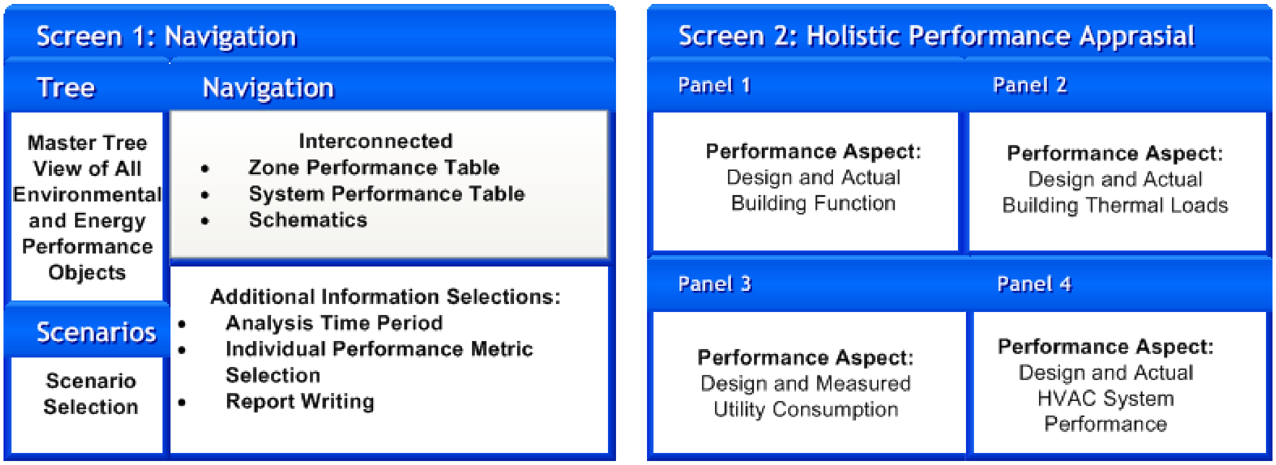

Figure 3: Specification of Screen Layout for an Information Delivery Tool. Specifications for Screen 1 allow Navigation of Building Performance Objects. Specifications for Screen 2 enable Holistic Building Performance Evaluation through performance data display.

Physical Screen 1 and 2 are available concurrently to the building manager.

The navigation screen has been specified as ‘Screen 1’. Users are familiar with the Microsoft Windows environment where selections are made in the left hand pane and viewed on the right as illustrated on ‘Screen 2’ Holistic Building Performance Evaluation. Screen 1 includes the Master Tree which describes the building and its systems and enables navigation of established performance objective and metric hierarchies. The Zone and System Performance Tables are also included in the top portion of the right hand side of Screen 1. A report panel is also included at the bottom portion of Screen 1 to maintain continuity with respect to building performance. Screen 2 compares ideal performance with measured performance on a metric by metric basis. Two screens were chosen to avoid information overload, excessive information retention and also so that the navigation screen always acts as a reference when performance data are viewed.

DEMONSTRATION

This demonstration illustrates a hypothetical scenario which depicts the down stream affects of an unauthorised reduction in zone temperature setpoint though a performance objective and metric hierarchy [1].The boundary conditions for this demonstration scenario are:

- Summer time cooling conditions;
- Outdoor temperature remains constant;
- Variable air volume system;
- Relative humidity setpoint is maintained;
- Occupancy levels are before and after setpoint change are considered equal;
- Sensible and Latent heat values for occupants (Jones 1997, Table 1.3);
- Cooling coil diverter valve (Variable Volume).

This scenario illustrates pre determined zone conditions of 21^{o}C and 50% relative humidity as illustrated in Figure 4. The zone loads remain constant throughout this example. The event is a manual change in zone temperature setpoint from 21^{o}C to 19^{o}C. Figure 4 depicts the standardised performance objectives and metrics that represent this scenario. Scenario navigation is achived through the master tree view depicted on the left hand side of Screen 1 in Figure 3.

The change in zone temperature setpoint affects the latent and sensible gains from occupants, thus changing the thermal comfort. There is a change in the ventilation system energy consumption, an increase in cooling coil load which increases chiller load, cooling related electrical consumption and ultimately building electrical consumption. Over time this deviation from design intent could increase the buildings annual CO_2 emissions resulting in additional fines for exceeding the threshold.

The Zone and System Performance Tables depict the downstream affects from the illustrated scenario. Both tables (Tables 1 and 2) would be presented in the upper right panel of Screen 1 for the building manager (Figure 3).

The example Zone Performance Table as illustrated in Table 1 highlights the discrepancy between the ideal or

[1] A comprehensive description of scenario analysis through performance metric hierarchies is included in (O’Donnell 2008)

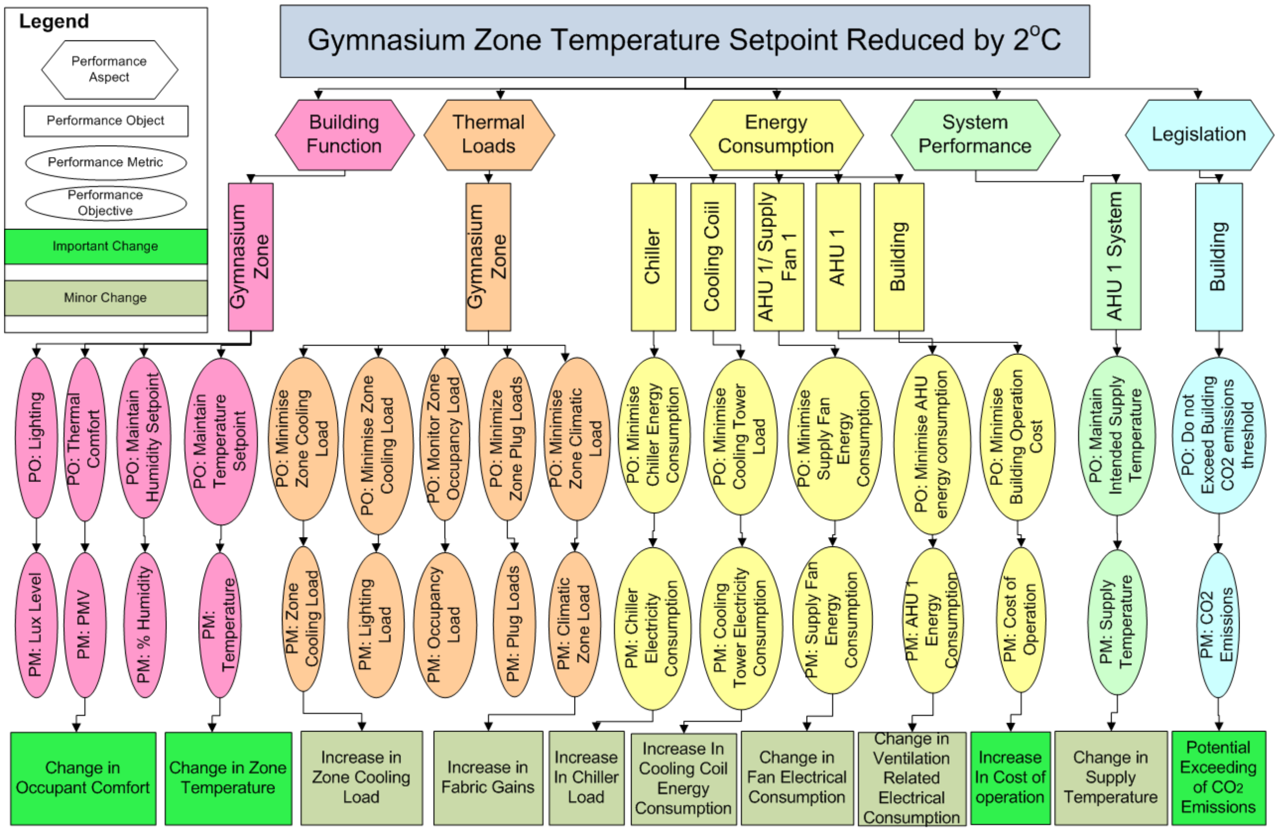

Figure 4: Sample Scenario for demonstration

Table 1: Sample Zone Performance Table for Demonstration Scenario

Zone Performance for DD/MM/YYYY HH:MM to DD/MM/YYYY HH:MM					
Zone	**Metric**	**% Indicator**	**Actual(Unit)**	**Ideal(Unit)**	**Error(Unit)**
Z1	Comfort	-14	-1	0	-1
Z1	Temp	5	19	21	2

Table 2: Sample Performance Table for Demonstration Scenario

Inefficiencies for DD/MM/YYYY HH:MM to DD/MM/YYYY HH:MM				
Metric	**% Indicator**	**Actual(kWh)**	**Ideal(kWh)**	**Cost (€)**
Cooling Tower Energy	20	2400	2000	32.0
Chiller Energy	—-	40	40	0.0
Cooling Coil Energy	6	85	80	.40

simulated zone temperature and the actual zone temperature. This table guides the building manager to the zone that is not operating as it is intended at design. Table 1 highlights the magnitude of the change in both the zone thermal comfort and zone temperature after the hypothetical trigger event.

Table 3: Metrics by Category as they Would be Presented in Information Delivery Tool User Interface

Category	***Metrics***
Design and Actual Zone Load	
Zone Cooling Load	X+
Ventilation Requirements	X?
Zone Fabric Gains	X+
Zone Occupant Latent heat gain	X-
Zone Occupant Sensible Heat Gain	X+
Design and Actual Building Function	
Lux Levels Maintained in the Zone	X
Thermal Comfort	X-
Maintain Humidity Control	X
Zone temperature	X-
Design and Actual HVAC System Operation	
Supply Air Temperature	X-
Chiller Load	X+
Condenser Loop Load	X+
Cooling Tower Energy Requirements	X+
Cooling Coil Flow	X+
Fan Power	X?
Design and Measured Energy Consumption	
Building Energy Consumption	X+
Building Electrical Consumption	X+
Cost of Operation	X+
Compliance with EU legislation	X
Cooling Electrical Consumption	X+
Ventilation Electrical Consumption	X?

The sample System Performance Table highlights the down stream consequences of not maintaining desired indoor environmental conditions. Table 2 clearly depicts how the cooling coil, chiller and cooling tower are consuming excessive energy which can in turn be traced back to the inefficiently operating zone.

Building managers may also use the Information Delivery Tool to examine the Performance Metrics relevant to this scenario in more detail. Table 3 includes the relevant metrics by category. A convention is applied for reading this Table, X denotes a key level of information, the mathematical symbols +, - and ? denote where quantifiable a positive, negative or unquantifiable change for each parameter. Panels 1-4 in Screen 2 of Figure 3 represent the Performance Aspects and Performance Metrics used in Table 3. Table 3 illustrates how building operation is affected by a trigger event. For example the 2^{o}C manual reduction in zone temperature depicted in the demonstration scenario (Figure 4) results in reduced thermal comfort and increased cost of operation. The Information Delivery Tool using the Scenario Modelling technique can explicitly link decisions made by the building manager to cost of building operation, therefore enhancing the quality of asset management.

CONCLUSION

This paper specifies an Information Delivery Tool to support optimal holistic environmental and energy management. The user specification considers in detail user profiles of building managers across a range of industries and supports:

- Holistic environmental and Energy Management;
- Scenario modelling technique;
- Underlying communication mechanisms that consist of standardised Performance Objectives and Metrics;
- A technique to compare ideal and actual performance at the component, system, zone and building level.

The information displayed by the Information Delivery Tool enables a building manager to explicitly link day to day decisions regarding building operation to cost of building operation, therefore enhancing the quality of asset management.

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