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Specification of Optimum Holistic Building Environmental and Energy Performance Information to Support Informed Decision Making

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A dissertation submitted to University College Cork (UCC) in candidature for the degree of Doctor of Philosophy

April 2009



Executive Summary

Political drivers such as the Kyoto protocol, the EU Energy Performance of Buildings Directive and the Energy end use and Services Directive have been implemented in response to an identified need for a reduction in human related CO_2 emissions. Buildings account for a significant portion of global CO_2 emissions, approximately 25-30%, and it is widely acknowledged by industry and research organisations that they operate inefficiently. In parallel, unsatisfactory indoor environmental conditions have proven to negatively impact occupant productivity. Legislative drivers and client education are seen as the key motivating factors for an improvement in the holistic environmental and energy performance of a building. A symbiotic relationship exists between building indoor environmental conditions and building energy consumption. However traditional Building Management Systems and Energy Management Systems treat these separately. Conventional performance analysis compares building energy consumption with a previously recorded value or with the consumption of a similar building and does not recognise the fact that all buildings are unique. Therefore what is required is a new framework which incorporates performance comparison against a theoretical building specific ideal benchmark. Traditionally Energy Managers, who work at the operational level of organiations with respect to building performance, do not have access to ideal performance benchmark information and as a result cannot optimally operate buildings.

This thesis systematically defines *Holistic Environmental and Energy Management* and specifies the Scenario Modelling Technique which in turn uses an ideal performance benchmark. The holistic technique uses quantified expressions of building performance and by doing so enables the profiled Energy Manager to visualise his actions and the downstream consequences of his actions in the context of overall building operation. The *Ideal Building Framework* facilitates the use of this technique by acting as a Building Life Cycle (BLC) data repository through which ideal building performance benchmarks are systematically structured and stored in parallel with actual performance data. The Ideal Building Framework utilises transformed data in the form of the Ideal Set of Performance Objectives and Metrics which are capable of defining the performance of any building at any stage of the BLC. It is proposed that the union of Scenario Models for an individual building would result in a building specific Combination of Performance Metrics



which would in turn be stored in the BLC data repository. The Ideal Data Set underpins the Ideal Set of Performance Objectives and Metrics and is the set of measurements required to monitor the performance of the Ideal Building.

A Model View describes the unique building specific data relevant to a particular project stakeholder. The energy management data and information exchange requirements that underlie a Model View implementation are detailed and incorporate traditional and proposed energy management. This thesis also specifies the Model View Methodology which complements the Ideal Building Framework. The developed Model View and Rule Set methodology process utilises stakeholder specific rule sets to define stakeholder pertinent environmental and energy performance data. This generic process further enables each stakeholder to define the resolution of data desired. For example, basic, intermediate or detailed. The Model View methodology is applicable for all project stakeholders, each requiring its own customised rule set. Two rule sets are defined in detail, the Energy Manager rule set and the LEED Accreditor rule set. This particular measurement generation process accompanied by defined View would filter and expedite data access for all stakeholders involved in building performance.

Information presentation is critical for effective use of the data provided by the Ideal Building Framework and the Energy Management View definition. The specifications for a customised Information Delivery Tool account for the established profile of Energy Managers and best practice user interface design. Components of the developed tool could also be used by Facility Managers working at the tactical and strategic levels of organisations. Informed decision making is made possible through specified decision assistance processes which incorporate the Scenario Modelling and Benchmarking techniques, the Ideal Building Framework, the Energy Manager Model View, the Information Delivery Tool and the established profile of Energy Managers. The Model View and Rule Set Methodology is effectively demonstrated on an appropriate mixed use existing 'green' building, the Environmental Research Institute at University College Cork, using the Energy Management and LEED rule sets. Informed Decision Making is also demonstrated using a prototype scenario for the demonstration building.

Contents

Executive Summary iii

Table of Contents viii

List of Figures xii

List of Tables xiv

Declarations xv

Acknowledgements xvii

Special Acknowledgement xix

List of Abbreviations xxi

1 Introduction 1

1.1 General . . . 1
1.2 Significance of Climate Change . . . 3
1.2.1 Energy Use and Climate Change . . . 4
1.2.2 Significance of Global Building Stock . . . 6
1.3 Legislative Drivers . . . 6
1.4 Research Motivation: Inefficient Buildings . . . 8
1.4.1 Optimum Productive Environments . . . 10
1.4.2 Client Education . . . 11
1.4.3 Environmental and Energy Management Resources . . . 12
1.4.4 Tools and Techniques . . . 14
1.4.5 Documentation across the entire BLC . . . 16
1.4.6 Ineffective Business Process Models . . . 18
1.4.7 Summary of Key Findings . . . 19
1.5 Thesis Objectives and Approach . . . 20
1.6 Thesis Structure . . . 22

2 Environmental and Energy Management **23**
2.1 Chapter Introduction . . . 23
2.2 Domain Review . . . 24
2.2.1 Energy Management: External Drivers . . . 24
2.2.2 Energy Management: Internal Drivers . . . 25
2.2.3 Energy Management: The Role and Background . . . 26
2.2.4 Energy Management: Data & Information . . . 27
2.2.5 Energy Management: Tools . . . 30
2.2.6 Energy Management: Techniques . . . 34
2.2.7 Review Findings . . . 36
2.3 Building Management Case Studies . . . 36
2.3.1 Case Study Findings . . . 38
2.4 Research Significance . . . 39
2.5 Chapter Conclusion . . . 43

3 Holistic Building Performance Appraisal **45**
3.1 Chapter Introduction . . . 45
3.2 Rudimentary Model of Thesis Concepts . . . 46
3.3 Holistic Performance Aspects . . . 49
3.4 Structured Building Performance Assessment . . . 51
3.5 Scenario Modelling Technique . . . 52
3.5.1 Scenario 1: Zone Temperature Set Point Reduction . . . 55
3.5.2 Scenario 2: Sudden Increase in Zone occupancy . . . 57
3.5.3 Scenario 3: Reduction in Artificial Lighting . . . 59
3.6 Performance Metric Combinations . . . 61
3.7 Chapter Conclusion . . . 64

4 The Ideal Building **65**
4.1 Chapter Introduction . . . 65
4.2 The Ideal Building Framework . . . 66
4.3 Ideal Building Framework Data Repository . . . 68
4.4 Building Object Hierarchy . . . 70
4.5 Ideal Performance Objectives and Metrics . . . 72
4.6 Chapter Conclusion . . . 77

5 Ideal Measurement Set **79**
5.1 Chapter Introduction . . . 79
5.2 Ideal Measurement Set: Requirements . . . 80
5.3 Specification of Datum Stream Formats . . . 84
5.4 Specification of Ideal Datum Sources . . . 87
5.4.1 Optimum Benchmark: Energy Simulation Models . . . 88
5.4.2 Actual Building Performance: Measured Data . . . 90
5.4.3 Utility Provider Data . . . 93
5.5 Chapter Conclusion . . . 94



6 Model Views of the Ideal Building **95**
6.1 Chapter Introduction . . . 95
6.2 Model View Data Exchange Requirements . . . 96
6.3 User Profiled Based Model View Definitions . . . 98
6.3.1 Specification of Model View Resolution . . . 99
6.4 Model View and Rule Set Process . . . 101
6.5 Model View Rule Set Specification . . . 105
6.6 Chapter Conclusion . . . 111

7 Specification of Information Delivery Tool **113**
7.1 Chapter Introduction . . . 113
7.2 Specifications for Screen Layout . . . 114
7.2.1 Screen Layout . . . 115
7.3 Specification of Interface Navigation and Use . . . 117
7.3.1 Screen 1 Navigation . . . 119
7.3.2 Specification of Performance Data Display: Screen 2 . . . 123
7.3.3 Specification of Save & Report Options . . . 128
7.4 Chapter Conclusion . . . 129

8 Assisting Decision Making **131**
8.1 Chapter Introduction . . . 131
8.2 Scope for Decision Assistance . . . 132
8.3 Proposed Decision Assistance . . . 133
8.3.1 Decision Assistance Example . . . 136
8.4 Chapter Conclusion . . . 137

9 Demonstration of Philosophy **139**
9.1 Chapter Introduction . . . 139
9.2 ERI Description . . . 140
9.3 ERI: Model View and Rule Set Methodology . . . 142
9.3.1 ERI: Energy Manager Rule Set . . . 144
9.3.2 ERI: LEED Accreditor Rule Set . . . 147
9.4 ERI: Ideal Building Framework . . . 150
9.4.1 ERI: Scenario Modelling . . . 151
9.4.2 ERI: Informed Decision Assistance . . . 154
9.5 Chapter Conclusion . . . 156

10 Research Results **157**
10.1 Research Conclusions . . . 157
10.2 Future Research . . . 161

Bibliography **187**

A Case Studies: Interviews **189**
A.1 Case 1: University College Cork . . . 190
A.2 Case 2: Industrial Plant . . . 193
A.3 Case 3: Intel Ireland . . . 196
A.4 Industry Overview Interview: RPS Group . . . 198
A.5 Analysis . . . 200
A.5.1 Analysis: Internal/External Drivers . . . 200
A.5.2 Analysis: Role . . . 201
A.5.3 Analysis: Data . . . 202
A.5.4 Analysis: Information . . . 203
A.5.5 Analysis: Tools . . . 203
A.5.6 Analysis: Techniques . . . 204

B Building Function **205**
B.1 Introduction . . . 205
B.2 Occupancy . . . 206
B.3 Lighting . . . 208
B.4 Legislation and Utilities . . . 209

C BIM Environment: An Implementation Option **211**
C.1 Populating the BIM for an Information Delivery Tool . . . 212

D Ideal Performance Objectives and Metrics Set **219**

E Energy Manager and LEED Accreditor Views **221**

F Exchange Requirements: Energy Manager Model View **223**

G Interactive View and Rule Set Methodology **231**

H User Interface Considerations **233**
H.1 Chapter Introduction . . . 233
H.2 Principles of User Interface Design . . . 233
H.3 Semantics of User Interface Specification . . . 235
H.4 Current Interface Technology Alternatives . . . 235

I ERI Energy Manager & ERI LEED View **239**

J ERI Prototype Scenario Measurement Streams **241**

List of Figures

1.1 400,000 Years of CO_2 and Temperature Correlations (Courtesy of (Barnola et al. 2003)) . . . 3
1.2 Average Global Mean Temperature: Recent Effects (IPCC 2007) . . 4
1.3 Global CO_2 Emissions by Region (IEA 2007) . . . 5
1.4 Breakdown of residential and commercial sector energy use in United States (2005) and China (2000) (Courtesy of (IPCC 2007)) . . . 9
1.5 The Present Building Stock Fails to Provide Energy Managers with the Data and Information They Require. . . . 13
1.6 Building Life Cycle Information Flow Requirements . . . 16
1.7 Thesis Research Objectives . . . 20
1.8 Thesis Overview . . . 22

2.1 Factors Influencing Organisational Environmental and Energy Management . . . 24
2.2 Design Intent Compared with Reality (courtesy of (Kiviniemi 2005)) 27
2.3 Partial Transfer of Information Across the Building Life Cycle (Courtesy of Barry O'Sullivan) . . . 29
2.4 Simplified Diagram of Conventional BMS and EMS Datum Sources and Functionality . . . 30
2.5 Siemens BMS Screen Shot of Block A Boilers System at the University College Cork Student Center . . . 32
2.6 Example of the EnergyFocus Energy Management Software Interface (provider wishes to remain anonymous) . . . 33

3.1 Hierarchy of Thesis Concepts Facilitating an As-Built Building Representation for Performance Evaluation . . . 47
3.2 Example Relationships between Performance Aspects and Building Objects . . . 50
3.3 A: Suggested Generic Structure of Performance Objectives and associated Metrics (Courtesy of (Hitchcock 2003), B: Sample Implementation of a Performance Objectives for Building Object Heating Coil 1) . . . 51
3.4 Generic Illustration of the relationships between Performance Aspects, Building Objects and Performance Objectives and Metrics. . 52

3.5 Generic Structure of Scenario Modelling Technique 53
3.6 Scenario Illustration Depicting the Effects of a Manual Change in Zone Temperature Setpoint. 56
3.7 Scenario Illustration Depicting the Effects of a Sudden Increase in Zone Occupancy 58
3.8 Scenario Illustration Depicting the Effects of an Automated Reduction in Zone Lighting while maintaining Zone Lux Setpoints 60
3.9 Proposed Requirements Specification Procedure to Create and Store Performance Metric Combinations for Any Building 63

4.1 Specification of the Ideal Building Framework which Includes the Individual Layers and the Requirement for Life Cycle Data Storage. 66
4.2 Building Information Model as a Central Repository for Building Life Cycle Performance Goals 69
4.3 The Required Interoperable Process which incorporates Standardised Performance Metrics to Track Indoor Environmental and Energy Information Across the Building Life Cycle 70
4.4 Structure of the Building Object Hierarchy Illustrating the Important Building Objects as Determined in Chapter 2 71
4.5 Processes Required to Deliver Holistic Environmental and Energy Information to the Energy Manager 72

5.1 The Ideal Measurement Set that Underpins the Ideal Building Framework 80
5.2 Sub Set of Scenario 1 illustrating the Relationship between Trigger Event, Performance Aspect, Building Object, Performance Objective and Metric and the Measurement Streams 81
5.3 Systematically Structured Naming Convention for Datum Points based on the Building Object Hierarchy 86

6.1 Steps required for reaching deployment of IFC based solutions (Courtesy of (Hietanen 2003)) 96
6.2 High Level Overview of the Automated Process and Rule Set Relationships as applied with the Ideal Building Framework 99
6.3 Process for Defining a Model View for a Specific Measurement Set of a Particular Building. Appendix G contains a fully interactive image. 104
6.4 Energy Manger Rule Set for Mechanically Conditioned Spaces. Appendix G contains a fully interactive image. 107
6.5 Energy Manager Rule Set for Non-Conditioned Zones. Appendix G contains a fully interactive image. 108
6.6 The LEED Rule Set for Credits that Relate to the Scope of this Thesis. Appendix G contains a fully interactive image. 109



6.7 Rule set for Financial Controllers. Process for Defining a Model View for a Specific Measurement Set of a Particular Building. Appendix G contains a fully interactive image. 111

7.1 Considerations for an Information Delivery Tool. 114
7.2 Specification of Screen Layout for an Information Delivery Tool. Physical Screen 1 enables Navigation of Building Performance Objects and Physical Screen 2 enables Holistic Building Performance Evaluation. 116
7.3 Proposed Logical Sequence for Navigating the Information Delivery Tool 118
7.4 Interface Example Step 1: Select Time 119
7.5 Interface Example Step 2: Select Scenario or Building Object from Performance Tables or Master Tree. Individual Metric Selection for chosen Building Object is also available. 121
7.6 Example of a Cooling Coil Icon Illustrating a 17% Excess when Compared with 'Ideal' Energy Consumption 122
7.7 Example Plot of a Boiler Flow Temperature Performance Metric for the Profiled Energy Manager 125
7.8 Example of Building Gas Consumption for the Profiled Energy Manager 126
7.9 Sample Carpet Plot that is to display Performance Metrics for the Profiled Energy Manager(Courtesy of Isakson 2004) 127
7.10 Interface Example Step 3: Performance Metric Display using the Specified Graphing Techniques for Scenario 1 Information (Section 3.5). 127
7.11 Interface Example Step 4: Report Writing Based on Observed Performance. 128

8.1 Comparison of Decision Making Environment for Traditional and Ideal Building Energy Management 133
8.2 Effective Decision Making is Dependant on Ideal Building Framework Information Presented by the Information Delivery Tool . . . 134
8.3 General Decision Assistance Process which Complements the View Methodology and Ideal Building Framework 135
8.4 Decision Assistance for a Scenario Illustration Depicting the Effects of a Manual Change in Zone Temperature Setpoint. 137

9.1 South Faade of the ERI Building at University College Cork, Ireland 140
9.2 Screen Shot Image of the ERI BMS Illustrating the Integrated Hybrid Heating and Cooling System 141
9.3 Process for Defining an Energy Manager of LEED Accreditor Model View Specific Measurement Sets for the ERI Building (Section 6.4) 143

9.4 ERI: Building Object Hierarchy illustrating the discrepancy between Ideal and installed measurements. A complete interactive ERI Building Object Hierarchy is contained in Appendix I 145
9.5 Overview of the LEED credits and the Building Objects with which they are associated 147
9.6 Informed Decision Making as Used with the Prototype ERI Building 151
9.7 Prototype Scenario Illustrating the Building Function Performance Aspect, Test Zone Building Objects and Performance Objectives and Metrics. 153
9.8 Decision Assistance for the ERI Prototype Scenario. System Operation is not in Accordance with Updated Design Intent 154

10.1 The Proposed Solution to the Identified Weaknesses in the Environmental and Energy Management of Buildings by Profiled Energy Managers 158
10.2 Research Results and Thesis Review 160

A.1 Trend and Siemens BMS that are Used at UCC. 192
A.2 Typical College Weekday Electricity Load Profile for UCC Site. Displayed by the EnergyFocus EMS. 193
A.3 EnergyFocus Schematic of Gas Consumption for a Pharmaceutical Site 195
A.4 Architecture of Intel Energy Management 196
A.5 Sample Overspend Table (Courtesy of Intel) 197
A.6 Simplified Diagram of Conventional BMS and EMS Datum Sources and Functionality 199

B.1 The Complexity of Building Energy Flows (Courtesy of (Clarke 2001)) 206

C.1 Information Delivery Tool: System Architecture 213
C.2 Relating Subtypes of IfcObject to IfcObjective Entities (Courtesy of (Morrissey & Hitchcock 2005)) 214
C.3 A Performance Indicator Hierarchy for a Particular IfcObjective (Courtesy of (Morrissey & Hitchcock 2005)) 215
C.4 Software Environment Required for an Information Delivery Tool . 216

List of Tables

2.1 Educational Qualifications of U.S. Facilities Managers and U.S. Managers (Courtesy of FMLink (2004)) 26
2.2 Case Study Overview 38

3.1 Interpretation of the Important Performance Metrics for the Three Chosen Scenarios. 61

4.1 Sample table of an Ideal Set of Performance Objectives and Metrics for the Established Profile of Energy Managers. 75
4.2 Datum Sources Available at Each Stage of the Building Life Cycle . 76

5.1 Sources of Data for the Ideal Measurement Set at each stage of the Building Life Cycle 82
5.2 Sample Section of the Ideal Set of Performance Objectives and Metrics for the established profile of Energy Managers. 83
5.3 Conditions for Format for Ideal Building Datum Sources 85
5.4 Specification of Format for Ideal Building Raw Datum Sources . . . 87
5.5 Suggested Resolution of Measurements (Courtesy of (Gillespie et al. 2006)) 92

6.1 Energy Manager Model View of a Cooling Coil Building Object. . 102
6.2 Sample Measurements for LEED Credit 'Energy and Atmosphere Credit 1: Optamise Energy Performance' at the Zone Building Object 110

7.1 Specification for Zone Performance Table 120
7.2 Specification for System Performance Table 121

9.1 Results from Application of the Automated Process using the Energy Management Rule Set 146
9.2 EA Credit 2: Relevant Measurement Streams for Renewable Energy Building Objects 148
9.3 Example of ERI Prototype Datum Streams. The Full Set is contained in Appendix I 152

A.1 Case Study Overview 200

F.1 Exchange Requirements of the Energy Management Domain. 223

Declarations

This thesis or any part thereof, has not been, or is not currently being submitted for any degree at any other university.

James Thomas O'Donnell

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List of Abbreviations

AEC/FM	Architectural, Engineering, Construction and Facilities Management
AHU	Air Handling Unit
ASHRAE	American Society of Heating Refrigeration Air Conditioning Engineers
B&E	Building and Estates Office. U.C.C.
BACnet	Building Automation and Control NETworks
BECs	Building Effectiveness Communication Ratios
BER	Building Energy Rating
BIM	Building Information Model
BLC	Building Life Cycle
BMS	Building Management System
BOC	Building Operator Certification
CIBSE	Chartered Institute of Building Services Engineers
CO_2	Carbon Dioxide
CSV	Comma Separated Variable
DOE	Department Of Energy
EMS	Energy Management System
EMCS	Energy Management and Control Systems
EPA	Environmental Protection Agency
EPBD	Energy Performance of Buildings Directive
EPI	Energy Performance Indicator
ERI	Environmental Research Institute
ESB	Electricity Supply Board
ESD	Energy Services Directive
EUI	Energy Use Intensity
GHG	Green House Gas

GIGO	Garbage In, Garbage Out
GSA	General Services Administration
GUI	Graphical User Interface
GUID	Global Unique Identifier
HVAC	Heating Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IAI	International Alliance for Interoperability
IBECS	Integrated Building Environmental Control System
IDD	Input Data Dictionary (EnergyPlus object definitions)
IDF	Input Data File (EnergyPlus input syntax for simulation)
IEA	International Energy Agency
IFC	Industry Foundation Classes
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilo Watt Hour
LBNL	Lawrence Berkeley National Laboratory
LEED	Leadership in Energy and Environmental Design
ODPM	Office of the Deputy Prime Minister
O&Ms	Operation & Maintenance Manuals
PBS	Public Buildings Service
PG&E	Pacific Gas and Electrical
PM	Performance Metric
PMV	Predicted Mean Vote
PO	Performance Objective
P_r	Performance Effectiveness Ratio
QS	Quantity Surveyor
RH	Relative Humidity
ROI	Return On Investment
SEI	Sustainable Energy Ireland
SMC	Solibri Model Checker
TMY	Typical Meteorological Year
USGBC	United States Green Building Council
UCC	University College Cork
VAV	Variable Air Volume
VBE	Virtual Building Environment
VSD	Variable Speed Drive



WSN Wireless Sensor Network



Chapter 1

Introduction

> "*The era of procrastination, of half-measures, of soothing and baffling expedients, of delays is coming to its close. In its place we are entering a period of consequences*"

(Winston Churchill 1936)

1.1 General

The Intergovernmental Panel on Climate Change (IPCC) has identified the environmental consequences of human related CO_2 emissions (IPCC 2007). The Stern report on "The Economics of Climate Change" highlights the economic implications of immediate and delayed solutions to climate change (UNFCCC 2007, Stern 2006). Society must place the current emphasis on energy efficiency in order to allow enough time for renewable energy technologies to penetrate the market (Glicksman 2008). It has been established that buildings alone account for 25-30% of global CO_2 emissions. The Energy Performance of Buildings Directive (EPBD), the Emissions Trading Directive and the Energy End-Use and Efficiency Services Directive have been implemented in an attempt to mitigate CO_2 emissions associated with inefficient building operation (UNFCCC 2007, EU 2006, 2003a, 2002). In parallel, unsatisfactory indoor environmental conditions have proven to negatively impact on occupant productivity (Clements-Croome 2003).

The adoption of improved building performance systems must be client driven as the many benefits of efficient operation include increased occupant productivity

and decreased utility bills. However clients require quantitative indicators of these benefits before committing to a life cycle performance based approach. This can be difficult to achieve as traditional building projects fail to incorporate performance based design and as a result performance benchmarks are not updated across the Building Life Cycle (BLC).

Satisfactory indoor environments are traditionally controlled by Building Management Systems (BMS) but not necessarily in an energy efficient manner (Claridge et al. 2003). Energy Managers who use traditional BMS do not have access to up-to-date ideal performance data and information required to optimally operate buildings.

This thesis systematically defines the key weaknesses of current practices with respect to holistic environmental and energy management in buildings and addresses each criterion in turn. The identified weaknesses are resolved through:

- Establishing a profile of current and future Energy Managers;
- Defining an up-to-date ideal benchmark of building performance that is updated across the BLC for comparison with actual measured data at operation;
- Specifying the Ideal Building Framework that supports building life cycle holistic environmental and energy management;
- Defining the Model View concept to support performance analysis by specific profiled stakeholders and developing the *Energy Manager Model View data exchange requirements*;
- Specifying context sensitive holistic environmental and energy information presentation formats for the profiled Energy Manager Model View;
- Specifying decision assistance processes for the profiled Energy Manager;
- Testing and validation of the key concepts with an operating building.

The following sections describe the significance of building operation in the context of the human effect on global climate change. This is followed by an investigation into the key aspects of traditionally inefficient buildings and a description of a proposed solution. The objectives and structure of this thesis will then be outlined.

1.2 Significance of Climate Change

The future fate of our environment is subject to constant scrutiny and debate across a wide variety of disciplines. A sharp increase in atmospheric levels of CO_2 and other Greenhouse Gases (GHG) is widely acknowledged to be responsible for a dramatic shift in worldwide weather patterns (Gaterell & McEvoy 2004, McMichael et al. 2006). It is highly probable that these increased emissions have been generated by the human use of fossil fuels (IPCC 2007). The findings of the Intergovernmental Panel on Climate Change (IPCC) based on analysis of 400,000 years of climatic data. Since the industrial revolution (circa 1800) the level of atmospheric CO_2 peaked sharply and has continued to rise steadily to the present day (Figure 1.1).

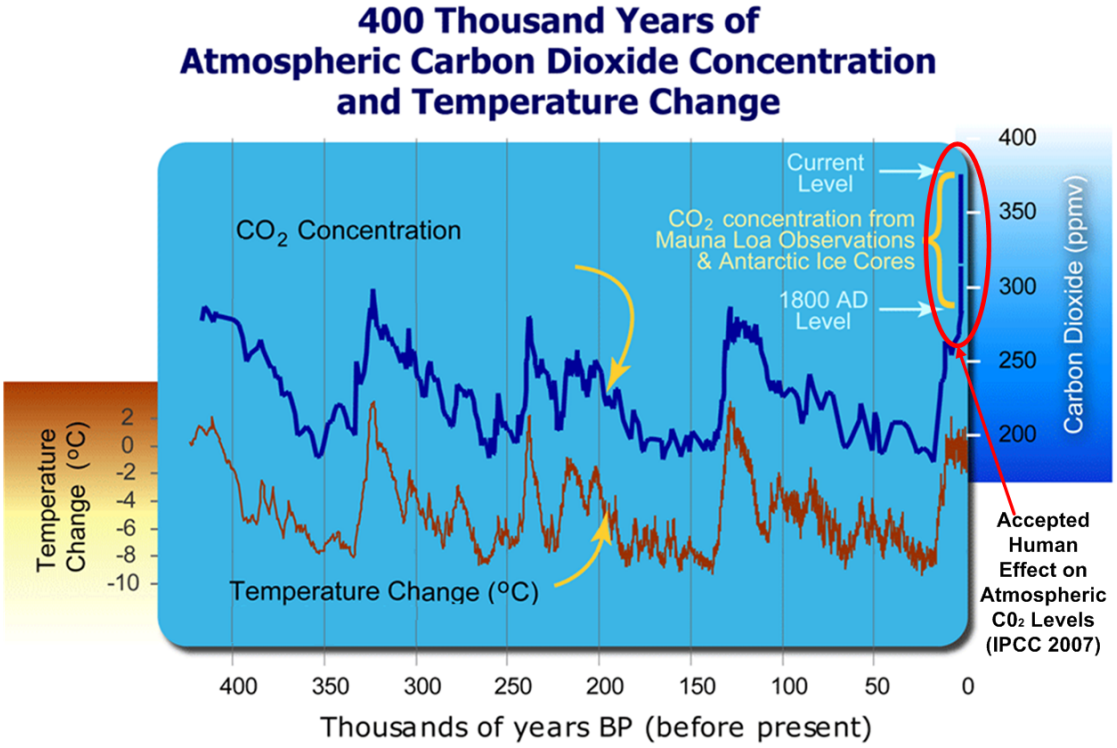


Figure 1.1: *400,000 Years of CO_2 and Temperature Correlations (Courtesy of (Barnola et al. 2003))*

This marked increase in atmospheric CO_2 has been attributed to a corresponding increase in global mean temperature (IPCC 2007). As illustrated in Figure 1.2 the period from 1850 to the present highlights a significant increase in average global temperature most notably since 1910. The hottest years on record have

occurred over the last 14 years with the hottest being 2005 (Gore 2006). It is clear that the human race is impacting significantly on the composition of the earth's atmosphere and the consequences are not fully understood.

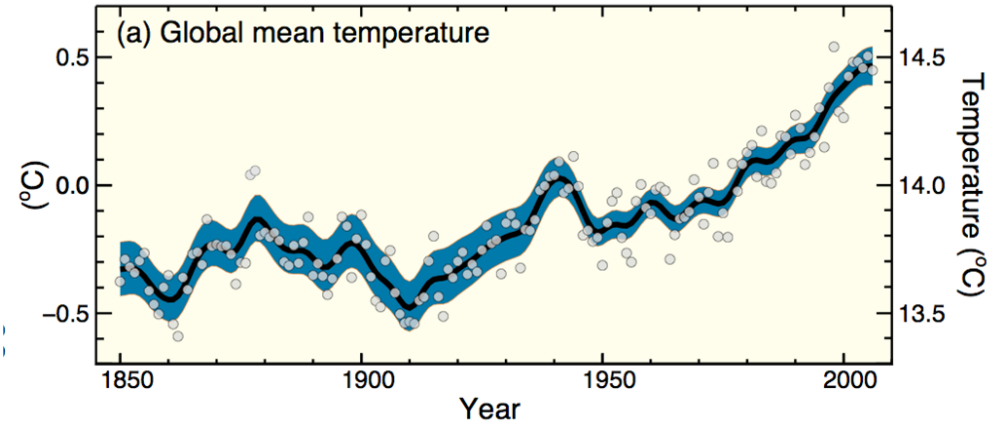


Figure 1.2: *Average Global Mean Temperature: Recent Effects (IPCC 2007)*

1.2.1 Energy Use and Climate Change

The IPCC have conclusively established a link between a rise in global mean air temperature and atmospheric CO_2 levels (IPCC 2007). However global energy consumption is also increasing and has almost doubled since 1970 (Figure 1.3) resulting in a rise in a rise in CO_2 emissions which shows no signs of abating. The major contributors to global CO_2 emission levels are the developed and industrialised countries of Europe and North America. Asia in its entirety contributes approximately 36.4% with China and Japan contribute approximately 14% and 15% respectively (Priambodo & Kumar 2001). As of 2006 China's rapidly developing economy and corresponding coal production has resulted in it becoming the world's leading contributor of recorded greenhouse gasses (NEAA 2007). Recent studies using province level information for evaluating China's CO_2 emissions determined that actual emissions are far higher than was previously calculated (Auffhammer & Carson 2008). Hubacek et al. (2007) estimate that India may in time surpass China in terms of population and CO_2 emissions.

The critical nature of greenhouse gas emissions was globally acknowledged when the Kyoto protocol was drafted in 1997. Its objectives are to reduce emissions of six key greenhouse gases by 2012 to an average of 5.2% below 1990 levels (UNFCCC

2007). In November 2004 the Kyoto protocol was ratified by Russia making it legally binding for all participating countries as of Feburary 16^{th} 2005 (UNFCCC 2007). Notable absentees include the United States and Australia with both countries maintaining that the cost of the process would be too much for their respective economies to bear. They also argue that the protocol is flawed as large developing countries including India, China and Brazil are currently not required to meet specific targets. In response the U.S. and Australia have spearheaded the "Asia Pacific Partnership on Clean Development and Climate" which also includes Japan, China, India and South Korea. Their philosophy is to ease climate change without affecting the progress of industry or economic development. Rather than concentrating on the reduction of CO_2 emissions the partnership believes the focus should be on alternative energy sources and scientific advancements to ease climate change (Asia-Pacific Partnership on Clean Development and Climate 2006).

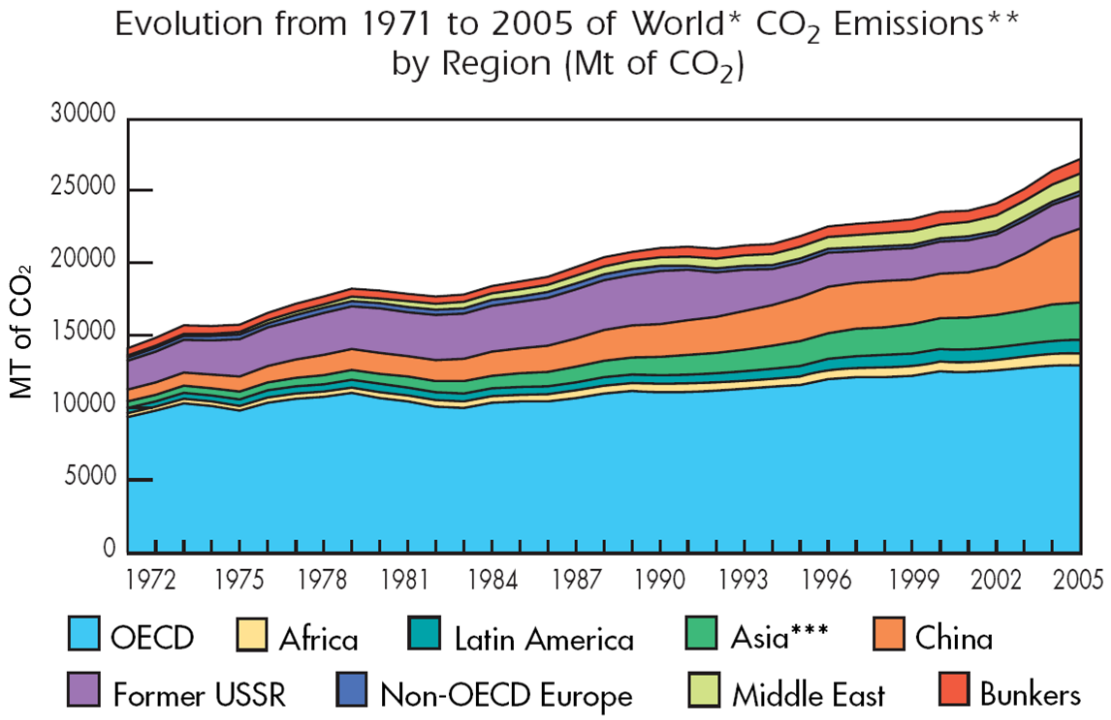


Figure 1.3: *Global CO_2 Emissions by Region (IEA 2007)*

"The Economics of Climate Change" stressed the dire environmental and financial consequences that face our planet if CO_2 emissions are not stabilised within reasonable levels by 2050 (Stern 2006). It stated that it would cost approximately 1% of global GDP to rectify present global CO_2 emissions but could cost up to

20% of GDP if global action waited until 2050 (Stern 2006). It is globally accepted that society must place the current emphasis on energy efficiency in order to allow enough time for renewable technologies to penetrate the market (Glicksman 2008).

1.2.2 Significance of Global Building Stock

Reports by the Intergovernmental Panel on Climate Change (IPCC) and the U.S. Department of Energy note that buildings account for 25-30% of total energy-related CO_2 emissions (Price et al. 2006). The overall building stock in the U.S. accounts for 40% of the total energy consumption of the country (Filippn 2000). It has been estimated that the operation of buildings (lighting, space heating and cooling) is responsible for about 50% of primary energy use in the EU and a slightly lower share of CO_2 and GHG emissions (EC 2005, Cohen et al. 2004). In the case of Ireland energy consumption in buildings accounts for approximately 30% of GHG emissions and approximately 40% of total energy consumed (Howley et al. 2006)[1]. The growth in final energy demand in the Irish services sector over the period 1990 to 2002 was on average 4.1% per annum (Howley et al. 2006) compared with 1.5% per annum within the EU-15 for the same period (Bosseboeuf et al. 2005). Buildings are included in the services sector and Ireland has a relative increase in the number of new buildings when compared with the EU as a whole. Therefore Ireland has a relatively greater responsibility to operate an efficient building stock. These figures indicate that there is extra incentive to mitigate excessive energy use especially as Ireland imports 90% of its energy requirements (SEI 2005)[2]. The projected rise in GHG emissions in Ireland from 1990 to 2010 is 25% of 1990 levels compared to the proposed limit of 13% under the EU burden-sharing agreement.

1.3 Legislative Drivers

Global environmental (Kyoto in 1990) and economic (Stern in 2006) arguments demonstrate that climate change is explicitly linked to fossil fuel related CO_2 emissions (Section 1.2.1). Current European legislation acknowledges that buildings are a significant contributor to climate change.

[1]The variance may be attributed to national energy sources and end use activities.
[2]The EU predict a 70% dependency on imported energy by 2030 (EC 2005)

Europe's target under the Kyoto Protocol is a reduction in the level of GHG emissions while also decreasing the current dependence on imported energy. The Energy Performance of Buildings Directive (EPBD) (2002/91/EC) and the Emissions Trading Directive (2003/87/EC), were commissioned to address these issues. The EPBD focuses on the energy performance of buildings and has been in effect since January 2003. It places demands on building owners to quantify energy usage throughout the BLC. As of January 4^{th} 2006 all EU buildings in excess of 1000m^2 that fall under the categories "new, to be renovated or open to the public" are required to carry an energy label. The design of this label is similar to those which currently accompany white goods (Bordass et al. 2004). It is also acknowledged that the new EU directives will significantly affect the asset value of buildings (SEI 2005). A building will no longer be viewed solely as a fixed capital item but as an item with an associated significant running cost. As a result of the new legislation operational energy costs will now have to be considered at the time of purchase. The Emissions Trading Directive (2003/87/EC), for which University College Cork (UCC) campus is a participant, requires that sites with a thermal input capacity in excess of 20 MW thermal input possess a GHG permit as of 2005. O'Gallachoir et al. (2007) and Georgopoulou et al. (2006) detail the current and future frameworks of operation for the emissions trading scheme. However the "Asia Pacific Partnership on Clean Development and Climate" does not have any legally binding targets for similar reductions in CO_2 emissions (Asia-Pacific Partnership on Clean Development and Climate 2006). This group of nations will consequently fall further behind 1990 levels in terms of reductions in CO_2 emissions if existing energy consumption trends continue and renewable technologies are not deployed to offset this increase.

A further Directive on Energy End-Use Efficiency and Energy Services (2006/32 /EC), also referred to as the Energy Services Directive (ESD) (EU 2006) came into effect on May 17th 2006. This is seen as the legislative driver for end use energy efficiency within the EU which each member state has two years to impose into national law. The Directive requires the establishment of an indicative target of 9% improvement in energy efficiency by 2016 for all member states. An action plan to achieve the target including a range of actions by different stakeholders was implemented as of June 2007 for the Irish residential building stock. Monitoring and reporting of progress towards this target was initiated in 2008 (SEI 2007). The

purpose of the Directive is to improve energy end-use efficiency in a cost effective manner for the member states by:

- Providing the necessary indicative targets, mechanisms, incentives and institutional, financial and legal frameworks to remove existing market barriers and address imperfections that impede the efficient end-use of energy;
- Creating the conditions for the development and promotion of a market for energy services and for the delivery of other energy efficiency improvement measures to final consumers;
- Placing an emphasis on measurement and verification of energy savings;
- Stipulating the public sector must play an exemplary role.

1.4 Research Motivation: Inefficient Buildings

This section focuses on the key issues that contribute to the inefficient operation of buildings. The quantification for potential improvements in building energy performance is initially presented and followed by the organisational value provided optimum productive environments. The importance of educating building owners is addressed and has subsequent consequences for the resources allocated to the stakeholder responsible for environmental and energy management. These resources contribute directly to the tools and techniques used in building performance analysis and the need for documentation across the entire BLC. This section concludes with an investigation of the weaknesses in current business process models and how they contribute to inefficiently operated buildings.

Building HVAC (Heating, Ventilation and Air Conditioning) systems are widely acknowledged to operate inefficiently (Piette et al. 2001). This is largely attributed to the lack of formal descriptive procedures that support the efficient operation of HVAC systems after the commissioning phase (Xu et al. 2005) in combination with irregular performance monitoring. Several case studies (Herzog & LaVine 1992, Claridge et al. 1994) suggest that energy savings of between 15% and 40% are attainable in commercial buildings by closer monitoring and supervision of energy-usage and related data (Salsbury & Diamond 2000). Poor documentation

of performance data together with a lack of assessment for the operation and maintenance phase of the building lifecycle are the primary culprits in inefficient energy use. This continues to occur despite the fact that current Building Management Systems (BMS) facilitate trending and archiving of various data types and provide a largely untapped resource for improving design, operation and energy efficiency of installed systems. Systems implemented in this manner contribute to a lack of formal operating procedures as they are not coupled with updated design intent. According to the European Commission research has shown that more than 20% of present energy consumption could be saved by 2010 based on 2000 levels by applying stricter standards to buildings undergoing refurbishment and to new buildings (EC 2005).

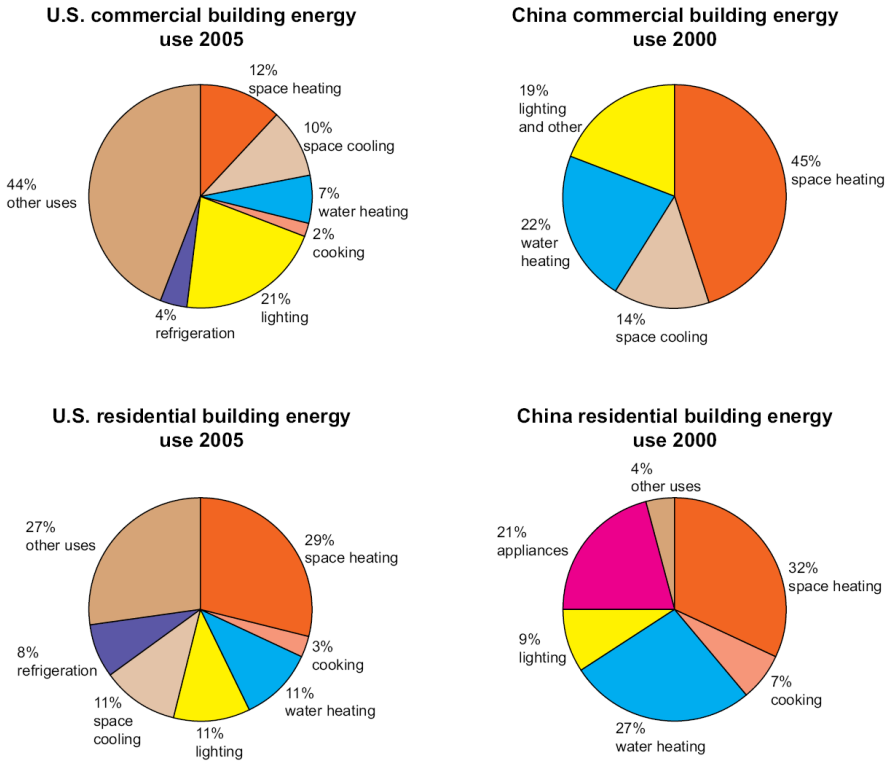


Figure 1.4: *Breakdown of residential and commercial sector energy use in United States (2005) and China (2000) (Courtesy of (IPCC 2007))*

The two largest sources of CO_2 emissions are the United States and China, figure 1.4 illustrates the breakdown of their commercial and residential energy use. A similar breakdown of Irish commercial and residential energy use is currently not available (Ryan 2007*a*). During operation individual buildings require a similar breakdown of energy use but currently this information is unavailable from

installed BMS/EMS (Gillespie et al. 2006). A deeper understanding of operation is possible if more detailed information is made available to Energy Managers in buildings. This information must recognise the education and background of Energy Managers if they are to fulfill their role with respect to organisational objectives and legislative compliance.

The following sections investigate the key areas that contribute to inefficient buildings. The key findings from which form the basis of the thesis research objectives. The added value of efficiently operated buildings must be quantifiable in accordance with the principles of information science if this thesis and other building related research is to be widely adopted (Bazjanac 2008).

1.4.1 Optimum Productive Environments

This section describes the organisational benefits of optimum productive indoor environments. The consequences of inefficient building operation are wide reaching for an organisation. Business organisations wish to maximise profit and a building itself can add value to an organisation's core business (Williams 2000). Poor indoor environmental conditions (ASHRAE 2004*b*) can have a detrimental effect on employee productivity and often result in decreased performance by commercial building occupants[3] (Mendell et al. 2002, Heerwagen 2000). For example absenteeism in the workplace costs the UK economy £12 billion every year and a significant portion of absenteeism is due to a poor work environment (Clements-Croome 2003). Financially speaking a "life cost ratio" is described in words of "initial capital cost", "operational cost" and "salary cost". On average a ratio of 1:10:200 is applicable to commercial buildings. In other terms operational and salary costs are 10 and 200 times greater than capital cost respectively (Clements-Croome 2004). Therefore the cost of designing for comfortable indoor environments is negligible when compared with the organisational benefit potentially resulting from them.

Existing literature contains strong evidence that the characteristics of buildings and indoor environments significantly influence rates of respiratory disease, allergy and asthma symptoms, Sick Building[4] symptoms, and worker performance. Theo-

[3]Recording occupant complaints is an effective mechanism of monitoring the effectiveness of building performance (Federspiel & Villafana 2003).

[4]For more information on Sick Building Syndrome refer to Apte & Erdmann (2002)



retical considerations and limited empirical data suggest that existing technologies and procedures can improve indoor environments in a manner that significantly increases health and productivity (Fisk & Rosenfeld 1997). At present we can develop only crude estimates of the level of productivity gains that may be obtained by providing better indoor environments but they are expected to be very large. For the U.S. estimated potential annual savings and productivity gains are in the region of $6 - $19 billion from reduced respiratory disease; $1 - $4 billion from reduced allergies and asthma; $10 - $20 billion from reduced sick building syndrome symptoms and $12 - $125 billion from direct improvements in worker performance unrelated to health. Sample calculations indicate that the potential financial benefits of improving indoor environments exceed costs by a factor of 18 to 47 (Fisk & Rosenfeld 1997). This awareness of the connection between human productivity and the working environment has driven some clients to implement intelligent systems in new buildings in order to achieve an energy-efficient environment that can maximize the efficiency of the occupants while simultaneously promoting maximum profitability for their own business (Himanen 2003, Sobchak 2003, Wigginton & Harris 2002, Smith 2002, Robathan 1994). However the vast majority of organisations are unaware of the connection between human productivity and the working environment and do not utilise beneficial technologies (Morrissey 2006*a*).

Inefficient building operation results from a range of individual and interconnected factors which are now be discussed in turn.

1.4.2 Client Education

This section describes the need for client education in the context of efficiently building operation. Clients commonly have a limited understanding of the design process, the construction process and building function (Morrissey 2006*a*) and consequently fail to understand that the building performance is an organisational asset 1.4.1. They have no tangible medium from which to understand the discrepancy between intended and actual operation but this barrier could be overcome by incorporating virtual models that act as an ideal representation of building performance. Many clients are unaware of how to demand a building that will perform effectively in an energy efficient manner and exceed minimum legislative

requirements (Morrissey 2006*a*). Design guidance is often given by actual designers such as architects and engineers and consequently the building falls into the mould of a traditional or code compliant fragmented design/build/operate scenario. At the heart of this is that actual energy consumption is often two to three times that of predicted design and that a performance based design of new buildings could consume 50-75% less energy relative to 2000 levels (Clarke 2001). Emerging mixed-mode HVAC systems that interactively support natural ventilation and air conditioning are demonstrating 40-75 % reductions in annual HVAC energy consumption for cooling (Loftness et al. 2004). In order to mitigate inflated operational expenses "clients must be educated and change their perspective in order to realise they can act as drivers for the process that would deliver a higher performing product" (Morrissey 2006*a*). Failure to match the expectations of clients or end-users could intensify the disconnect between the expectation and fulfilment of the intelligent building. This may result in a serious decline in confidence and interest in intelligent technologies (Pati et al. 2006).

1.4.3 Environmental and Energy Management Resources

This section describes the role and resources of Energy Managers. Across the spectrum of global organisations/institutions/industry the title and subsequent role of the individual or group responsible for energy management can vary dramatically (Tay & Ooi 2001). Roles such as *Facilities Manager, Building Manager* and *Building Operator* can incorporate energy management. At an operational level this responsible person is often not allocated the necessary resources to perform their jobs optimally. The convention adopted for this thesis is *the role of the Energy Manager* and this will be used consistently throughout the text.

The human race evolves through specialist professionals (Diamond 2005). The building management domain cannot evolve and deliver optimum environmental and energy management if the professionals concerned are not equipped with the correct information and tools to perform their jobs correctly. For illustration purposes an analogy with the aeronautical industry is used. The Plane Manager or pilot works for an organisation that operates under strict legislative guidelines. A pilot must undergo extensive training and pass stringent examinations before he is allowed to fly independently. While in the air a pilot relies on the information

provided from cockpit instrumentation and his perception of weather conditions. Essentially the pilot is completely dependant on accurate information to fly the plane properly and to guide passengers safely to their destination.

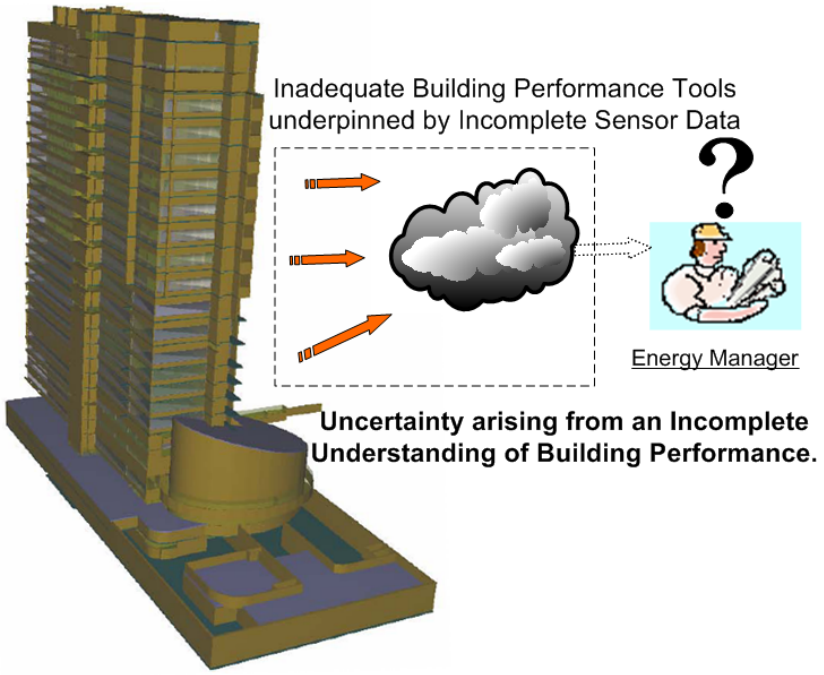


Figure 1.5: *The Present Building Stock Fails to Provide Energy Managers with the Data and Information They Require.*

The Energy Management role must be carefully specified within the context of each unique organisation's objectives. Energy Managers, like pilots, rely on instrumentation and data presented to them from BMS and EMS to safely and efficiently manage a building. However the information viewed is not as reliable as that in a cockpit and in fact is not legally required. *In order to make well judged decisions Energy Managers must therefore base decisions on the information at hand. Data provided must be reliable, accurate and relevant to the time period being considered.* All too often the data provided to Energy Managers is inadequate and they are subsequently forced to base decisions on incomplete and/or inaccurate information (Figure 1.5). A pilot is provided with consistently accurate information because of aviation safety requirements and is comfortable in the knowledge that the decision he makes based on this reliable data will be correct. Conversely an Energy Manager, who is provided with inadequate information and inaccurate data is still forced to make decisions which are not always judged to

be correct. This situation is unavoidable due to the methods by which the information they require is currently defined structured and displayed. Emerging European legislation now places a legal requirement on building owners to assess and monitor their properties with respect to energy use and systems performance (Section 1.3).

Many buildings operate inefficiently under the current systems. In order to reduce mounting utility and maintenance costs organisations have taken measures such as reducing employee numbers or upgrading energy consuming devices (Mahling & Lehman 2005). The resultant under-staffing and equipment failures due to insufficient maintenance ultimately have a negative impact on occupant productivity and building function and may lead to further losses. It is vital that these organisation become aware that the benefits from a performing building far outweigh the costs incurred.

1.4.4 Tools and Techniques

This section describes the tools and techniques that are available to Energy Managers. Conventional wisdom dictates that the most important decisions regarding building operation are taken at design time (Papamichael et al. 1997). If the consequences of design decisions tend to be more abstract they receive little extra attention, resources or fine-tuning (Selkowitz et al. 1996). However these 'abstract' issues grow to be tangible overheads for the client in the form of large utility bills. Traditional design practices which 'design to code' have often proven not to produce an energy efficient building stock. Generally, existing building codes that are prescriptive in nature (Hui 2002) do not necessarily promote the development of environmentally friendly energy efficient buildings. Building designs that focus on energy efficiency and environmental impact from the early schematic phases of building design can sometimes exceed code requirements by more than 50% and even reduce initial cost (Larsson 1995).

Existing operational techniques compare normalised bulk energy consumption against similar buildings. Energy Star is a United States national tool based on building characteristic and energy use data from the DOE/EIA Commercial Building Energy Consumption (CBECS) survey. This tool is a regression-based



model which includes building type, floor area, energy use and location inputs as well as occupancy-related factors such as number of occupants, operating hours and number of computers (EnergyStar 2006). Location is used to obtain weather data for use in the model. The Energy Star score (0-100) is an estimate of how many similar buildings nationwide have higher energy use intensities (EUI). An Energy Star score of 75 signifies that the building's energy use intensity is better than 75% of similar buildings nationwide if the building also meets the indoor environment criteria (Matson & Piette 2005).

Cal-Arch is a web based tool that graphically shows how a building's EUI compares with its sample set of similar buildings and reports the percentage of buildings in the database that have lower EUI (Cal-Arch 2005). Cal-Arch is a simplistic distributional model based on building type, floor area, energy use and location. It was designed as an initial simple tool to provide a public view into the California Commercial End-Use Survey (CEUS) data. The tool is simple in design because the data from the Cal-Arch CEUS are limited. The current tool is easy to use and provides a relative ranking of a building's EUI within the distribution of energy use intensity for the CEUS buildings in the Cal-Arch database (Cal-Arch 2005).

If suitably educated clients became a reality the outdated and ineffective design process could be eradicated. Design teams could be given the freedom to innovate provided this innovation was proven to work. For example California's Title 24 grants the designer freedom to move away from a prescriptive based design if the alternative can be demonstrated to be at least as energy efficient (CEC 2005). Title 24 performance compliance is based on whole building energy performance simulation. The use of the EnergyPlus simulation engine to demonstrate legislative compliance will be permitted as of 2008 (Huang et al. 2006). In Ireland only Dun Laoghaire-Rathdown County Council has moved away from the traditional prescriptive approach. Their regulations state new developments must consume 40% less energy than the national prescriptive guidelines and that 20% of the consumed energy must come from renewable energy sources. A means of demonstration has not yet been defined (RTE 2007).

A holistic understanding of building performance is unattainable using cur-

rent building design and operational management tools and techniques. Efficiency cannot be determined from displayed sensor readings without data access, storage and post processing. Scheduling information is not displayed concurrently with BMS data. Functionality that accompany BMS schematics cannot communicate efficiency or *relate performance to an 'ideal benchmark' for the desired level of analysis.*

1.4.5 Documentation across the entire BLC

This section describes the lack of formal documentation across the BLC and how it contributes to inefficient building operation. Current building performance assessment is fragmented as it fails to address all stages of the BLC. Actual building performance is often inconsistent with design expectations. Predictive techniques employed are not necessarily incorrect but may suffer from inadequate information about actual operation. Design professionals seldom have an opportunity to operate and monitor building performance.

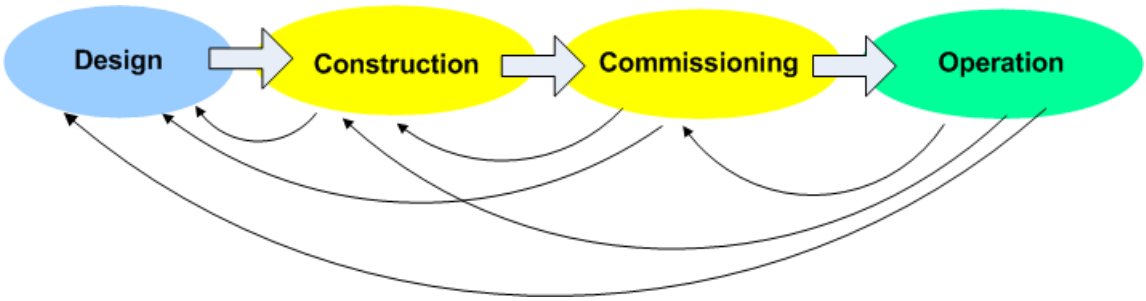


Figure 1.6: *Building Life Cycle Information Flow Requirements*

CIBSE Guide F incorporates a comparative table for normal and best practice buildings of similar type (CIBSE 2004). The CIBSE log book is a repository for all building related operational information and is used in the United Kingdom (CIBSE 2006*a*). The CIBSE Log Book greatly assists transfer of information to and from the Energy Manager and is a pragmatic first step that will have a huge impact on the operation of Britain's existing building stock. The CIBSE log book is currently not a legal requirement in Ireland. In reality it is another step in the traditional design/build/operate process where a completely new approach is needed for new buildings and refurbishments. In the United States Energy Managers are limited to guidance from the "FEMP Guidebook for Federal Energy



Management" (Liu et al. 2002) or the FEMP operation and maintenance guide (Brambley et al. 2005). The information flow that is ideally required between the different phases of the BLC is highlighted by Figure 1.6.

A number of previously developed building and facility performance frameworks exist. Hitchcock (2002) and O'Sullivan (2004a) explain the merits and drawbacks of many of the leading frameworks in the context of building life cycle performance analysis. Organisations such as the International Council for Building (CIB) (CIB 1953), American Society for the Testing of Materials (ASTM) (ASTM 1898), International Code Council (ICC) (ICC 1994), United States Green Building Council/ Leadership in Energy and Environmental Design (USGBC/LEED) (USGBC 2005), and British Research Establishment's (BRE) Environmental Assessment Method (BREEAM) (BREEAM 2005) all have their own respective frameworks and rating systems for building performance.

In order to make decisions all professionals across the BLC, especially the Energy Manager, need to be able to predict and assess the performance of their ideas with respect to various criteria such as alternative designs, comfort, aesthetics, energy, environmental impact and economics. Performance prediction with respect to environmental impact requires complicated models and massive computations which are usually possible only through computer-based tools (Papamichael 2000). Performance prediction and assessment through all forms of such simulation tools including Computational Fluid Dynamics (CFD) (CFX), Daylighting (Radiance) and Cost Estimation (Timberline) provide the basis for informed decision making (ANSYS 2008, Radiance 2008, Timberline 2008). Buildings are the only products that are not tested before delivery to the client (Bazjanac 2004*b*). *Virtual testing increases the probability of buildings that operate as intended and minimise the risk of failure.*

Statistical analysis using a 'sample of similar buildings' fails to account for the unique nature of each building. By definition, all building performance assessments must be simulation based before construction. This assessment must be updated throughout the BLC and utilised at an operational level. In light of this the traditional job description which focuses on keeping systems operating and only reacting to complaints and alarms fails to achieve optimal building operation.

1.4.6 Ineffective Business Process Models

This section describes how current ineffective business models contribute to inefficient building operation. It is widely accepted that the construction industry operates through inefficient business process models and buildings consume more energy than intended at design. The Latham Report was commissioned as a result of inefficient procedures across the construction industry as a whole (Latham 1994). A more recent report published for the National Institute of Standards and Technology (NIST) conservatively estimates $15.8 billion per year is lost in U.S. capital facilities industry (commercial/institutional buildings and industrial facilities) due to inadequate use of interoperability with $9.1 billion attributed to inefficient building operation (Gallaher et al. 2004). Mills et al. (2005) deduced that if commissioning was undertaken across the entire U.S. building stock a potential annual energy savings of $18 billion could be achieved.

Traditional design/build contracts pay designers a percentage of the capital cost associated with their respective area of a project. Consequently these payroll structures often financially penalise stakeholder teams who pursue load reduction which can result in equipment downsizing as such measures may result in a fee reduction for the designer responsible (Hitchcock et al. 1998). This type of fee structure is counter productive to the client's operational needs[5] and is extremely restrictive for a design team. Final design is all too often the latest design at the time of deadline (Khemlani 2004). Designers are only required by law to design to minimum code requirements code. Innovation which will require additional workload and risk is simply not deemed cost effective or measurable.

Designs resulting from traditional practices do not meaningfully account for environmental impact of a particular project. *Without change the marketplace will be condemned to repeat a history of poor design, ineffective building operation, elevated CO_2 emissions and an inability to emulate the success stories* (Morrissey 2006*a*). Pati et al. (2006) support dialogues between stakeholders in the design process through rational expressions of building performance. Dialogue must be maintained among all BLC project stakeholders in order to deliver optimum building operation. Existing data communication and data regeneration procedures among the design team are inhibiting factors to the efficiency of the overall design

[5]In Ireland Architects are entitled to 2-5% of capital cost while Mechanical and Electrical designers obtain approximately 1%



focus (Bazjanac 2001). For example a simulation specialist may have to recreate a domain specific representation of an existing project. A central data repository from which all project stakeholders can interact is a fundamental requirement for BLC performance based design and operation of buildings.

1.4.7 Summary of Key Findings

The key findings associated with a worldwide inefficient building stock are:

- The building stock is a significant contributor to worldwide CO_2 emissions (Section 1.1 & 1.2);
- Absence of Internal Organisational Drivers (Section 1.4.2);
- Immature External Legislative Drivers (Section 1.3);
- Requirement for the currently absent breakdown of performance related information for experience and inexperienced Energy Managers (Section 1.4.4);
- Unrealised significance of building function especially with regard to office environments (Section 1.4.1);
- Systems that do not account for the link between building function such as human productivity and indoor environmental conditions (Section 1.4.4);
- Client education has not yet evolved to demand energy efficient buildings (Section 1.4.2);
- Requirement for a specifically defined Environmental and Energy Management role within organisations is uncommon (Section 1.4.3);
- This defined Energy Manager role requires customised information originating from virtual models and measured physical datum streams (Section 1.4.3);
- This defined Energy Manager role requires techniques for comparing accurate ideal performance benchmarks, as provided by virtual models, with actual measured performance (Section 1.4.4);
- Requirement for ideal performance to be stipulated at design, updated and tracked across the BLC (Sections 1.4.5 & 1.4.6);

- Requirement for a performance framework to capture design intent and communicate among all BLC stakeholders (Section 1.4.5 & 1.4.6).

1.5 Thesis Objectives and Approach

The proposed *research question* is formulated based on the key findings listed in Section 1.4.7. *How can an Energy Manager, working at the operation level of an organisation, make informed decisions?*

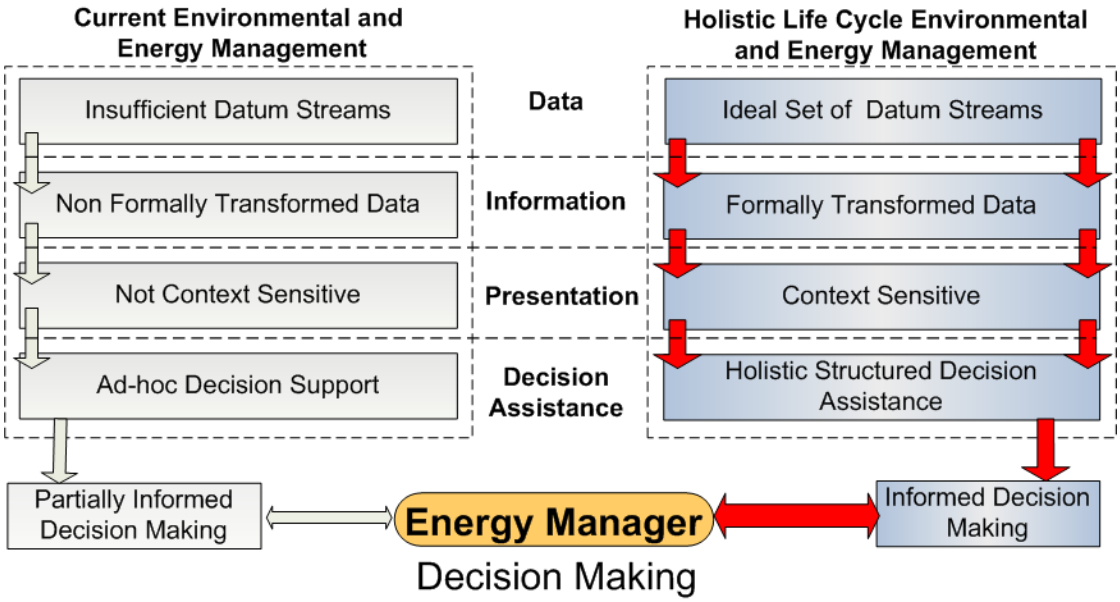


Figure 1.7: *Thesis Research Objectives*

This thesis aims to address this research question by defining a framework capable of providing holistic structured decision assistance regarding the environmental and energy management of buildings for the established profile of Energy Managers. This framework must address the key existing discrepancies stated in Section 1.4.7 and specify the important components of the proposed solution (Figure 1.7). These are:

- Remove the need for current ad-hoc decision making and specify non-prescriptive decision assistance processes for Energy Managers;
- Eliminate the limitations of proprietary software by outlining context sensitive information presentation for profiled stakeholder Views that enables optimum building performance;



- Eliminate ad-hoc data access by defining a rule based process that outputs context specific stakeholder (Energy Manager) data and information;
- Define the ideal set of datum streams and the sources of these datum streams that in turn underpin context specific stakeholder (Energy Manager) data;
- Maintain consistency between design intent by specifying a required Building Life Cycle compliant storage mechanism to realise holistic environmental and energy management;
- Define, through a background analysis, the domain of Environmental and Energy Management in buildings and its respective key elements. Develop a context sensitive information presentation technique that incorporates a comparison of actual operation and an ideal building performance benchmark for the profiled Energy Manager;
- Identify the weaknesses in current building and energy management practices and in doing so establish the key criteria under which the entire domain should be analysed. A structured case study analysis using the established criteria will complement the literature findings and reinforce the value of the key criteria;
- Effectively demonstrate the requirements for an appropriately selected public building.

This thesis stipulates that Energy Managers, working at the operational level of an organisation, can achieve optimum energy management by closing the gap between ideal and measured performance. It is imperative to note that performance can only be measured if the required function is defined in a quantified manner (Augenbroe & Park 2005). Therefore both ideal and measured performance should be quantified in the same way, thus enabling a one-to-one comparison. Numerous factors influence performance targets for a particular building and these may include legislative standards, rating systems etc. A performance based design process that results in realistic and quantifiable performance targets is required. Performance targets must also be updated to reflect changes that occur across the BLC, thus ensuring a one-to-one comparison of ideal and measured performance during operation (IAI 2006).

1.6 Thesis Structure

The Thesis overview is illustrated in Figure 1.8. Chapter 2 defines the domain of building environmental and energy management and identifies the weaknesses in current practice. The research significance of this thesis is also outlined. Chapter 3 describes the requirements of holistic environmental and energy management and proposes a solution, initially in the form of a rudimentary model. Chapter 4 introduces the framework to support holistic environmental and energy performance. Chapter 5 describes the data that underpins the proposed framework. Chapter 6 defines a process that enables all stakeholders interested building performance to access only the data relevant to their particular discipline. Chapter 7 specifies a holistic environmental and energy management information delivery tool that is specifically designed for use by Energy Managers. Chapter 8 investigates the decision making process of the Energy Manager and outlines new decision assistance processes that support holistic environmental and energy management. Chapter 9 demonstrates the concepts introduced throughout the thesis on an existing prototype building. Chapter 10 discusses the conclusions from this research, the limitations and the future work required.

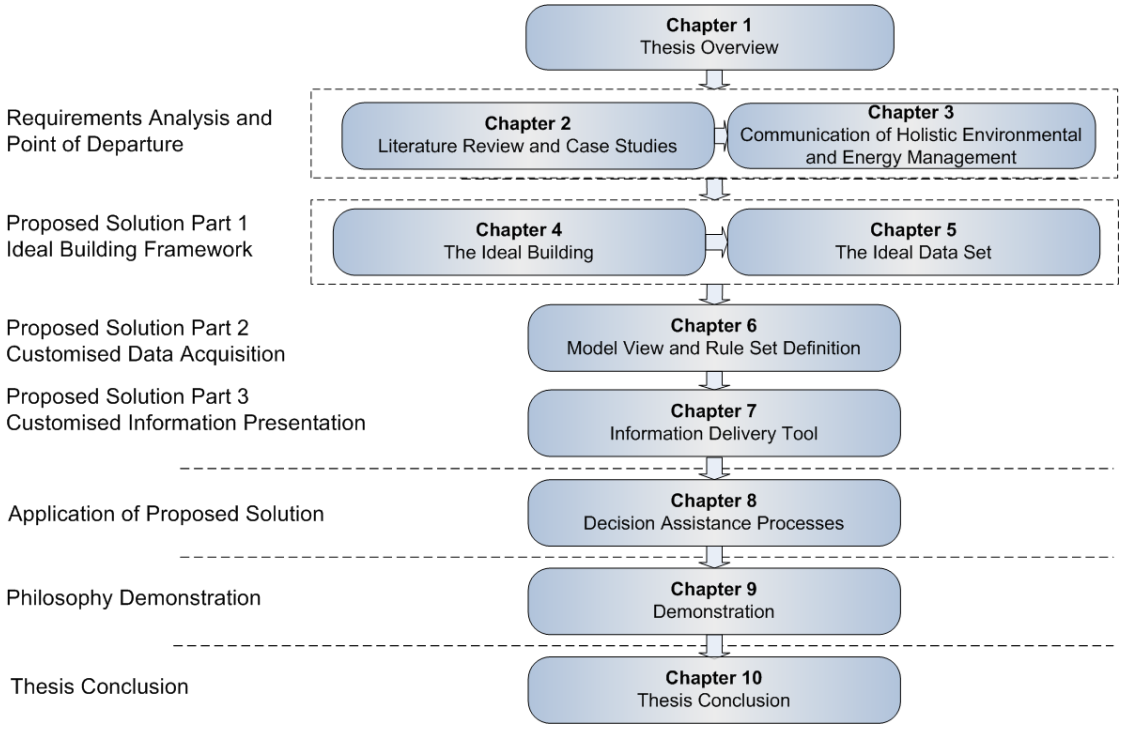


Figure 1.8: *Thesis Overview*

Chapter 2

Environmental and Energy Management

A well performing building is one that should

> "*support high levels of energy efficiency, occupant comfort and productivity, and indoor air quality, with low operating and maintenance costs*"

(Hitchcock et al. 1998)

2.1 Chapter Introduction

This chapter examines in detail the domain of Environmental and Energy Management in buildings. It focuses primarily on environmental and energy management activities and the factors that directly influence these activities. The chapter layout is as follows:

- Literature review of current best practice environmental and energy management of the built environment;
- Case study of three organisations that reflect current environmental and energy management in buildings;
- Requirements analysis for domain advances addressed in this thesis based on a synthesis of the literature review and the case studies;
- Research significance based on the findings of the requirements analysis.

2.2 Domain Review

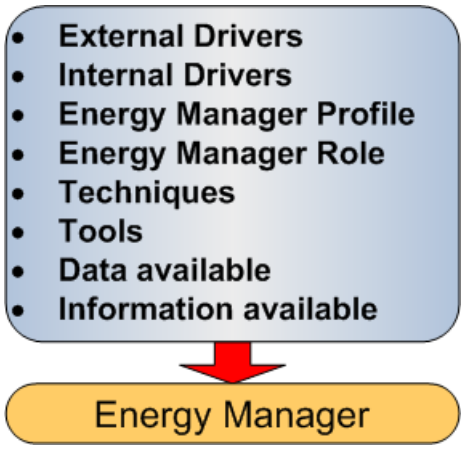


Figure 2.1: *Factors Influencing Organisational Environmental and Energy Management*

This section describes the *drivers* (environmental, political, legislative, economical and public image) for organisational energy management. The significance placed on the external and internal drivers ultimately determines the *role* of the Energy Management department. The factors that influence organisational environmental and energy management are illustrated in Figure 2.1. The personnel responsible for energy management are profiled under the categories of *role*, experience, knowledge and education. This section also describes the weaknesses in current energy management with respect to *data, information, tools* and *techniques*.

2.2.1 Energy Management: External Drivers

In certain circumstances public image can act as an external driver but the key external organisational energy management driver is legislation (Geoghegan & Fenner 2007, O'Connor 2007, Ahern 2006). The Emissions Trading Directive (Directive 2003/87/EC) places a legal requirement on monitoring site related CO_2 emissions based on existing thermal input capacity and fossil fuel energy consumption (EU 2003a). For the first time Financial Controllers must now take account of the financial penalties associated with exceeding the predefined energy consumption threshold. Carbon credits are purchased or sold on a per ton basis. Current analysis predicts 100 Euro per ton purchased and 40 Euro per ton sold (O'Gallachoir et



al. 2007). A legally binding requirement has now been established for maintaining energy efficient buildings or pay financial penalties. Emissions trading has been implemented in two phases 2005-2007 and 2008-2012 to coincide with the time frame for the Kyoto protocol (Georgopoulou et al. 2006).

The Energy Performance of Buildings Directive (2002/91/EC) requires that all Buildings are certified with an energy label (EU 2002). The objective is to qualify and quantify the energy consumption and efficiency of the entire European building stock which would in turn stimulate an ethos of energy efficiency and market focus that underpins energy efficiency in the built environment.

The EPBD will be superseded by the Energy Services Directive (Directive 2006/32/EC) which has been drafted to remove existing market barriers such as reluctance to invest in metering due to intangible returns on investment and came into effect on May 17^{th} 2008. The Energy end use and Services Directive will also address imperfections that impede the efficient end use of energy within buildings especially with regard HVAC system performance (EU 2006). Cumulatively this legislation proposes to create a 9% improvement in building stock energy efficiency by 2016 (SEI 2007). Buildings, HVAC systems and HVAC system components will require reliable data that can be formally transfered for the analysist concerned (Section 1.5).

2.2.2 Energy Management: Internal Drivers

Capital cost is the primary internal driver in relation to energy management. Typically managed organisations regard energy as one of many utility bills that have to paid and not optimised. In fact 25% of the top FTSE 100 companies do not utilise a Building Management System (BMS) (BSI 2006). In practice energy managers spend a minimal amount of time focusing on energy consumption due to the resources allocated by the organisation (Section 2.3). A BLC cost is generally not considered in new or retrofitted buildings where capital cost is the primary driver. In cases where operational cost is considered, a 2-3 year return on investment is required (Geoghegan & Fenner 2007, Keane 2007, RPS 2007).

Standard practices with respect to building energy management are only now beginning to emerge. European Standard EN 16001 which is based on Irish Stan-

dard IS 393 is due in mid 2009 and an international ISO standard is expected within two years Morrissey (2008). IS 393 is effective for organisations with an annual energy spend in excess of €750,000 and modifications are required to make this standard accessible for all organisations (Morrissey 2008). The availability of these standards should make energy management more accessible to organisations but require internal initiative to be implemented.

2.2.3 Energy Management: The Role and Background

In the context of this thesis an Energy Manager is responsible for the energy management of an individual building. Three roles that have the potential for energy management exist within organisations and these roles are Facilities Manager, Building Manager and Building Operator. The resources allocated for Facilities Manager, Building Manager and Building Operator significantly depends on the internal and external drivers that affect the organisation. A Facilities Manager may operate at a higher level and can be responsible for a number of buildings. Regardless of the level of responsibility their primary function is resource management at strategic and operational levels of support (Nutt 2000). The scope of this discipline typically covers all aspects of property; space; environmental control; health; safety and support services (Alexander 2004). Building Managers perform a subset of the facility manager's tasks, typically for an individual building. In contrast to a Facilities Manager, or Building Manager, a Building Operator is involved in the day to day operation and maintenance activities. The Building Operator Certification (BOC) provides customised training that focuses on energy-efficient building maintenance practices, advanced equipment troubleshooting and preventive maintenance (BOC 2007).

Table 2.1: *Educational Qualifications of U.S. Facilities Managers and U.S. Managers (Courtesy of FMLink (2004))*

Survey Percentage	**Educational Qualification**
18%	High school Degree
17%	Associate Degree
42%	Bachelor's Degree
22%	Master's Degree
1%	Doctorate Degree

Approximately 68% of Building Managers are responsible for energy manage-

ment (FMLink 2004)[1]. The experience and education of Facility and Building Managers varies considerably. The average experience of U.S. Building Managers is 17 years (FMLink 2004). Table 2.1 illustrates their educational qualifications. Traditionally Building Operators have been qualified tradesmen (FMAA 2003).

If the education and experience of personnel responsible for energy management vary so dramatically their work experience will vary accordingly. Adequate training could compensate for this disparity in education and experience. However the reality is that training is seldom provided for the Energy Manager (RPS 2007). A generic profile of Energy Managers must consider this variation in educational background, experience and training provided in order to advance the environmental and energy management domain.

2.2.4 Energy Management: Data & Information

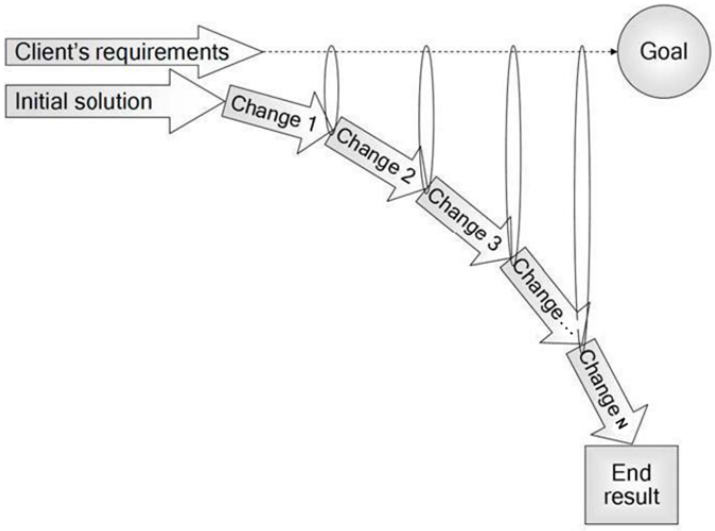


Figure 2.2: *Design Intent Compared with Reality (courtesy of (Kiviniemi 2005))*

The Building Life Cycle (BLC) is a complex disconnected process composed of interactions between the different project stakeholders (Hitchcock 1996). The inadequacies of information archival and sharing between stakeholders have been clearly documented by Luskay & Forester (2001) and Hitchcock (1996). Research at Texas A&M University has found that the majority of older buildings and even

[1]The level and scope of energy management activities was not discussed in the survey.

in many new buildings, space use is quite different from the original plan (Claridge et al. 1994). In essence a disconnect exists between initial design and building operation (Figure 2.2). An Energy Manager operates downstream in the BLC. Loss of data and fragmentation of information are the legacy of this outdated design/building/operate process. An Energy Manager requires up-to-date, pertinent information for building operation but this is often absent (Hitchcock 1996).

The types of data/information that are required by the Energy Manager are illustrated in Figure 2.3. Design information is partially transferred to the construction/commission stages. The subsequent transfer between construction/commissioning and actual operation further dilutes information available for Energy Managers. Performance information including intended system operation is not updated across the BLC. Information generated by the construction/commissioning phase of the BLC is transferred in the form of Operation and Maintenance (O&M) manuals, schematics etc. However O&M manuals are often incomplete (Keller et al. 2007). At operation, available documentation fails to reflect changes across the BLC. O&M records are traditionally stored in an ad-hoc manner (CIBSE 2006*a*).

The relative amount of information loss across the BLC is evident. Holistic environmental and energy management necessitates that all required building performance information is transferred across the BLC. The consequences of information loss across the BLC (Figure 2.3) are:

- Actual building performance is often inconsistent with design expectations, as design intended operation fails to be communicated to Energy Managers. Less than 2% of design professionals utilise simulation tools to enhance design (CCTP 2005). Predictive techniques that quantify building energy performance are not necessarily updated accross the BLC;
- A disconnect exists between design professionals and Energy Managers. Design professionals seldom have the opportunity to operate and monitor buildings (Bordass et al. 2004). Similarly an Energy Manager may not fully comprehend the design intent of the architect or engineer particularly in light of a lack of technical education. In such situations Energy Managers require access to the missing necessary information as a basis for informed decisions.

Information Management / Information Description	Design Stage – HVAC Designer				Construction & Commissioning Stage – M&E Contractor				Operation Stage – Facilities Manager		
	Received	Generated	Stored	Handed On	Received	Generated	Stored	Handed On	Received	Generated	Stored
Brief Provided by Client											
Building Profile	x		x	/	/				/		/
User Profile	x		x							x	x
Energy Requirements	x		x								
Design Information											
Design Calculations		x	x								
Simulation Models		x	x								
Simulation Output		x	x								
HVAC Schematics		x	x								
Design Alternatives		x									
Design Intent		x	x	/	/					/	/
HVAC Component Specifications		x	x	x	x		x				
HVAC Operational Schedules		x	x	x	x		x				
Construction & Commissioning Information											
BMS Specifications						x	x	x	x		x
Operational & Maintenance Manuals (including:)						x	x	x	x		x
As-Built Schematics						x	x	x	x		x
As-Built Component Specifications						x	x	x	x		x
Component Maintenance Requirements						x	x	x	x		x
Component Commissioning Data						x	x	x	x		x
Operational Information											
Building Performance History											
Utilities Bills										x	x
Sensor Readings										x	/
Component Performance History										x	
Component Maintenance History										x	/
BMS Alarm Records										x	

x = Full Information Transfer
/ = Partial Information Transfer

Figure 2.3: *Partial Transfer of Information Across the Building Life Cycle (Courtesy of Barry O'Sullivan)*

Unambiguous communication of ideal and actual building performance information is required by Energy Managers to allow them to fulfill their roles. The BLC information loss has a direct impact on the tools used during operation. Energy Managers are limited to the use of BMS and Energy Management Systems (EMS) or Energy Management and Control Systems (ECMS) systems. Section 1.4.4 identifies the necessity for simultaneous access to environmental and energy management information. An adequate data set that can be appropriately transformed into information in a format that recognises the technical competencies of the end user is required. A performance benchmark for comparison at operation must also reflect updated design intent.

2.2.5 Energy Management: Tools

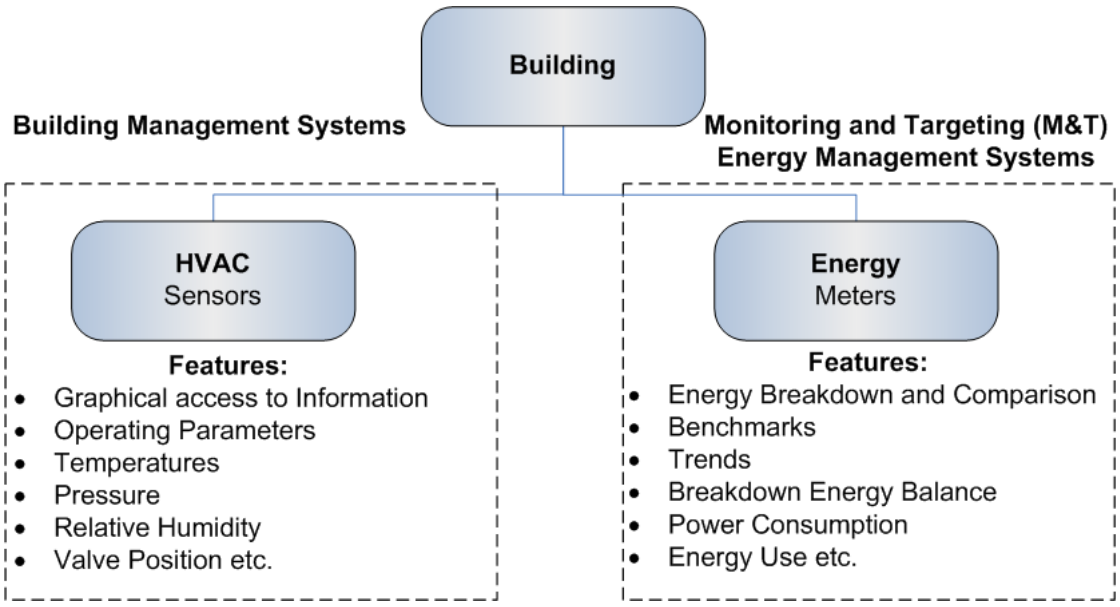


Figure 2.4: *Simplified Diagram of Conventional BMS and EMS Datum Sources and Functionality*

BMS and Energy Management Systems (EMS) are proprietary, integrated software and hardware environments. The absence of BMS standardisation coupled with competition for market share results in independent and non-compatible system development. BACnet^{TM} was developed to provide an open, non-proprietary protocol specification that allows building automation controllers of different manufacturers to communicate with each other (ASHRAE 2003*a*, Bushby 1997). However BMS/EMS still possess non-standardised proprietary interfaces and vendor



competitiveness has resulted in additional functionality. Consequently BMS/EMS are becoming more complex over time and are difficult for the average operator to understand given the educational and experience previously outlined (Lowry 2002, Hyvrinen & Krki 1996). Additional training overhead is required for each new system or system update (Agarwal et al. 1996). In conjunction with traditional procurement policy it is conceivable that numerous non-compatible systems can appear on one site (Ahern 2006), therefore increasing the training and maintenance overheads (Cylon 2005, Honeywell 2007, Siemens 2007). Hatley et al. (2005) states that in the absence of compatible hardware and communication protocols, maintenance can become extremely problematic as seamlessly integrating these systems is an inefficient overhead.

Current available operational performance data and information is accessed through a BMS interface and/or an EMS. A generic breakdown of functionality is depicted in Figure 2.4. BMS focus on system operation and include alarm signals for pre-programmed important criteria. Key system information is available for predefined points, for example boiler flow temperature. A sample BMS interface as used by Energy Managers and illustrated in Figure 2.5 is representative of most available interfaces (RPS 2007). Some data and information for the primary hot water source in this particular building is displayed. It is impossible for an Energy Manager to obtain a complete understanding of system performance from the information provided in Figure 2.5. An Energy Manager can determine the system is working within expected tolerances but end use information such as zone occupancy status is unavailable. An example of two separate systems that individually satisfy specific requirements illustrates the problem. An air conditioning system controls the fresh air requirements of this zone environment. A second radiator system adds necessary heating to the zone. The zone contains industrial processes that routinely contaminate the air beyond acceptable air quality safety limits. The safety operational strategy increases supply air flow and exhaust through windows that open, for such an event, when air borne contaminants reach an unacceptable level. An Energy Manager will observe through a conventional BMS that both systems are operating within acceptable limits. In this situation radiators located by the open windows should be bypassed to avoid unnecessary energy consumption. However traditional BMS interfaces do not provide the Energy Manager with the ideal information as all systems appear to be operating normally.

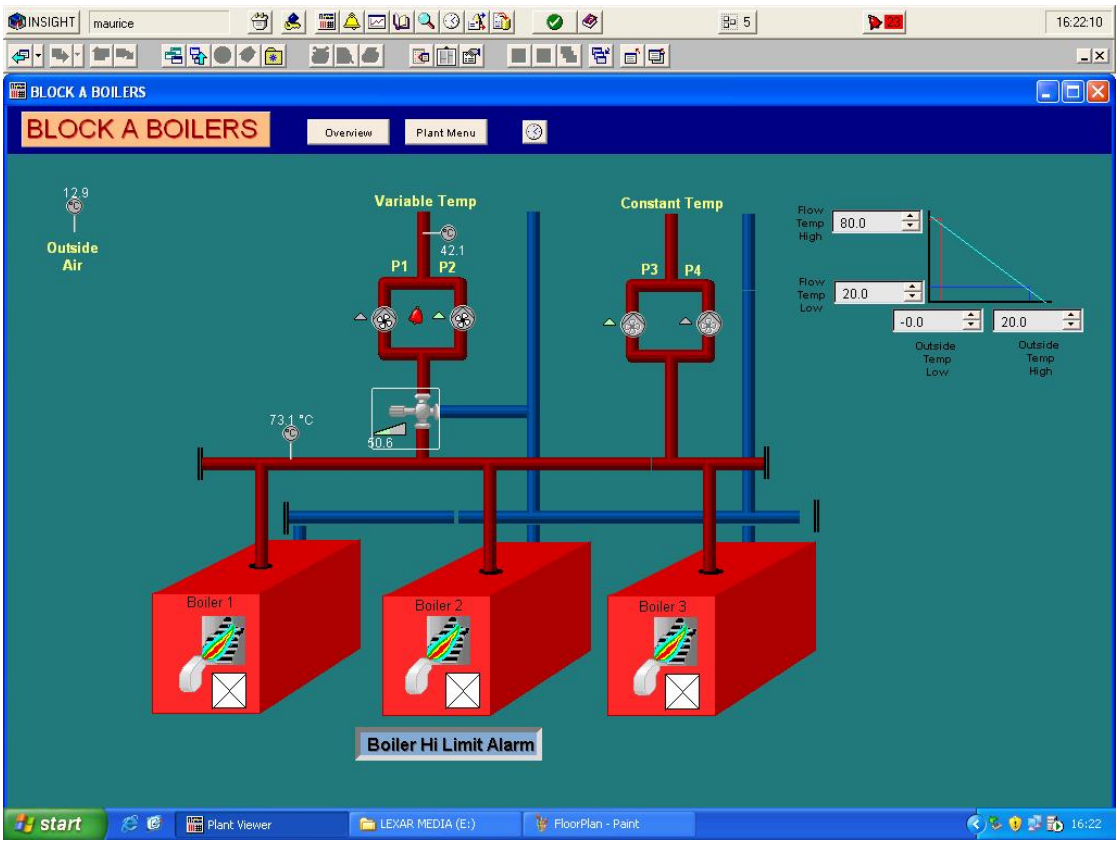


Figure 2.5: *Siemens BMS Screen Shot of Block A Boilers System at the University College Cork Student Center*

In depth HVAC and system experience is required to deduce meaningful conclusions from a conventional BMS interface. The usefulness of information displayed through an interface is dependant on the experience, knowledge and training of the end user. Interfaces which update readings at regular intervals (Figure 2.5) cannot convey system operation as intended by design. Efficiency cannot be determined from displayed sensor readings without data storage and data post processing. Scheduling information is not displayed concurrently with BMS data. Trend display and alarm functionality that accompany such BMS schematics cannot communicate efficiency or relate performance to an 'ideal' for the desired level of analysis. Depending on the complexity of the system under assessment monthly analysis of utility bills may not uncover areas of inefficient operation. Furthermore, most BMS do not include energy monitoring in their scope and are limited in collecting, archiving, and displaying important building performance data (Piette et al. 2001). More modern BMS incorporate data archival but Energy Managers need

assistance in extracting useful information from the large volume of data produced (Piette et al. 2001). It is at the Energy Manager's discretion to define and calculate meaningful metrics based on the information available to him. Considering the profile of personnel previously developed in Section 2.2.3 it is highly probable that the selection and calculation of appropriate metrics is beyond the capabilities of many Energy Managers.

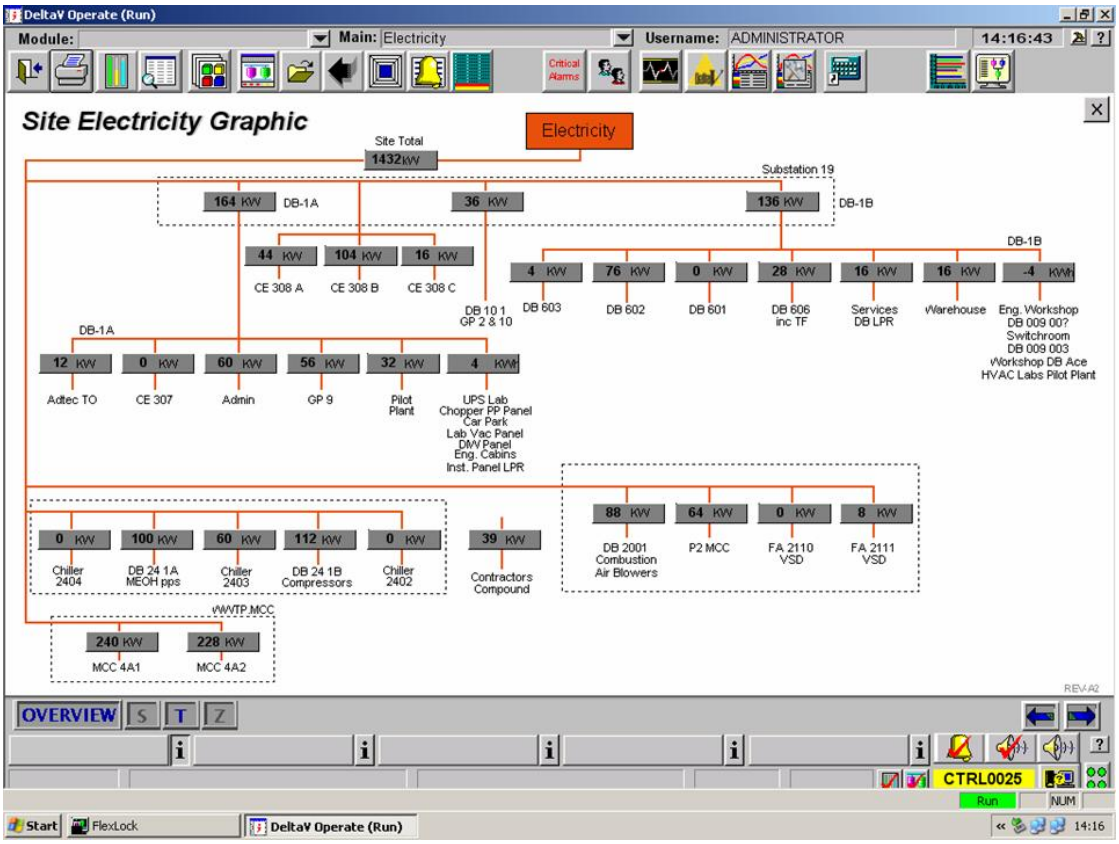


Figure 2.6: *Example of the EnergyFocus Energy Management Software Interface (provider wishes to remain anonymous)*

EMS primarily focus on the major energy consuming devices in a facility. Organisations are now realising the benefits of utilising both systems. Energy management software as illustrated in Figure 2.6 graphically depicts energy consumption for a developed site of buildings and how this energy use is categorised. This interface offers an instantaneous snapshot of how the particular site is consuming electrical energy. Quick access to archived data and a comparison with benchmarked performance is available by selecting the data stream and the time period

desired by the Energy Manager. Interfaces as depicted in Figure 2.6 do not incorporate efficiency calculations or create reports for the Energy Manager. Energy consumption (e.g. chiller, compressors) is displayed but the use of this energy in cooling coils, chilled beams and so on requires additional end use sub-metering. Energy Managers are restricted to partially informed decision making in the absence of holistic performance information. A retrofit to include sub-meters can be extremely expensive if not included in the original design (O'Connor 2007). The combination of current BMS and EMS do not provide the Energy Manager with all of the information he requires in his role. Informed decision making by Energy Managers will not become a reality if present hardware and software configurations continue.

It is clear that a holistic approach to environmental and energy management requires simultaneous access to the data used by BMS and EMS. Certain *objects* are common to all buildings, for example Floors, Zones, Systems, System Components etc. It is logical that performance evaluation should focus on evaluating these defined tangible objects. Energy Managers can therefore associate performance with objects, thus facilitating a structured approach to energy management. The transformation and presentation of this information from raw datum streams for each defined object must consider the end user.

2.2.6 Energy Management: Techniques

As we have seen Energy Managers do not have the appropriate data, information and tools needed to provide optimal results (Piette et al. 2001). Consequently the role has coined the term *GIGO* "Garbage In, Garbage Out" (Hand et al. 2005). Maintenance records, energy and efficiency reports and trend analysis should be accessible to Energy Managers but this is often not the case (Piette et al. 2001). If used correctly measured HVAC time-series are descriptive of building performance but are wholly dependent on strict boundary conditions such as weather and control strategies.

Systematic procedures to address inefficient building operation are beginning to emerge (Mills et al. 2004, Hampton 2003, Claridge et al. 1994). Researcher procedures use a monitoring process of"continuous commissioning" 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 more than eighty American 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. While researchers have demonstrated success by bringing in experts who use their knowledge, experience and resources to 'fix' building systems (Baumann 2005, 2004) few tools are available to the on-site engineer to conduct such improvements (Piette et al. 2001). Again the established profile of Energy Managers must be considered when transforming and presenting building performance information.

Most energy managers track how energy is used solely on the monthly utility bill (Piette et al. 2001). Monthly energy consumption can be benchmarked against previous monthly energy consumption 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[2]. However a fundamental flaw exists for this procedure. *Each and every building is unique and what if all the buildings in the sample set are inefficient?* (Federspiel et al. 2002). It is impossible to assess the many disparate impacts of these heterogeneous factors in a single output without any comparison with an 'ideal' (Morrissey 2006*a*). In the context of building management an 'ideal' may be considered an up to date virtual representation of a building's energy performance for comparison with measured data.

Optimal operation as opposed to improved performance should be the objective of the Energy Manager. The format of the information required for building operation must consider the profile of the Energy Manager. Traditional benchmarking techniques must be updated to now compare with a building specific ideal benchmark. The proposed techniques are Scenario Modelling and Performance Metric combinations (Sections 3.5 & 3.6).

[2]CIBSE Guide F: Energy efficiency in buildings includes best practice EUI values for different building types (CIBSE 2004)

2.2.7 Review Findings

The important finding from the literature review is the establishment of key criteria for describing the domain of Environmental and Energy Management. The defined criteria are:

- *External drivers* are the key driver for organisational energy management. The implementation of *internal drivers* is organisation dependant but if deployed require a payback period of 2-3 years;
- *Role* and resources of each Energy Management department are dependant on the internal organisational drivers. Profile of Energy Managers can vary dramatically under the headings of education, experience and knowledge;
- Energy Managers who have ad-hoc access to *data* and *information*. Transformation of raw data is dependant on the profile of the Energy Manager. Decision making is based on the results of this *data* transformation;
- *Tools* used by each Energy Manager are not context sensitive and do not convey holistic building performance;
- *Techniques* employed by each Energy Manager are inadequate. Analysis against an ideal performance benchmark is not conducted.

2.3 Building Management Case Studies

The following case studies were undertaken to establish current environmental and energy management practice in buildings. The choice of Energy Managers is reflective of world wide energy management for the pharmaceutical, ICT and public body organisations. Three Energy Managers were chosen as a representative sample of building energy management in Ireland: University College Cork (UCC); Pfizer Pharmaceuticals and Intel Ireland. The University College Cork study provides a background into how a typical university campus operates and is reflected across buildings world wide (Neumann & Jacob 2007, Matson & Piette 2005). The Energy Manager is degree educated but his qualification is in a unrelated field. The Pfizer case study was chosen to investigate how energy is managed at an industrial plant. The Pfizer Energy Manager who is a qualified electrician was also voted Irish Energy Manager of the Year 2006 (O'Connor 2007). The



third case study of Intel Ireland was chosen as the company which incorporates the most advanced BMS/EMS in Ireland. The Energy Management Team are qualified mechanical and electrical engineers. Intel Ireland is also one of Ireland's largest electrical consumers.

A template for analysis of the case studies was developed to incorporate and investigate the issues uncovered in the literature review (Section 2.2). The following categories, as identified in Section 2.2.7, are the basis for the case study analysis:

- Energy Management *Drivers*: Delivery of product and legislation;
  - Overall objectives of the organisation;
  - *Role* and job description of Energy Management in terms of the objectives of the overall organisation (Resources Allocated);
  - *Profile* of the Energy Manager- Education, Experience, Training Provided.
- *Information* used and the underlying *data*;
- *Tools* used;
- Energy Management *Techniques/Strategies*;
  - Problem Identification;
  - Integrated maintenance support within the organisation.
- Benchmarking *Techniques*;
  - Comparison with previous consumption;
  - Comparison with owned building stock consumption;
  - Comparison with a normalised statistical sample;
  - Comparison with a simulated ideal.
- Other relevant features.

2.3.1 Case Study Findings

A review of present practice energy management was conducted based on the literature review and a number of carefully selected case studies. An overview of the case study findings is presented in Table 2.2. The notation used in the table is **O** for normal or typical practice, – for less than normal or typical practice and + for greater than normal or typical practice. A comprehensive case by case description and a case study analysis is provided in Appendix A. The criteria are addressed in the same order as in the literature review (Section 2.2).

Table 2.2: *Case Study Overview*

Categories	**Case 1: UCC**	**Case 2: Pfizer**	**Case 3: Intel**
External Drivers	O	+	+
Internal Drivers	–	+	+
Role	–	O	+
Data	–	O	+
Information	–	O	O
Tools	–	O	+
Techniques	–	O	O

External Drivers are the most important factor in efforts to increase the performance of the building stock. All three case studies adhered to legislative requirements.

Internal Drivers are more influential for organisations that incorporate energy intensive processes in product delivery. Pfizer recognise the importance of integrating and resourcing the Energy Management department and have identified IS-393 accreditation as part of their medium to long term energy efficient production process. Intel Energy Management focuses on an efficient production process. UCC is initiating energy management as part of its organisational objectives.

The financial controllers ultimately dictate the *role* of energy management within each organisation. Intel and Pfizer have identified the benefit of integrating and resourcing the Energy Management department. The UCC Energy Manager has other responsibilities including security and communications.

Industry wide ambiguity exists with respect to the *data* required to optimally monitor buildings. Intel identified the importance of data and log numerous data

streams. Pfizer measures process critical datum streams. UCC data monitoring is based on datum streams specified by control specialists at design. Errors identified with data archival are not prioritised.

Data underpins *information* used by energy management departments. There is an accompanying industry wide uncertainty regarding the information required to optimally manage building performance. Intel developed customised energy management software but acknowledge that they are information poor. Pfizer measure energy consumption data but identified the absence of energy end use data. UCC focus on energy performance information at the campus or portfolio level. Performance analysis for individual buildings is typically not conducted due to the absence of required data.

Customised *tools* have proven to yield greater environmental and energy management benefits as opposed to off the shelf software. A key finding is that all Energy Management departments require information at defined levels. These levels are: Building Portfolio; Site; Building; Building Storey or Tenant; Zone; HVAC System; HVAC System Components; Utility Types; Utility Breakdown; Energy End Use Categories. Intel have customised energy management software tools and additional functionality is added on request. UCC and Pfizer use off-the-shelf software and have difficulty extending the software to satisfy their specific organisational needs.

Existing benchmarking *techniques* are inadequate as they do not account for the unique nature of each organisation which in turn contains unique buildings. Measured actual performance is not benchmarking against a theoretical ideal energy consumption as provided by a whole building energy simulation model. Intel normalise their energy consumption values to account for variances in production while Pfizer and UCC benchmark against past energy consumption values.

2.4 Research Significance

The following section outlines the significance of this thesis. It synthesises the findings of the literature review and the case studies and discusses the research significance under the following headings:

- Internal and external *Drivers* for organisational energy management;
- *Role* and *Expertise* of energy management departments within the parent organisation;
- Energy Managers accessibility to *Data*;
- *Information* used by Energy Managers;
- *Tools* used by Energy Managers;s.

This section also explains how these areas are symbiotic, therefore remedying one area will only result in marginal improvement in building performance. It will conclude that a holistic solution is required.

Currently *external drivers* such as legislative requirements exist with respect to CO_2 emissions, CO_2 emissions trading and industry specific regulations. This thesis intends to resolve, where relevant, the disconnect between legislative requirements and day to day environmental and energy management.

Organisational or *internal drivers* primarily focus on achieving an organisation's objectives of which building function, product production or employee productivity are the most common. Organisations place varying levels of importance on energy management. Consequently the role of energy management differs between organisations. Environmental and energy management must be an integrated and resourced function within enterprise management and demonstrate legislative compliance.

The *role* of energy management also identified the disparity with regard to educational background, experience and knowledge of existing Energy Managers. The identified variation establishes a profile of existing and future Energy Managers (Sections 2.2.3 and 2.3). In the context of a holistic building performance solution the established profile of all Energy Managers must be carefully considered to ensure that future developments are context sensitive.

There is substantial disparity between the layout, navigation and functionality of building performance *tools* (BMS, EMS etc.). Customised software tools



would enable rapid, automated, cost-effective, meaningful, unambiguous navigation and presentation of building performance information for Energy Mangers. An information delivery tool must contain background functionality which supports context sensitive presentation, navigation and control for all relevant levels of resolution as opposed to the inadequacies of non-context sensitive user interfaces. The literature review and case study findings conclude that performance is analysed at certain levels, for example zone or HVAC system, to facilitate logical and structured holistic environmental and energy appraisal. The Building Object concept is now introduced where each Building Object corresponds to a level determined in Section 2.3.1. These structured *Building Objects* will be used throughout this thesis to support holistic environmental and energy management activities and are:

- Building Portfolio;
- Site;
- Building;
- Building Storey;
- Tenant;
- Zone, Micro-Zone (Required for optimum HVAC and lighting control);
- HVAC System;
- HVAC System Components;

Utility Types, Utility Decomposition and Energy End Use categories will be assigned to the most appropriate building, site or portfolio 'Building Object'.

In essence an Energy Manager requires the most relevant *information* for a specific *Building Object*. This thesis will specify a generic building performance information set that is capable of defining the performance of any building at the level of each Building Object. The optimum context sensitive presentation format for this information must also be defined.

However the Energy Management domain is severely limited by the *data* measured in each individual building. "*You cannot monitor what you do not measure*"

(Morrissey 2006*a*). This thesis must define a generic process through which all stakeholders with an interest in building performance can access and formally transform the data they require for a particular building (Section 1.5). This process must be applicable across the entire Building Life Cycle (Section 1.5). An specific measurement *Model View* would define that data required by a stakeholder interested in an aspect of building performance, for example an Energy Manager. Different *Model Views* would underpin the performance information required by different stakeholders but as stated in Sections 1.4 & 2.2.3 this thesis focuses primarily on the role of Energy Managers. It is further necessary to specify the assumptions, considerations and requirements of each datum stream. These measurements form a hypothetical measurement set and the conditions in which such a information set could exist must also be specified.

Quantitative *benchmarking* against past or normalised past performance and comparison of energy consumption against a statistical set of other similar buildings has fundamental flaws (Federspiel et al. 2002). Even the most advanced comparative *techniques* such as the GSA Building Performance Toolkit which offer normative and objective performance indicators falls short of comparing each building to an optimum benchmark as provided by a detailed whole building energy simulation model (Augenbroe & Park 2005). What if all the buildings in the sample set used for comparison are inefficient? Each and every building is unique and should theoretically be compared with itself. "*It is impossible to assess the many disparate impacts of heterogeneous factors in a single output (EUI as the traditional benchmark comparison for building performance) without any comparison with a theoretical optimum* "(Morrissey 2006*b*). A 'theoretical optimum' may be considered to be an up to date virtual representation of a building's energy performance for comparison with measured data. A theoretical optimum energy consumption is not used by Energy Managers. This thesis will specify a framework capable of capturing design intent in the form of qualitative and quantifiable performance indicators and update it across the entire Building Life Cycle.

This thesis will further specify guideline mechanisms through defined context sensitive processes for investigating non-optimal performance in any building thus providing substantial decision assistance. Energy Managers could then base decisions on the information at hand instead of guesswork and experience.



A holistic solution will transform the manner of building operation. More comfortable indoor environments lead to enhanced worker productivity (Clements-Croome 2003, Fisk & Rosenfeld 1997). Fewer occupant complaints will result in faster resolution of problems. Maintenance requests more efficiently if an Information Delivery Tool was applied at a 'Building Portfolio' level (Mahling & Lehman 2005) and would not require training on various BMS/EMS systems. A customised context sensitive holistic environmental and energy management tool will require an ideal benchmark as provided by a virtual model and measured data (Section 1.4.2). Lower energy consumption will result in lower energy bills and reduce liability and litigation expenses relating to indoor air quality (IAQ) issues such as Legionnaires disease. It will enable investigation of more cost effective energy configurations, schedules and tariffs (Rabie & Delport 2002). It is the authors opinion that the first step in delivering holistic environmental and energy management will facilitate greater transparency with an organisation's financial controllers. Energy Managers will have the ability to accurately demonstrate and achieve energy savings while reduced energy consumption will give credibility to energy management in the eyes of the financial controllers. Retrofitting opportunities and a Building Life Cycle approach to new building projects could become a reality.

2.5 Chapter Conclusion

Energy Management must be integrated and resourced within enterprise management and where required demonstrate legislative compliance. This requires:

- A holistic approach that clearly supports an integrated view of environmental and energy management using defined Building Objects and incorporate explicit relationships to legislative compliance;

- Benchmarking that is building specific, clearly coupled with 'design intent and be presented in a format that carefully considers the established profile of the Energy Manger end user;

- Environmental and energy data must be formally transformed to support holistic environmental and energy management in a context sensitive manner that recognises the role and educational background of Energy Manager.

Chapter 3 will now address the requirement for context sensitive, holistic performance, information presentation technique that incorporates a comparison of actual operation and an ideal building performance benchmark for the profiled Energy Manager. This technique must ultimately contribute to informed decision making as outlined in the research objectives (Section 1.5). The Scenario Modelling technique and its components is now outlined in Chapter 3.

Chapter 3

Holistic Building Performance Appraisal

> "*What gets us into trouble is not what we don't know. Its what we know for sure that just ain't so.*"

Mark Twain

3.1 Chapter Introduction

This chapter proposes a holistic approach to environmental and energy management in buildings to address the domain weaknesses established in Chapter 2. These include ad-hoc access to non-formally transformed performance data which is in turn presented in a non-context sensitive format. Each weakness must be resolved individually but solved in context of the research objectives and research significance of this thesis (Section 1.5 & 2.4). The chapter key sections are:

- Development of a rudimentary model that integrates the concepts presented in this thesis;
- Categorisation of holistic building performance requirements under key *Performance Aspects*;
- *Standardised Performance Objectives and Metrics* as the most effective *data transformation* method for the developed profile of Energy Managers;

- Introduction and definition of the *Scenario Modelling* technique which illustrates through Performance Objectives and Metrics the downstream effects of a change on all relevant *Aspects* of environmental and energy performance;

- *Combinations of Performance Objectives and Metrics* that define the union of scenarios that can be created for a specific building.

3.2 Rudimentary Model of Thesis Concepts

The solution proposed by this thesis focuses on improving building management at the operational level of organisations. For maximum effect the proposed solution must also consider the higher levels of building performance management within organisations which are 'strategic' and 'tactical'. Strategic management focuses on overall decision making at the corporate client level (Augenbroe & Park 2005) and should be defined by hard indicators for strategic level decisions (Pati et al. 2006). Hard indicators are applicable for whole facility assessment. Tactical building management focuses more on a client-building match and evaluation of performance with respect to specific client needs (Pati et al. 2009). These criteria are known as soft indicators. A prototype tool for tactical building evaluation is described in Augenbroe & Park (2005). This thesis focuses on the importance of the Energy Manager and proposes a solution for optimising operational level environmental and energy performance of buildings. This section now formalises the requirements of Chapter 2 into a series of concepts and develops a rudimentary model of the proposed solution (Figure 3.1).

In developing the rudimentary model a review of existing data integration and interoperability solutions was undertaken. Current integration or interoperability solutions take a data centric solution betting on the existence of generic mappings between design information and analysis tools (Augenbroe et al. 2003). It was found that in the context of this thesis, which is optimum building operation, a full representation does not currently exist in literature. A generic and object level representation of the Environmental and Energy Management domain is presently absent. This thesis provides a framework for defining performance requirements and evaluating actual measurements against an ideal performance equivalent. Chapter 1 stated that performance benchmarks need to be updated

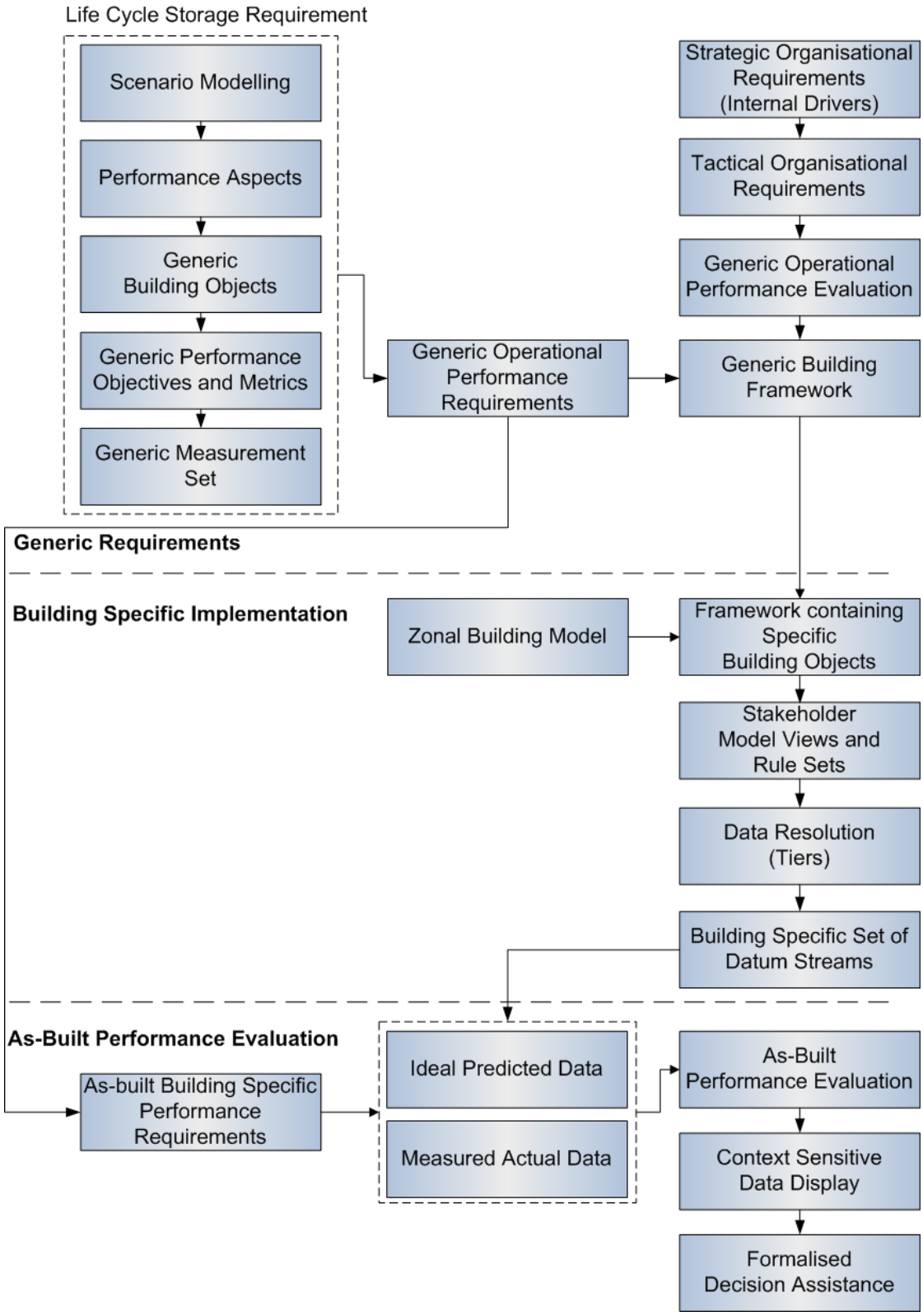


Figure 3.1: *Hierarchy of Thesis Concepts Facilitating an As-Built Building Representation for Performance Evaluation*

across the entire building life cycle for use during operation. The solution provides a generic domain description and subsequently defines the domain data exchange requirements to be used during operation and at other stages of the BLC if necessary. Chapters 3-8 will present different components of this solution. The rudimentary model is comprised of three distinct sections; 'generic requirements', 'building specific' and 'as-built'. These are now discussed in turn.

The generic performance requirements focus particularly on environmental and energy management at the organisational level. These requirements culminate in a life cycle framework capable of supporting qualitative and quantitative performance descriptions that are applicable to all buildings.

The rudimentary model then advances to 'building specific' performance concepts that are elicited from the underpinning generic framework. A fundamental requirement is that Building Objects, as defined in Chapter 2, exist in the form of a zonal object model. The key concept facilitated by the building specific representation is the process for allocating Model View specific measurement streams for a specific building.

The as-built representation enables operational performance evaluation through an extension of the building specific model to include measured and ideal predicted performance data. Traditional forms of as-built building representations include as-built drawings or Building Information Models (BIM), O&M manuals, commissioning representations, energy auditing representations, energy rating system representations, inverse whole building energy simulation models, etc. However these representations fail to extend to as-built performance framework representations. Therefore the rudimentary model depicted in Figure 3.1 addresses the identified issues and consolidates the concepts outlined for specific as-built representations.

The first component of the proposed solution must now be developed. Section 3.3 now defines the key areas of building operation that are relevant to Energy Managers.

3.3 Holistic Performance Aspects

The *Performance Aspects* concept categorises building operation for the established profile of Energy Managers as determined in Section 2.2. The five distinct but strongly related Performance Aspects originate from the criteria established in Chapter 2 which were in turn founded in response to the research objectives outlined in Section 1.5. The objective of each Performance Aspect is for Energy Managers to understand the implications of their decisions on holistic building performance. The Performance Aspects are defined as follows:

- **Building function** or specific environmental conditions for a predefined zone function such as an office space server room or manufacturing floor. Building function must incorporate lighting performance and the lighting related electrical load for each zone (Section 1.4.1);
- **Thermal Loads** that contribute and arise from Building Function (Appendix B);
- **Energy Consumption** based on the *internal driver* criterion, minimise cost of operation (Section 2.2.5);
- **System Performance** is the final Performance aspect as the HVAC Systems maintain required zone conditions (Section 2.2.5);
- **Legislation** based on the key criterion established in Section 2.4, *external drivers*.

A relationship between Performance Aspects and Building Objects must be established. Chapter 2 established Building Objects as the common objects that Energy Managers use when analysing all levels of building performance. It can be clearly seen from Figure 3.2 that five Performance Aspects can be linked to relevant Building Objects. Also a particular Building Object can have associations with more than one Performance Aspect. For example, a zone Building Object can link to the "Building Function" and "Thermal Loads" Performance Aspects as shown in Figure 3.2. This customisable relationship enables context specific information analysis for each Building Object.

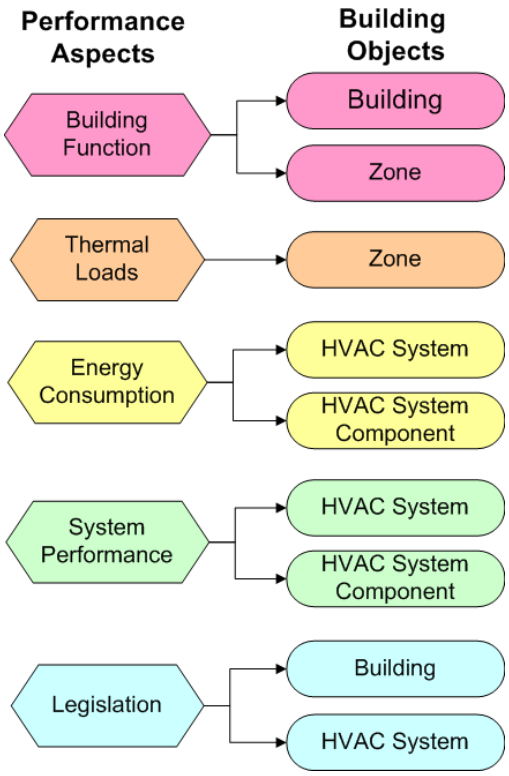


Figure 3.2: *Example Relationships between Performance Aspects and Building Objects*

Existing tools and techniques for monitoring building performance fail to demonstrate the explicit relationships between Building Function, Energy Consumption and associated environmental impact. The importance of building function is outlined in Section 1.4.1 and the consistent focus is on the role of the zone with respect to achieving a well performing building. However the importance of Building Function or zone operation is contingent on numerous independent factors such as zone occupancy and lighting and must be comprehensively illustrated. This is described in Appendix B.

Performance Aspects and Building Objects are concepts used to aid understanding of building performance. A flexible, standardised and structured communication technique capable of conveying the complex and interdependent performance characteristics of each Building Object is required and outlined in the following sections.

3.4 Structured Building Performance Assessment

This section describes a formal data transformation method that is most appropriate for conveying holistic building performance in the context of Performance Aspects and Building Objects for the established profile of Energy Managers. This data transformation method will underpin existing as well as future building performance *techniques* such as Scenario Modelling (Section 3.5) and benchmarking and should be applicable at the level of any Building Object. For example, in order to establish if a zone Building Object is too hot or too cold and quantify the magnitude of the discrepancy such as 2^{o}C colder than the stated setpoint.

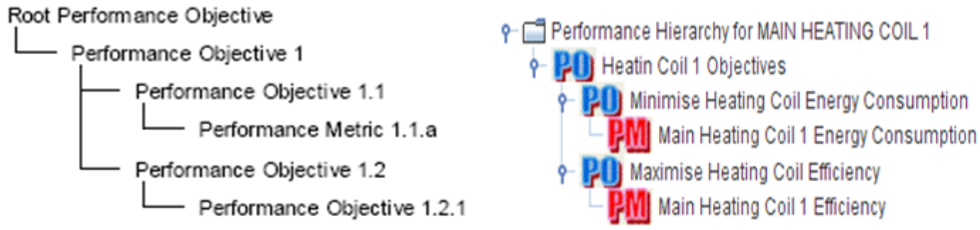


Figure 3.3: *A: Suggested Generic Structure of Performance Objectives and associated Metrics (Courtesy of (Hitchcock 2003), B: Sample Implementation of a Performance Objectives for Building Object Heating Coil 1)*

Standardised Performance Objectives and Metrics are a methodology for the explicit representation of qualitative (Objective) and quantitative (Metric) criteria in a dynamic and structured format (Hitchcock 2003). Each Performance Metric must be capable of being predicted or measured at each stage of the building life cycle so its Objective can be evaluated. They may vary as a project evolves. This technique requires a data model which is capable of tracking Performance Objectives and Metrics, thus archiving a history of building changes across its entire life cycle. Performance Metrics should fundamentally measure, reflect or significantly influence a particular Performance Objective.

Performance Metrics are expressible in a format that recognises profiled end users and presents a mechanism for addressing and simplifying the complexity of building performance for this profiled end user. Quantitative Performance Metrics transform raw data such as sensor measurements and simulation output into meaningful user specific information in a logical structured format. This Performance Metric Information supports effective decision making in relation to energy

consumption, efficiency values etc. The generic structure of Performance Objectives and Metrics and a sample implementation to illustrate how they could be applied to a heating coil Building Object is illustrated in Figure 3.3.

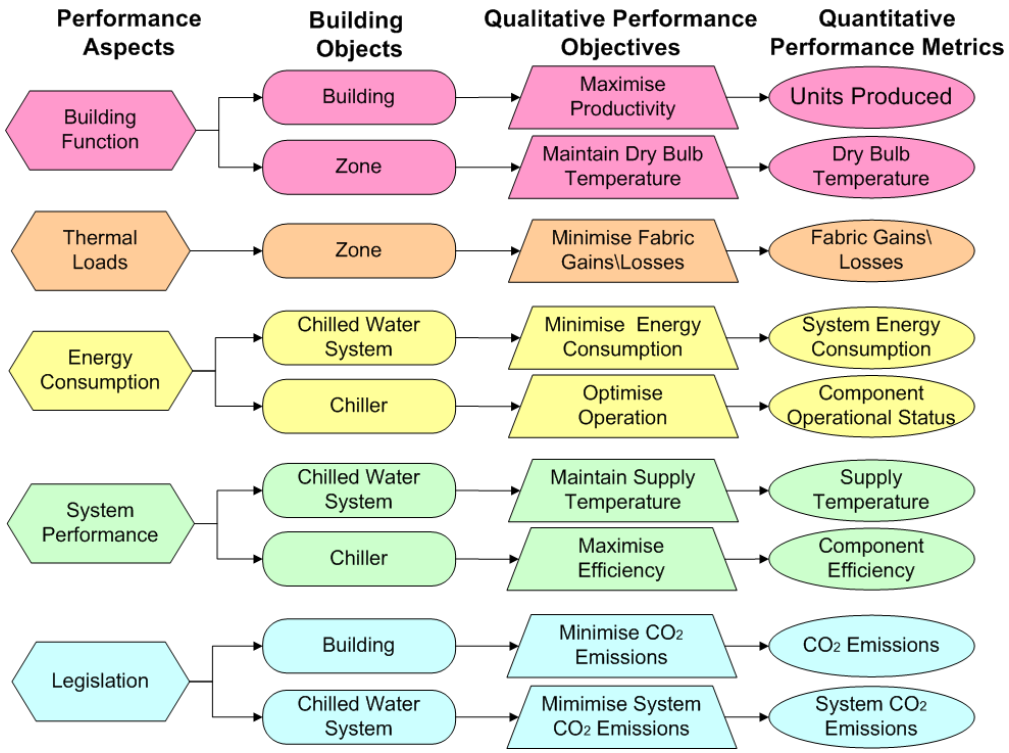


Figure 3.4: *Generic Illustration of the relationships between Performance Aspects, Building Objects and Performance Objectives and Metrics.*

However the robust nature and flexibility of standardised Performance Metrics does not automatically present the Energy Manager with the optimum information display format. An information delivery technique that combines Performance Aspects, Building Objects, Standardised Performance Objectives and Metrics as illustrated in Figure 3.4 and also accounts for the established profile of Energy Managers must be defined.

3.5 Scenario Modelling Technique

This section describes a scenario based *technique* that addresses the incomplete access to information highlighted in Section 1.5 and Chapter 2 for unambiguous understanding of building performance. This technique utilises Performance Aspects,

Building Objects, Standardised Performance Objectives and Metrics to present context sensitive information for the established profile of Energy Managers. It is proposed that once refined this technique could be implemented in an information delivery *tool* which would effectively display relevant *data* and *information* for the established profile of Energy Managers (Section 2.2.4). The widespread applicability of the technique is illustrated through three sample scenarios.

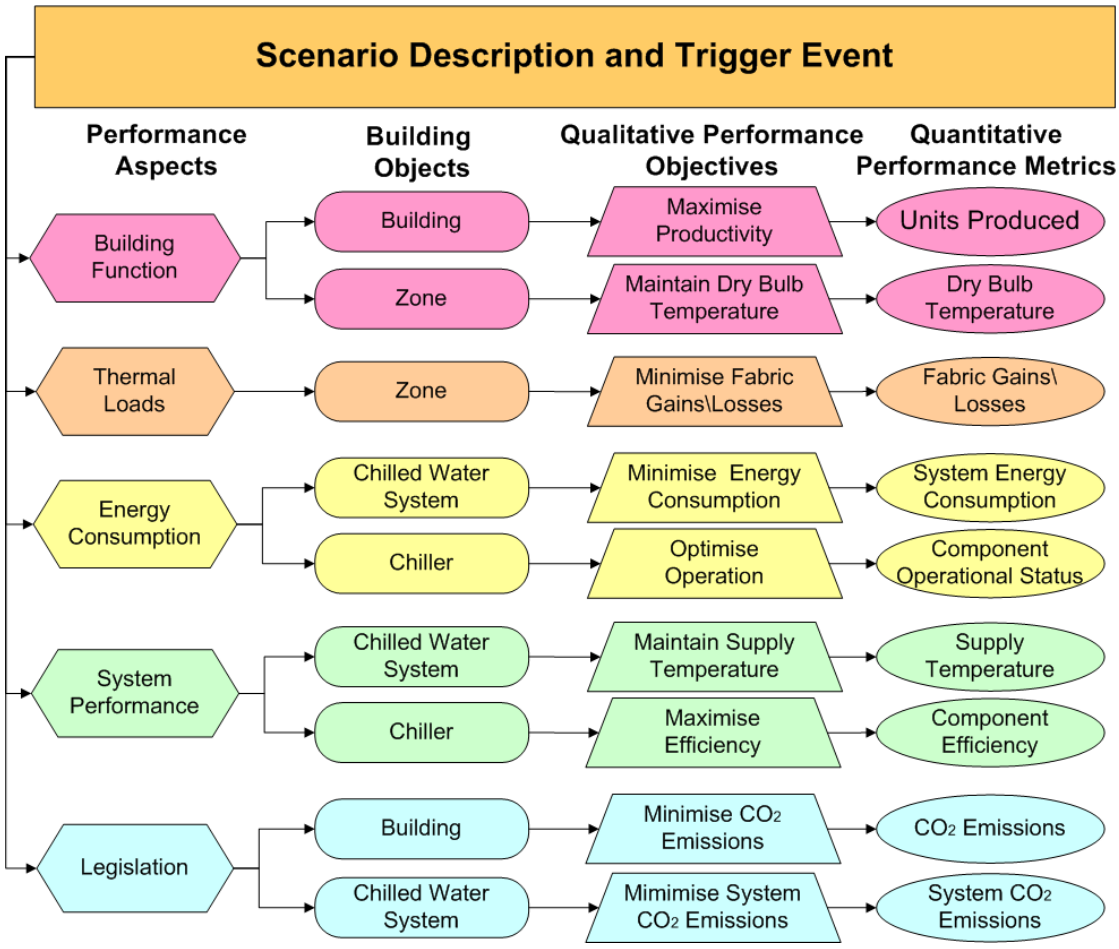


Figure 3.5: *Generic Structure of Scenario Modelling Technique*

The defined *Performance Aspects* illustrate the importance of building function, thermal loads, HVAC system performance, energy consumption and building performance with respect to legislation (Section 3.3). An Energy Manager also requires the ability to monitor the effect of a localised change on the building's performance, the building's energy consumption as a whole and building performance with respect to legislation. The scenario modelling technique, as illustrated in Figure 3.5, represents the relationships between a Trigger Event, Performance

Aspects, Building Objects and Performance Objectives and Metrics. The key is that Scenario Models enable Energy Managers to access unambiguous quantified expressions of building performance.

Context sensitive Performance Metrics enable a complete understanding of each Building Object. The research objectives required a technique that incorporates a comparison of actual operation and an ideal building performance benchmark (Section 1.5). Performance Metrics enable a one-to-one comparison between measured performance and an ideal performance benchmark which is provided by a whole building energy simulation model (Section 5.4) for a particular Building Object and is in turn analysed for a particular Performance Aspect. The *cause* and *effect* of each Performance Metric must be accessible in order for an Energy Manager to understand the consequences of his actions. Standardised Performance Objectives and Metrics enable the description and quantification of all Building Objects thus facilitating a holistic understanding of building operation.

Scenario modelling is most appropriately described through examples. Each of the following scenarios is illustrated using the following criteria:

- Boundary conditions or limitations of the scenario;
- Description of pre-event conditions;
- Description of the event and downstream effects of the event;
- Scenario schematic.

Each building is unique and will therefore have unique operational scenarios. The sample scenarios are not building or system specific but represent common occurrences in building operation. Each of the following scenario diagrams illustrates pre-event steady state conditions in a building, a trigger event followed by a transitional period and the downstream effects of the trigger event when a post-event equilibrium is restored. The scenarios are modelled in such a way as to illustrate certain building performance characteristics. These are:

1. Indoor environmental conditions, zone temperature setpoint and cooling;
2. Indoor environmental conditions, ventilation, cooling and plug loads;
3. Indoor environmental conditions, zone artificial lighting and heating;

3.5.1 Scenario 1: Zone Temperature Set Point Reduction

The boundary conditions for Scenario 1 are:

- Gymnasium Zone;
- Summer time cooling conditions;
- Outdoor temperature remains constant;
- Variable air volume system;
- Relative humidity setpoint is maintained;
- Occupancy levels before and after setpoint change are considered equal;
- Sensible and Latent heat values for occupants at different temperatures taken from (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 (Figure 3.6). The internal thermal gains remain constant throughout. The *event* is a manual change in zone temperature setpoint from 21^{o}C to 19^{o}C.

The change in zone temperature setpoint increases the sensible and decreases the latent occupant gains thus changing the thermal comfort of the occupants. There is a change in the ventilation system performance. There is an increased cooling coil load which increases chiller load which in turn increases cooling related electrical consumption and therefore building electrical consumption. Over time this deviation from design intent could increase the building's annual CO_2 emissions with corresponding implications with respect to impending EU legislation.

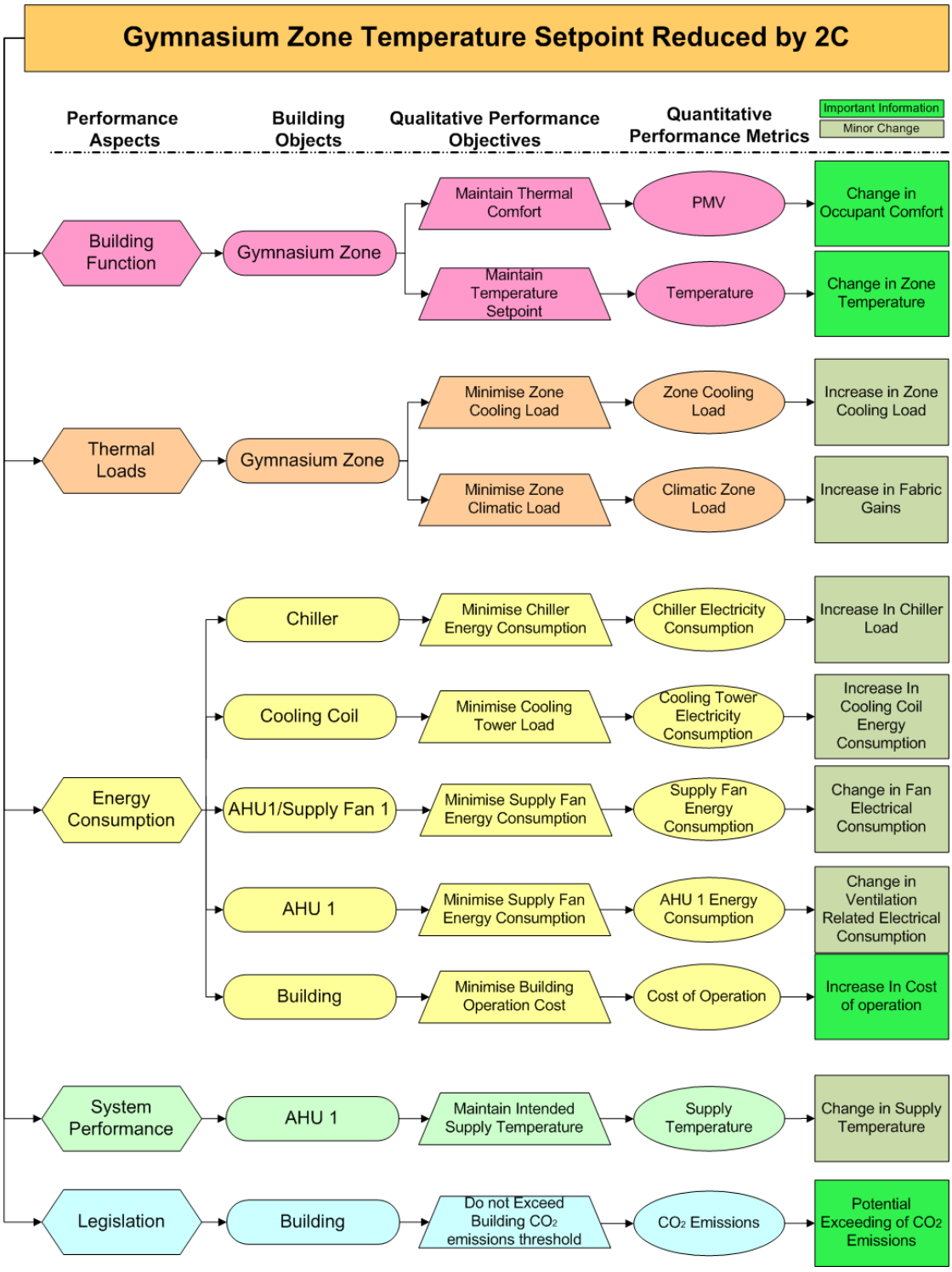


Figure 3.6: *Scenario Illustration Depicting the Effects of a Manual Change in Zone Temperature Setpoint.*



3.5.2 Scenario 2: Sudden Increase in Zone occupancy

The Boundary conditions for Scenario 2 are:

- Large Art Gallery where a large number of occupants enter simultaneously;
- Summer time cooling conditions;
- Outdoor temperature remains constant;
- Zone Temperature and Humidity set points are maintained;
- Variable Air Volume (VAV) system;
- It is assumed that after the new occupants to the space will use additional electrical equipment in the space;
- Cooling Coil Mixing Valve (constant volume).

This scenario illustrates pre-determined zone conditions of 21^{o}C and 50% relative humidity (Figure 3.7). The *event* is a sudden dramatic increase in zone occupancy. The other zone loads remain constant throughout this example.

A large sudden increase in zone occupancy consistent with a tour entering an art gallery would increase the latent and sensible gains to the space. Consequently additional supply air at a constant set point (VAV) is required, increasing the fan speed and electrical load. There is also an increased cooling coil load which increases chiller load which in turn increases cooling related electrical consumption and building electrical consumption. Over time this deviation from design intent could increase the building's annual CO_2 emissions with corresponding implications with respect to impending EU legislation.



Figure 3.7: *Scenario Illustration Depicting the Effects of a Sudden Increase in Zone Occupancy*

3.5.3 Scenario 3: Reduction in Artificial Lighting

The boundary conditions for Scenario 3 are:

- Large open plan office space zone;
- Winter time heating conditions;
- Outdoor temperature remains constant;
- Lux levels are automatically controlled to minimise use of artificial lighting while also accounting for glare;
- No direct solar radiation enters the zone;
- Constant volume air system.

This scenario illustrates the downstream effects of automatically reducing artificial lighting when sufficient daylighting is present. Pre determined zone conditions of 21^{o}C and 50% relative humidity and a satisfactory Lux level at the working plane (Figure 3.8). The *event* is sudden solar radiation after a cloud has passed.

The downstream effects of the trigger event are an increase in daylight levels and an automatic reduction in artificial lighting levels and consequently lighting related electrical consumption. There is a reduction in lighting related heat gain to the space which must be compensated for by the heating system. The zone temperature and relative humidity are not affected. There is an increase in the zone supply temperature which results from an increase in heating coil load. The boiler load increases to satisfy the additional load on the heating coil. Ultimately building gas consumption increases and building electrical load decreases when compared with pre event conditions. Over time this deviation from design intent could increase the building's annual CO_2 emissions resulting in additional fines for exceeding the permitted EU threshold.

Each scenario describes an event and the downstream performance implications of this event. It is proposed that a number of scenarios could describe the performance of any building. Key Performance Metric *information* could be accessed by more than one scenario. Combination of scenarios requires investigation and specification.

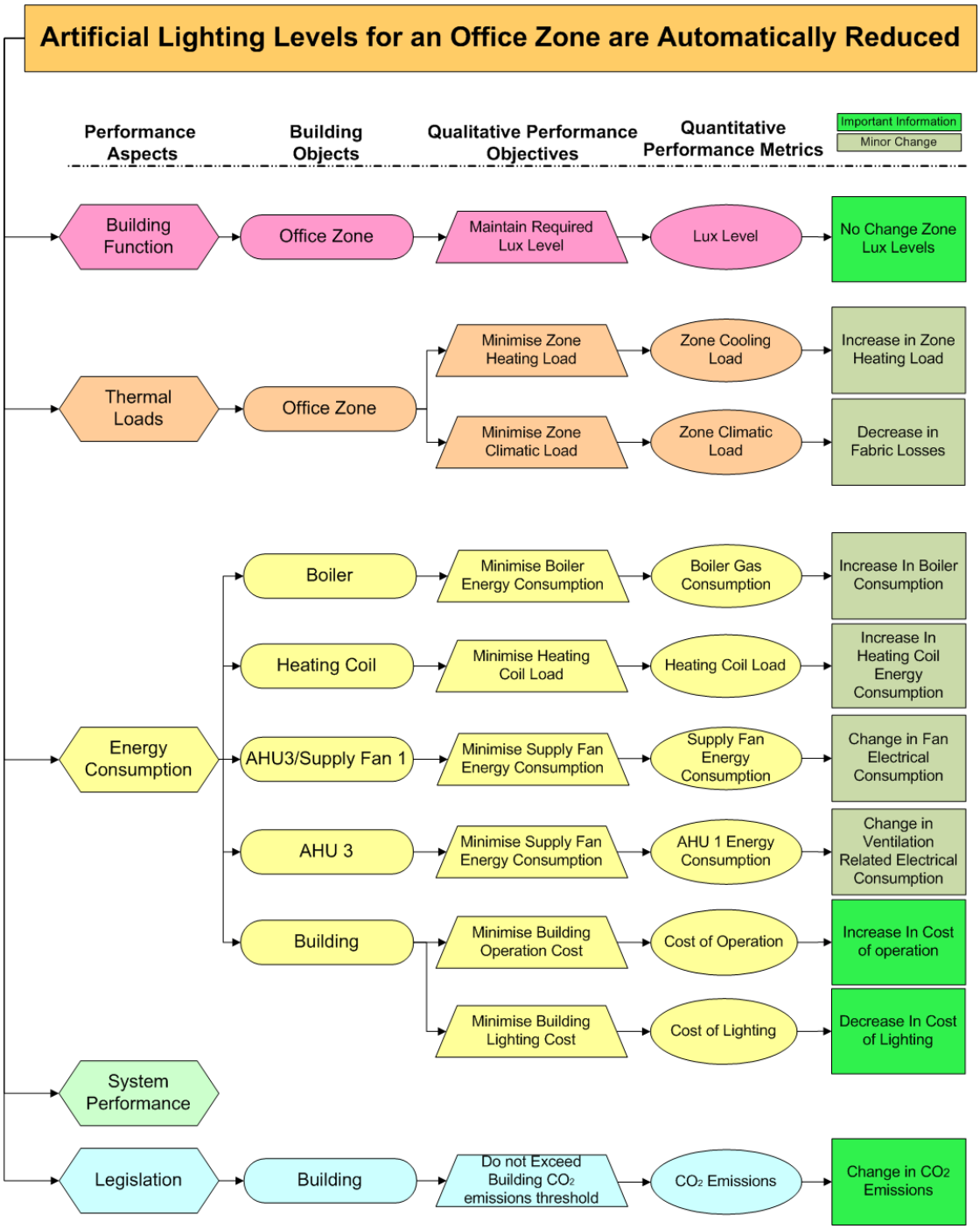


Figure 3.8: *Scenario Illustration Depicting the Effects of an Automated Reduction in Zone Lighting while maintaining Zone Lux Setpoints*



3.6 Performance Metric Combinations

Scenario Modelling illustrates the relationships between a trigger event, Performance Aspects, Building Objects and Standardised Performance Objectives and Metrics. Each scenario when fully detailed can be described by a number of quantitative Performance Metrics that are associated with appropriate Building Objects.

Table 3.1: *Interpretation of the Important Performance Metrics for the Three Chosen Scenarios.*

Performance Metrics	**Setpoint Reduction**	**Occupancy Increase**	**Artificial Lighting**
	Scenario 1	**Scenario 2**	**Scenario 3**
Building Energy Consumption	X+	X+	X+
Cost of Operation	X+	X+	X+
Lux Levels Maintained in the Zone	X0	Xo	X0
Supply Air Temperature	X-	X-	X+
Thermal Comfort	X?	X?	X?
Building Electrical Consumption	X+	X+	X-
Compliance with EU legislation	X0	X0	X0
Zone cooling Load	X+	X+	
Occupancy Thermal Comfort	X0	X0	
Chiller Load	X+	X+	
Condenser Loop Load	X+	X+	
Cooling Tower Energy Requirements	X+	X+	
Cooling Related Electrical Consumption	X+	X+	
Cooling Coil Flow	X+	X+	
Humidity Control	X0	X0	
Ventilation Requirements	X?	X+	
Fan Power	X?	X+	
Ventilation Related Electrical Consumption	X?	X+	
Zone Temperature	X-	X0	

Performance Metrics	**Scenario 1**	**Scenario 2**	**Scenario 3**
Ventilation Related Electrical Consumption	X?	X+	
Ventilation requirements	X?	X+	
Sensible zone load		X+	
Zone Latent Load		X+	
Zone humidity		X+	
Heating Coil Load			X?
Boiler Load	X?		
Heating Gas Consumption	X?		
Building Gas Consumption	X?		
Fabric Gains	X+		
Lighting Levels Maintained, Combination of Natural and Artificial Light			X0
Natural Light (beam or diffuse radiation) Related Sensible Heat Gain to the Zone			X+
Occupant Related Latent heat gain to the space	X-		
Occupant related sensible heat gain to the space	X+		
Zone Lighting Electrical Consumption			X-
Lighting Electricity Consumption			X-
Artificial Lighting Related Sensible Heat Gain			X-

The objective of the Metric Combinations *technique* is to identify the key Performance Metric *information* accessed by more than one scenario. Metric Combinations are based on combining the Performance Metrics from a number of scenarios and together they comprehensively describe the performance of a given building. A sample analysis based on the scenarios presented in Section 3.5 illustrates the applicability of the metric combination approach. The information identified from this type of analysis is the required monitoring information for a particular building. This is the purpose of the Scenario Modelling *technique*. Table 3.1 categorises the important metrics and downstream effects of each scenario

trigger event. The mathematical symbols '+, -, 0 and ?' denote, where quantifiable, a positive, negative, unaltered or unquantifiable change for each Performance Metric.

Scenario Modelling highlights the effect of a trigger event on the indoor environmental design conditions, the required changes to the supply system and the subsequent change in building environmental conditions and energy consumption. The analysis also highlights the unique nature of each scenario and the quantity of information required for a complete understanding of building performance. Table 3.1 illustrates that a scenario specific Performance Metrics set contains metrics that are common to other scenarios. Therefore combining the Performance Metrics from a building's operational scenarios would result in a complete building specific Performance Metrics set.

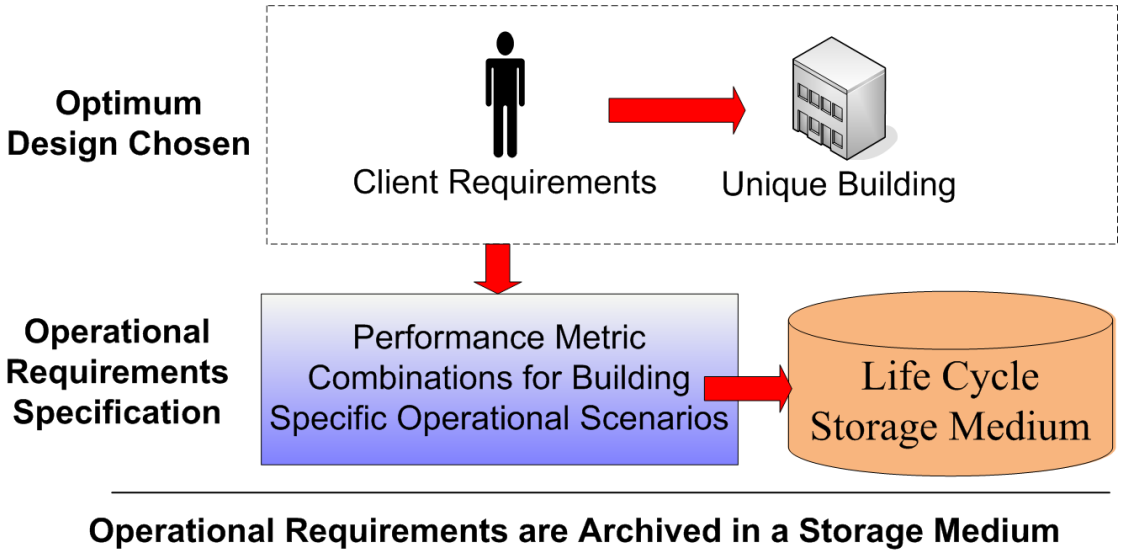


Figure 3.9: *Proposed Requirements Specification Procedure to Create and Store Performance Metric Combinations for Any Building*

An iterative design process should result in the optimal design solution and determine the complete building specific Performance Objectives and Metrics set. This design solution should also store the relationships between Performance Objectives and Metrics, Building Objects, Performance Aspects and the predefined operational scenarios. However such a complex data set necessitates storage and access mechanisms across the entire BLC. A repository capable of storing standard-

ised Performance Objectives and Metrics Combinations is required. The processes involved with storing this type of performance information in a suitable repository is outlined in Figure 3.9. A suggested description and technical implementation of a data repository through Industry Foundation Classes (IFC) is included in Appendix C. A repository capable of storing and granting access to this complex performance information across the entire BLC must now be defined.

3.7 Chapter Conclusion

The Scenario Modelling *technique* supports formally transformed data and information requirements established in the research objectives (Section 1.5). This *technique* enables context sensitive benchmarking of actual performance against ideal performance as provided by a whole building energy simulation model. Energy Managers can now make informed decisions and visualise the holistic downstream consequences of their actions.The Scenario Modelling *technique* is composed of:

- Scenario description or trigger event;
- Performance Aspects as defined in Section 3.3;
- Building Objects as defined in Chapter 2;
- Standardised Performance Objectives and Metrics which communicate information for the established profile of Energy Managers (Section 3.4).

It stands to reason that each building is unique and will therefore have a unique set of Scenarios that define its operation. The Metric combinations technique captures the union of all building specific Scenarios and therefore the building specific set of performance metrics.

A Framework capable of creating, storing and accessing this context sensitive formally transformed data across the entire building life cycle is required. A generic set of Performance Objectives and Metrics capable of describing all buildings therefore must also be defined. This generic set would allow designers to create building specific performance representations in the form of Performance Metric combinations from a standardised source which would in turn be stored across the BLC. Chapter 4 introduces the concept of the Ideal Building.

Chapter 4

The Ideal Building

> "*It is widely accepted that explicit performance appraisal by simulation defines a best practice approach to building design*"

(Clarke 1999)

4.1 Chapter Introduction

This chapter describes the Ideal Building that supports holistic environmental and energy management decision making through the Scenario Modelling and Performance Metric Combination techniques proposed in Chapter 3. The life cycle Ideal Building Framework enables context sensitive *data* and *information* transformations as required by the established profile of Energy Managers (Chapter 2). The specifications for the framework also include the Ideal Set of Performance Objectives and Metrics which are capable of defining the performance of any building. This chapter outlines the following:

- The Ideal Building Framework and framework components;
- Ideal Building Framework data repository requirements that facilitate life cycle storage and access to relevant data and information. This is a fundamental requirement of the Ideal Building Framework;
- A Building Object Hierarchy which logically structures the Building Objects of the Ideal Building Framework;
- Specification of a generic Ideal Performance Objectives and Metrics Set that can define the performance of any building for downstream user interaction.

4.2 The Ideal Building Framework

The objective of the Ideal Building Framework is to address the inadequacies with respect to operational data that have resulted in partially informed decision making by Energy Managers. The consequence is a global building stock that does not perform to design expectations (Chapter 1 & 2). The Ideal Building Framework details the relevant data and data transformations required to support the established profile of Energy Managers. Context sensitive information underlies defined Scenarios which consist of Performance Aspects, Building Objects and Performance Objectives and Metrics (Section 3.5).

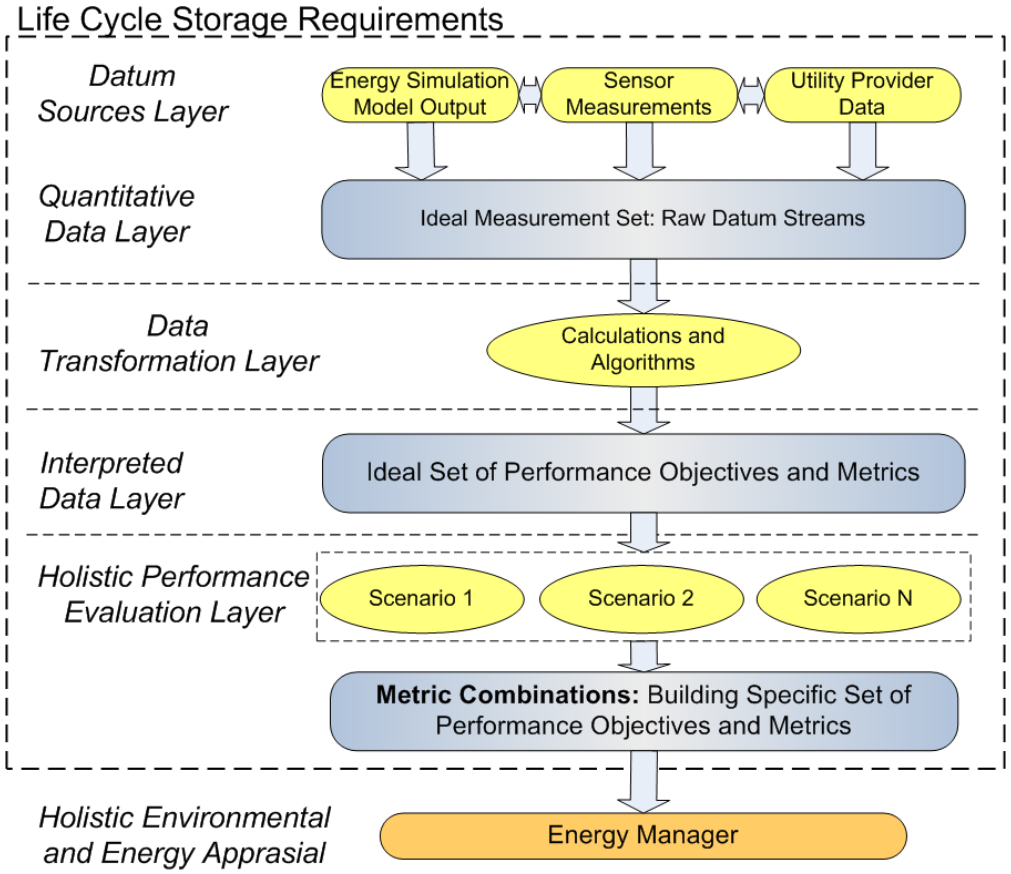


Figure 4.1: *Specification of the Ideal Building Framework which Includes the Individual Layers and the Requirement for Life Cycle Data Storage.*

The Ideal Building Framework specification (illustrated in Figure 4.1) reflects the requirements and findings of the literature review (Section 2.2), the case studies (Section 2.3) and holistic Aspects of environmental and energy management (Section 3.3). The objective is to define a life cycle performance framework which uses



the *ideal set* of datum streams to underpin context sensitive data transformations for a specific end user. The generic framework specifications ensure it is applicable to *all buildings*. The layered approach demonstrated in Figure 4.1 utilises the generic Scenario Modelling technique, the generic Ideal Set of Performance Objectives and Metrics and the generic Ideal Measurement Set for building specific performance analysis. Combinations of Scenarios can describe the performance of any building which require information in the form of Performance Objectives and Metrics and the underlying datum streams (Section 3.6). The individual layers of the Ideal Building Framework reflect these required relationships and are:

- A Building Life Cycle Information Repository Layer that accommodates the requirements of all other layers (Section 4.3);
- Holistic Performance Evaluation Layer that supports the Scenario Modelling technique which is underpinned by Performance Metric Combinations that define the performance of a particular building (Chapter 7 & 8).
- Interpreted Data Layer that defines a logically structured generic set of Ideal Performance Objectives and Metrics from which the performance of any building can be defined and evaluated. This Ideal Set is applied for each defined Building Object (Section 4.5);
- A Data Transformation Layer that defines the algorithms that convert raw data into Performance Metrics (Section 4.5);
- A Datum Sources or Quantitative Data Layer which are available at each phase of the life cycle (Chapter 5). The sources are ideal performance as obtained from a virtual simulation model, measured actual performance from physical sensors and meters and utility provider data. It is imperative that these datum sources can be compared on a one to one basis, thus enable a fair comparison of actual operation with ideal benchmarked performance using Performance Metrics (Section 1.5);

It must be stated that the Ideal Building Framework requires hardware and software advances before it can be commonly implemented in real buildings. The cost of installing traditional wired sensors is currently prohibitive especially where retrofits are required. Electrical wiring that connects plugs, lights etc. to the closest power board is not conducive to desired metering strategy (CIBSE 2006*b*).

Plug loads and Lighting loads should be attainable from their own individual boards in order to assist the breakdown of energy consumption for the Energy Manager. Advances in Wireless Sensor Networks (WSN) and emerging measurement technologies offer flexible solutions for sensor design and installation (Jang et al. 2008, Keller et al. 2007, Federspiel 2006, ennovatis 2007). A complete set of sensor specifications as desired by the Ideal Building Framework includes measurements defined by both metric combinations and building control specialists. The Ideal Building Framework also demands advances in whole building energy simulation engines which provide virtual performance benchmarks (Chapter 5). Certain CAD vendors are beginning to integrate energy modelling software tools with their products but users are limited to using the companion tool as opposed to choosing from tools available on the market (Bentley 2003).

The "Interpreted Data Layer" and "Data Transformation Layer" are described in Section 4.5. The quantitative Data Layer" is addressed in Chapter 5.

4.3 Ideal Building Framework Data Repository

Any up to date virtual representation of building performance requires information from all phases of the Building Life Cycle (BLC) (Section 2.4) which can be generated by simulation tools. This BLC information must be stored in a structured manner and be available for downstream access by all project stakeholders especially the Energy Manager (Section 3.6). Building Information Models (BIM) provide a logical, navigable structure for storing Performance Metric Combinations, Scenarios, Performance Aspects, Building Objects and Metrics (Figure 4.2). All relevant data and information is stored in and is accessible through a BIM.

BIM is an industry term used to define 3-D, intelligent, object oriented, AEC/FM specific CAD models (Khemlani 2003). In the recent past product models or BIM could exchange geometric data but virtually no "downstream" data after CAD (Bazjanac 2004*a*). The Ideal Building Framework, as shown in Figure 4.3, uses BIM for post CAD information exchange through the following steps:

- Step 1 defines the 'Building Information Model - Static'. This model represents the physical structure, geometry, materials and HVAC systems of a specific building;

- Step 2 defines the performance framework parameters. These include Performance Aspects; Building Objects; Performance Objectives and Metrics and required datum streams to populate the Performance Metrics;
- Step 3 defines the "BIM - Static and Performance Framework and Operational Data". This information supplements the performance framework with benchmark and measured data[1].

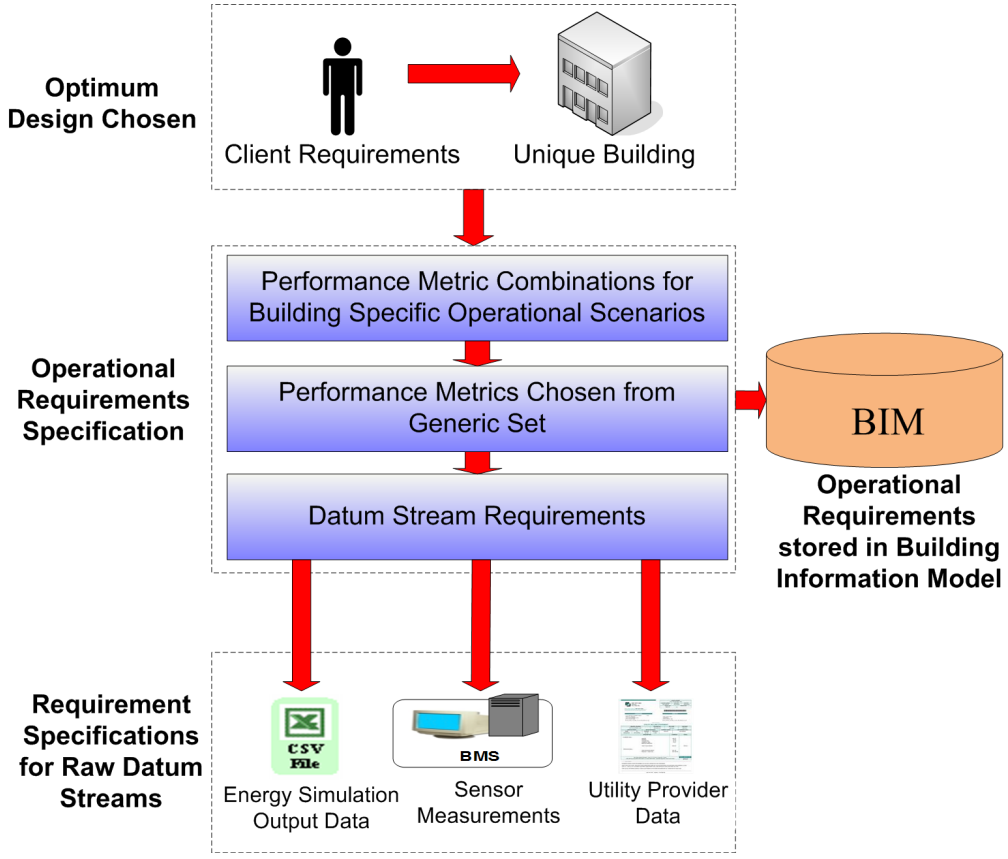


Figure 4.2: *Building Information Model as a Central Repository for Building Life Cycle Performance Goals*

Building Information Models are logical and structured data repositories. However the Ideal Building Framework requires a hierarchy that fulfils the requirements of all life cycle phases while also meeting the requirements of the end user.

[1]See Chapter 5 for a complete description on an Ideal Benchmark as provided by whole building energy simulation model output and measured datum streams.

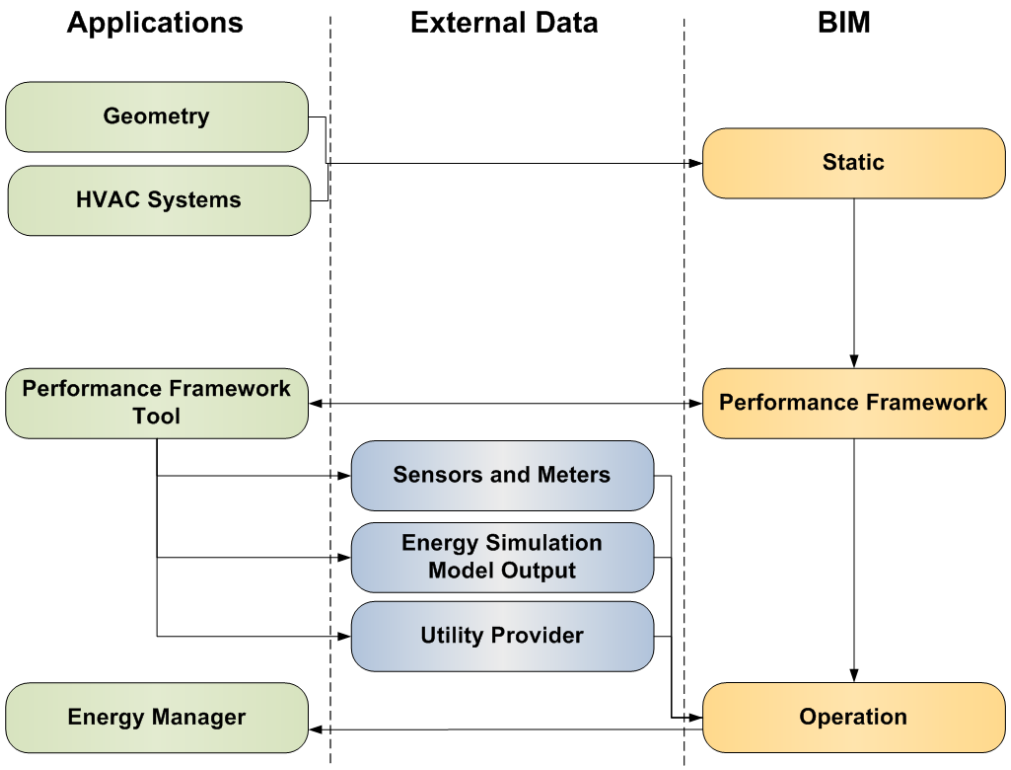


Figure 4.3: *The Required Interoperable Process which incorporates Standardised Performance Metrics to Track Indoor Environmental and Energy Information Across the Building Life Cycle*

4.4 Building Object Hierarchy

The chosen structure of the Building Object Hierarchy categorises defined Building Objects for the established profile of Energy Managers. Case studies reveal the absence of a standardised representation for environmental and energy Building Objects (Chapter 2). Proprietary interfaces have independent representations of Building Objects for system operation and utility consumption. RPS (2007) stated that a standardised and structured representation of Building Objects that facilitates building function, utility consumption and systems operation would significantly benefit industry. It is most important that this representation of Building Objects accounts for the profile of Energy Managers established in Chapter 2 in order for it to be adopted by industry. Therefore the chosen structure incorporates Building Objects that industry is familiar with but places these objects within a structured hierarchy.

The *'Building Object Hierarchy'* which incorporates a logical structure of the buildings geometric and HVAC *Building Objects* and includes *Building Portfolio, Site, Building, Building Storey/Tenant, Zone and Micro-Zone* (Figure 4.4). The included *Hot Water Systems, Cold Water Systems and Air Systems* are associated with each zone to emphasise the importance of a zone centric approach to building performance analysis (Section 1.4.1). The Systems and System Component Building Objects are representative of traditional BMS tools and activities (refer to Chapter 2). The Building Object Hierarchy generically defines Building Objects for an as-built representation of the Ideal Building. The behaviour of all Building Objects can be described by standardised Performance Objectives and Metrics (Section 3.4). The 'Building' Object can be described by Performance Objectives and Metrics that represent the utility types, utility consumption and energy end use categories. An example is illustrated in Figure 4.4. This example includes cost, energy consumption and energy use categories and represents traditional energy management activities.

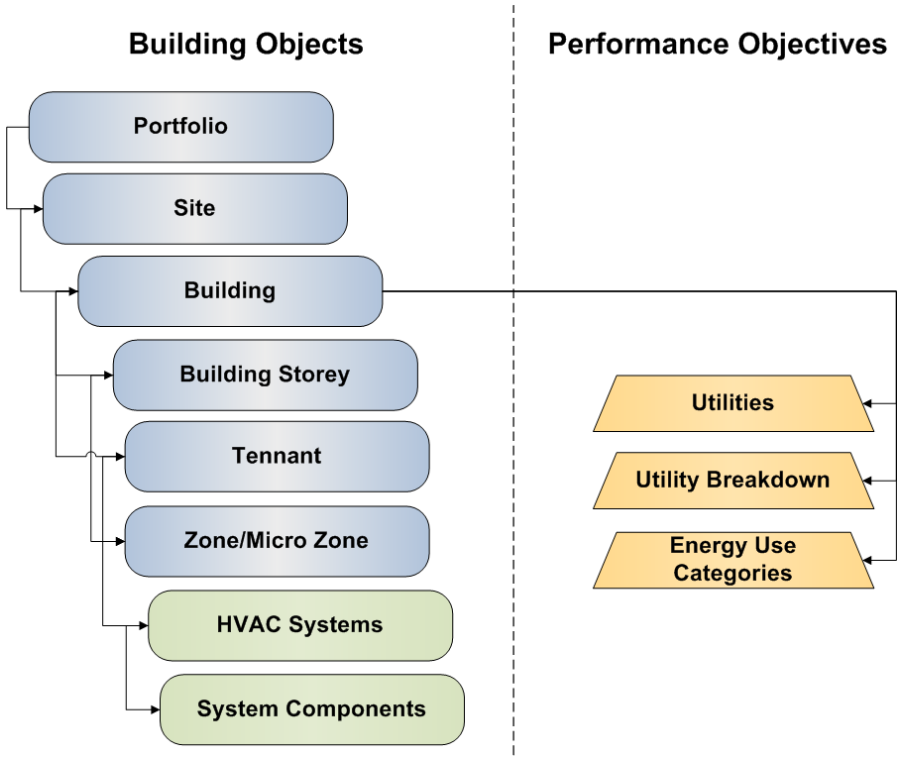


Figure 4.4: *Structure of the Building Object Hierarchy Illustrating the Important Building Objects as Determined in Chapter 2*

4.5 Ideal Performance Objectives and Metrics

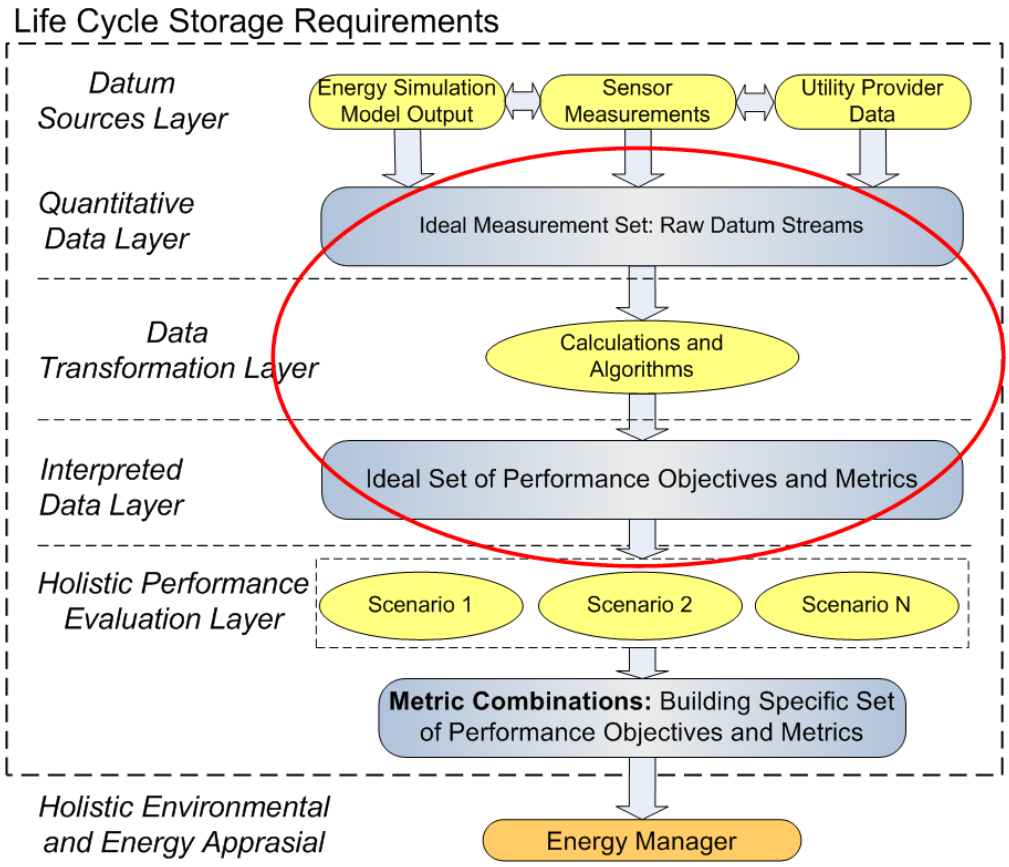


Figure 4.5: *Processes Required to Deliver Holistic Environmental and Energy Information to the Energy Manager*

The Ideal Set of Performance Objectives and Metrics is capable of defining the performance of every Building Object for all phases of the Building Life Cycle. Logically the most prudent building specific environmental and energy management information (Scenario Modelling resulting in Performance Metric Combinations) should be selected from a generic building performance information set. Defining this ideal set could alleviate unnecessary and inefficient post processing of raw datum streams. The Ideal Set of Performance Objectives and Metrics would eliminate the "data rich, information poor" situations described in Chapter 2 thus enabling improved decision making by the Energy Manager. Context sensitive formally transformed data would replace ad-hoc and inefficient processing of datum streams. The Energy Manager's productivity would increase if the Ideal Set of information underpinning the building specific set of Performance Objectives and



Metrics (Figure 4.5) delivered accurate, relevant information thereby eliminating current ad-hoc building performance appraisal techniques. The Ideal Set of Performance Objectives and Metrics utilises Building Objects for a defined structure. It is comprehensive as it can be applied to all buildings yet extensible to account for future advances in building technologies.

The Ideal Performance Objectives and Metrics Table reflects the Building Object Hierarchy and uses standardised Building Objects as defined by ASHRAE (ASHRAE 2004*a*) (Section 4.4). Table 4.1 illustrates example Building Objects, Performance Objectives and Performance Metrics and can be used as a reference for understanding the Ideal Table structure as it is described throughout this section. Appendix D contains the entire Idea Performance Objectives and Metrics Set. Performance Objectives and Metrics are defined for each Building Object in the Performance Hierarchy. For example Campioli et al. (2007) suggests using kWh/m^3/year as opposed to the traditional kWh/m^2/year for office spaces as floor to ceiling heights differ from building to building. This new Performance Metric may be applied for mechanically conditioned zones but is not applicable for cases which incorporate natural ventilation and high ceilings. This alternative Energy Use Intensity (EUI) has also been incorporated in the Ideal Metrics set. The Ideal Building Framework promotes a bottom up approach for aggregating metrics. For example 'individual fan energy consumption' Performance Metrics combine for the Performance Metric 'total ventilation energy consumption'.

The specifications for the Ideal Table of Performance Objectives and Metrics are now proposed. The Table representing the Ideal Set of Performance Objectives and Metrics adopts a structure that facilitates unambiguous understanding of holistic building operation. Table 4.1 illustrates sample Building Objects, Performance Objectives and Performance Metrics and can be used as a reference for understanding the Ideal Table structure as it is described throughout this section. Appendix D contains the entire Idea Performance Objectives and Metrics Set.

The'*tag*' column acts as a unique identifier for formally transformed data and can quickly identify and reference a specific Performance Objective and Metric. Certain tags are preceded by a *'M'* which denotes the practical set that are currently used by high-tech industry (Gillespie et al. 2006, Geoghegan & Fenner 2007)

(Chapter 2, Appendix A). It is important to note that the majority of Performance Objectives and Metrics contained in the Ideal Set are not typically used by high-tech industry.

Performance Objectives and Metrics are assigned to a particular Building Object (Chapter 2). Column Three records all the applicable '*Building Objects*'. The complete table contained in Appendix D is specified in accordance with the Performance Hierarchy developed in Section 4.4.

The complete '*Performance Objectives*' (Column Four) and '*Metrics*' (Column Five) set was expanded from the practical set (Campioli et al. 2007, Dodier et al. 2006, Gillespie et al. 2006, Katipamula & Brambley 2006, Augenbroe & Park 2005, Barley et al. 2005, Pless et al. 2005, Deru & Torcellini 2005*b*,*a*, Deru et al. 2005, Rosen et al. 2005, ASHRAE 2004*b*, Labs21-LBNL 2002, Bourne & Carew 1996, Chauvel et al. 1980). This set of formally transformed data is extensible and can be updated to reflect new technologies that emerge. The Units are also included for quantification of each Performance Metric.

Performance Objectives can vary depending on scenario and building. For example "Minimise: Electrical Consumption " may not be an appropriate Performance Objective for a building that can take advantage of cheap electricity tariffs.

Therefore the "Ideal Set of Performance Objectives and Metrics" incorporates a qualifier list which is applicable for all Performance Metrics. For example the "minimise" qualifier is applicable to the "electricity consumption" Performance Objective. The full list of qualifiers was derived from existing performance metric literature and includes: Maximise; Minimise; Optimise; Reduce; Maintain; Monitor; Increase; Decrease; Control (Campioli et al. 2007, Dodier et al. 2006, Gillespie et al. 2006, Katipamula & Brambley 2006, Augenbroe & Park 2005, Barley et al. 2005, Pless et al. 2005, Deru & Torcellini 2005*b*,*a*, Deru et al. 2005, Rosen et al. 2005, ASHRAE 2004*b*, Labs21-LBNL 2002, Bourne & Carew 1996).

Table 4.1: *Sample table of an Ideal Set of Performance Objectives and Metrics for the Established Profile of Energy Managers.*

Tag	**Building Object**	**Performance Objective**	**Performance Metric and Unit**	**Measurement Streams Required**	**Units**	**Interval**	**Calculation**
M1001	**Site**	:Outdoor DB Temp	Outdoor Dry Bulb Temp (^{o}C)	Outdoor DB Temp sensor	(^{o}C)	1 minute	None Needed
M1003	**Site**	:Outdoor % Humidity	Outdoor Humidity (%)	OA Humididy	(%)	1 minute	None Needed
M1004	**Site**	:Average Daily DB Temp	Average Daily Outdoor Temp (^{o}C)	Outdoor DB Temp sensor	(^{o}C)	1 minute	Sum Daily values/No. values
M1101	**Building**	:Building Energy Use	Total Energy Use (kWh)	Electricity Bills	(Cost)	1 minute	Sum (Utility Totals)
M2001	**Building**	:Peak Electricity Cooling Load	Peak Electricity Cooling Load (kW)	Sum Electrical Sub Meters (Chillers)	(kWh)	1 minute	None Needed
3001	**Air System**	:Air System Energy Use	Energy Consumption (kWh)	Each Component Elec	(kWh)	1 min	None Needed
M5001	**Boiler**	:Boiler Energy Output	Energy Output (kWh)	Flow & Return Temp, Mass Flow Rate	(^{o}C, m^3/s)	1 min	$Q = M \times C_p \times (T_f - T_r)$



For each performance metric the underlying '*Datum Streams*' required are included (Chapter 5). The datum streams may originate from actual measurements, benchmark predictions from whole building energy simulation model output or from a utility provider. The applicability of each datum source at each phase of the Building Life Cycle is depicted in Table 4.2.

Table 4.2: *Datum Sources Available at Each Stage of the Building Life Cycle*

Datum Source	**Design**	**Construction**	**Commissioning**	**Operation**
Simulated	Yes	Yes	Yes	Yes
Measured	No	No	Yes	Yes
Utility Provider	No	No	Yes	Yes

The '*Frequency*' column indicates the required frequency for optimal understanding of each performance metric. Standard industry practice is to record data at hourly or sub-hourly intervals (every 10 - 15 minutes). Inefficiencies and faults are more clearly distinguishable using a one minute recording interval (Piette et al. 2001). However the sheer scale of size of the possible generated data needs careful consideration (Chapter 5). Therefore the majority of Performance Metrics in the Ideal Set are at a one minute interval.

The '*Calculations*' column represents the Data Transformation Layer of the Ideal Building Framework (Figure 4.5) and defines the algorithms used to generate each metric from the raw datum measurements. For example the Performance Metric 'Boiler Heat Output', included in Table 4.1, measured in kWh requires three sensor measurements: Boiler Water Flow Temperature; Boiler Water Return Temperature and Boiler Water Flow Rate. The calculation column can assist an Energy Manager's understanding of influential variables. The applicable algorithm is stated for the lowest frequency of measurement resulting in an instantaneous value measured in kW and is stated in Equation 4.1. The desired kWh value is the output for the *time period* of analysis.

$$\dot{Q} = \dot{m} \times C_p \times (T_f - T_r) \tag{4.1}$$

At this point it should be noted that such a table can always be extended to incorporate new systems and components or to add new performance metrics that will benefit an Energy Manager. The available datum streams underpin the Ideal

Performance Objectives and Metrics Set (Figure 4.5). The datum sources vary, each with it own limitations, assumptions, considerations and requirements. Table 4.1 is a representative sample of the Complete Ideal Performance Objectives and Metrics Table.

The Ideal Building Framework quantitative data layer is presently undefined and requires detailed specification.

4.6 Chapter Conclusion

The Ideal Building Framework is developed in response to the requirements of the Benchmarking, Scenario Modelling and Metric Combinations techniques. It is presently a conceptual definition of how all buildings should define and formally transform data, given the established profile of Energy Mangers. The Ideal Building Consists of:

- A layered life cycle performance framework and process that is applicable to all buildings;
- Defined Building Object Hierarchy which logically structures Building Objects to enable navigation for Energy Managers;
- A BIM to act as a data repository for structured life cycle performance data and information in the form of Performance Objectives and Metrics which are in turn associated with Building Objects;
- A generic Ideal Performance Objectives and Metrics set capable of defining the performance of any building and thereby the performance of the Ideal Building. This generic ideal set incorporates individual datum streams and algorithms that formally transform raw data into relevant Performance Metrics.

The primary components of the Ideal Building have been discussed and specified. However the datum streams that underpin the Ideal Building Framework must now be defined and validated. Chapter 5 introduces the concept of the Ideal Measurement Set.

Chapter 5

Ideal Measurement Set

"*Performance is more compelling than design awards*"

(Michael G. Ivanovich, HPAC 2005)

5.1 Chapter Introduction

The measurement streams that underpin the Ideal Performance Objectives and Metrics set are identified in Chapter 4. This chapter defines the Ideal Measurement Set and details the datum sources required to form the basis of the Ideal Building Framework by:

- Determining the requirements of the Ideal Measurement Set;
- Specifying systematically structured raw datum stream formats to enable the benchmarking technique;
- Identifying and describing each datum source that underlies the formally transformed data or Ideal Set of Performance Objectives and Metrics. These datum sources are:
  - Real-Time measurements from physical sensors or meters;
  - Whole Building Energy Simulation Model output;
  - Utility Provider data.

5.2 Ideal Measurement Set: Requirements

The interpreted data layer or Ideal Measurement Set underpins the Ideal Set of Performance Objectives and Metrics (Figure 5.1). The latter is capable of defining the performance of any building therefore the Ideal Measurement Set is capable of measuring the environmental and energy performance of any building.

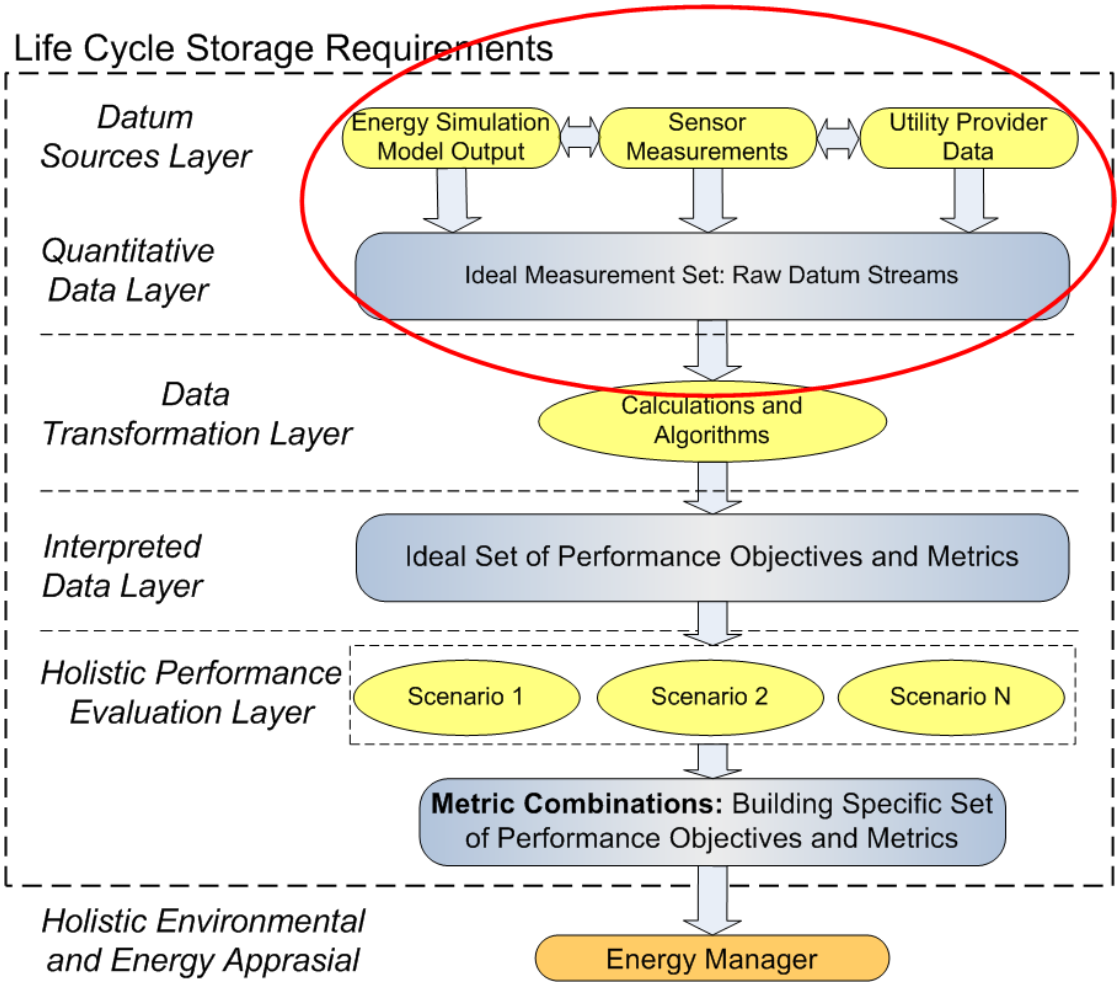


Figure 5.1: *The Ideal Measurement Set that Underpins the Ideal Building Framework*

The Scenario Modelling *technique*, as discussed in Chapter 3, supports the benchmarking *technique* through Performance Metrics tracking which in turn defines the datum streams required for a specific scenario (Section 4.5). An example relationship for the Scenario 1 trigger event, selected Performance Aspects, Building Objects, Performance Objectives, Performance Metrics and the required datum streams for the chosen metrics as defined in Section 3.5.1 is depicted by Figure

5.2. The sample scenario highlights the two of the major changes as a result of the trigger event, under the Performance Aspect of 'Building Function' and 'Energy Consumption'. The measured and benchmark zone temperature Performance Metrics highlight the 2^{o}C dry bulb temperature discrepancy. The measured and benchmark chiller output Performance Metrics highlight the resultant change in chilled water output. This metric is generated through the formally transformed process defined in Section 4.5 and is dependant on three datum streams that are processed through the illustrated formula. This example does not have a requirement for 'Utility Provider' data as these data are used by 'cost' and 'tariff' related Performance Metrics.

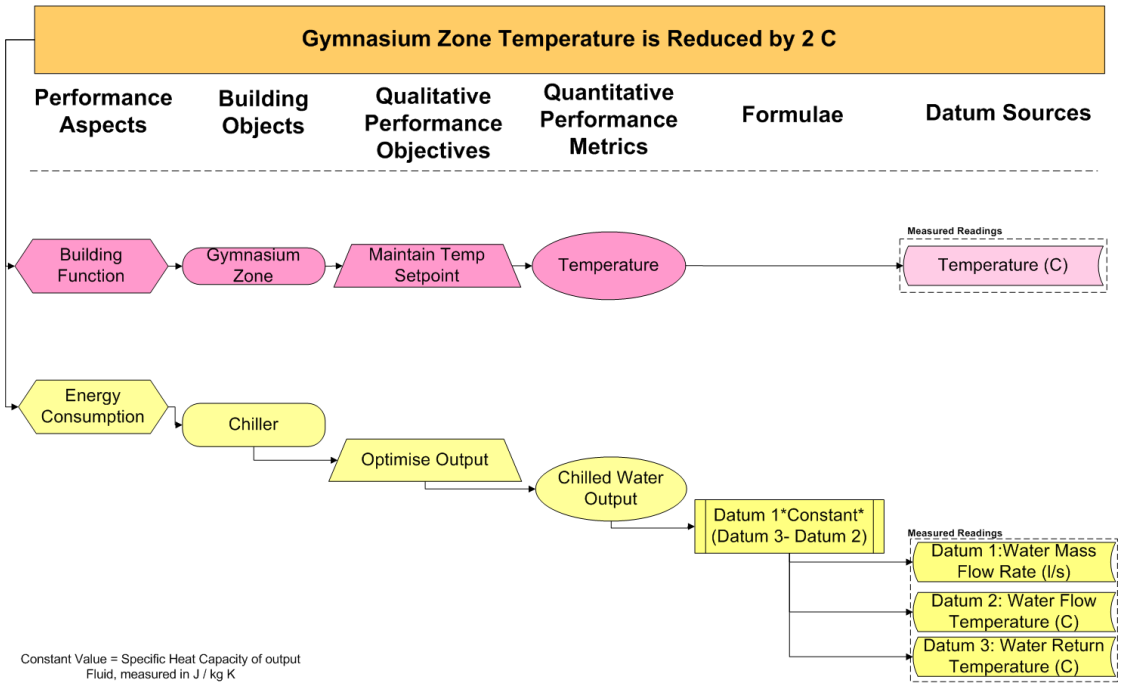


Figure 5.2: *Sub Set of Scenario 1 illustrating the Relationship between Trigger Event, Performance Aspect, Building Object, Performance Objective and Metric and the Measurement Streams*

The example illustrates that under each and every Performance Metric information generated from three distinct sources must be compared on a one-to-one basis. The format of individual datum streams must be systematically structured to enable benchmarking through a one-to-one comparison of Performance Metrics. Systematically structured datum formats facilitate automated post processing of data and removes the need for manual intervention by Energy Managers. Data format guidelines also ensure consistency of performance data across all phases of

the Building Life Cycle (BLC). The availability of datum streams with respect to BLC phase is illustrated in Table 5.1.

Table 5.1: *Sources of Data for the Ideal Measurement Set at each stage of the Building Life Cycle*

Datum Source	Design	Construction	Commissioning	Operation
Simulated	Yes	Yes	Yes	Yes
Measured	No	No	Yes	Yes
Utility Provider	No	No	Yes	Yes

Table 5.2 illustrates the updated and complete Ideal Set of Performance Objectives and Metrics that incorporates individual datum sources[1]. It can be clearly seen that the '*Minimise*: Building Energy Use' Performance Objective requires data from three distinct sources but '*Monitor*: Outdoor Dry Bulb Temperature' only requires data from two datum sources[2]. The format of these data are specified in Section 5.3 and the content of the datum streams is detailed in Section 5.4.

The Ideal Building Framework through the Ideal Set of Performance Objectives and Metrics is capable of describing the performance of all buildings. It is logical that sub-sets of the Ideal Performance Objectives and Metrics Set would be of benefit to stakeholders concerned with building performance apart from the Energy Manager. For example Mechanical Engineers at design, Controls Specialists during commissioning or Energy Auditors for retrospective building performance analysis. Therefore a definitive Ideal Measurement Set creates the possibility for multiple stakeholder *views* of building performance. In essence these *views* should facilitate the requirements of profiled professionals with regard to building performance. There are numerous possible views of the Ideal Measurement Set including:

- Financial Controller View;
- Civil or Electrical or Mechanical Engineer View;
- Controls Specialist View;
- Energy Management View;
- Building Rating System View.

[1]Appendix D details a structured description of all the required measurement streams
[2]Minimise and Monitor are two of the defined qualifiers established in Section 4.5

Table 5.2: *Sample Section of the Ideal Set of Performance Objectives and Metrics for the established profile of Energy Managers.*

Tag	**Performance Object**	**Performance Objective**	**Performance Metric and Unit**	**Measurement Streams Required**	**Units**	**Interval**	**Calculation**	**From BMS**	**From Simulation**	**From Utility**
M1001	**Site**	:Outdoor DB Temp	Outdoor Dry Bulb Temp (^{o}C)	Outdoor DB Temp sensor	(^{o}C)	1 min	None Needed	Yes	Yes	No
M1003	**Site**	:Outdoor % Humidity	Outdoor Humidity (%)	OA Humididy	(%)	1 min	None Needed	Yes	Yes	No
M1004	**Site**	:Average Daily DB Temp	Average Daily Outdoor Temp (^{o}C)	Outdoor DB Temp sensor	(^{o}C)	1 min	Sum Daily values/no of values	Yes	Yes	No
M1101	**Building**	:Building Energy Use	Total Energy Use (kWh)	Electricity Bills, Gas Bills, Water Bills	(Cost)	1 min	Sum (Utility Totals)	Yes	Yes	Yes
M2001	**Building**	:Peak Elec Cooling Load	Peak Elec Cooling Load (kW)	Sum Electrical Sub Meters (Chillers)	(kWh)	1 min	None Needed	Yes	Yes	No
M3001	**Air System**	:Air Sys Energy Use	Sys Energy Consumption (kWh)	Each Component Elec	(kWh)	1 min	None Needed	Yes	Yes	No
M5001	**Boiler**	:Boiler Energy Output	Energy Output (kWh)	Flow & Return Temp, Mass Flow Rate	(^{o}C, m^3/s)	1 min	$\dot{Q} = \dot{M} \times C_p \times (T_f\text{-}T_r)$	Yes	Yes	No

The Ideal Set of Performance Objectives and Metrics defines all measurements at one minute intervals as control issues can remain undiagnosed with less frequent data logging (Section 4.5). Individual *views* of the Ideal Performance Objectives and Metrics Set may request information (Performance Metrics) at different frequencies of measurement and different resolution of data. For example a Financial Controller may request monthly monetary energy consumption values while a controls specialist may require a Variable Air Volume (VAV) speed signal at a one second interval. The Ideal Measurement Set must account for resolution, accuracy and frequency of data to provide reliable information for the end user (Gillespie et al. 2006, Stum 2006, Piette et al. 2001). The content and structure of these datum streams is not presently specified.

5.3 Specification of Datum Stream Formats

Energy Managers require whole scale data management to support benchmarking through the Scenario Modelling technique . Data management includes automated post processing of simulation output and recorded measurements (Morrissey 2006*b*). Traditional data post processing has been performed in spreadsheet packages with mixed results (Pilgrim et al. 2002, Prazeres & Clarke 2003). The person responsible for post processing requires simulation, building operation and software domain knowledge. The required post processing algorithms are represented by the Data Transformation Layer (Section 4.5) and are contained in the 'Calculations' column of the Ideal Performance Objectives and Metrics table of Appendix D. The algorithms/calculations are dependant on consistent and structured raw datum streams. The convention proposed by this section enables a one-to-one comparison of raw data thus enabling a one-to-one comparison of all Performance Metrics.

A systematically structured naming convention is required to ensure consistent formally transformed data through a *one-to-one* comparison of simulation output and measured data. A ten element string will systematically define datum point names (Figure 5.3). Each point name would include ten elements, some of which will be blank. This structured approach assists automated naming of points for the specific purposes of building energy management. Element 1 indicates if the point is virtual or measured and element 10 is the measurement description. Elements 2



to 7 relate to the geometric elements from the Building Object Hierarchy (Section 4.4). For Example, the measured point name for dry bulb temperature measurements for zone 'G.28' in Figure 5.3 is Measured/UCC/Lee Road/ERI/Ground Floor/ / G.28/ / /Dry Bulb Temperature. The elements not relevant to this point are left blank. Similarly elements 8 and 9 are used specifically for HVAC Systems and HVAC system components. A virtual temperature measurement for a fan component located on the roof would be named as following 'Virtual/UCC/Lee Road/ERI/Roof/ / /AHU 1 /Fan 1/Dry Bulb Temperature'.

Table 5.3: *Conditions for Format for Ideal Building Datum Sources*

Raw data sources must have corresponding time stamps, i.e. times must not be out of synchronisation.
Data must not contain duplicate records or duplicate time stamps in output files.
Units must be clearly distinguishable for each field and should be contained in the data name field.
Data must be within expected range which are predefined during design and updated across the BLC
Data must be consistent and free of gaps
Data must be free of nonsensical values. If values have been altered then include a warning message in the first line of the file. Taylor Engineering (2006) provide solutions for missing or corrupt data through advanced interpolation algorithms.
Any files containing interpolated data must contain a warning to that effect labelling the time periods affected. This would be conducted through an extra first row of a file consisting of an appropriate warning message.
All Input files must be adjusted for daylight savings.
Data are to be continuous with no missing time steps.
Data time steps are to correspond (BMS readings to be at the same time interval as simulated output).

The BMS and the simulation model data requirements are noted in Section 5.4. Automated post processing necessitates a standardised raw data storage format. Specifications have been created to rectify the fact that very little data are actually stored in real buildings. Data can also be stored at a poor measurement interval or inconsistent. For example stored values may not have the same time stamp. Table 5.3 summarise the data formats that are best suited to consistency and reliability in the energy management domain. In practice rule based data checking routines would be required to validate all data used.

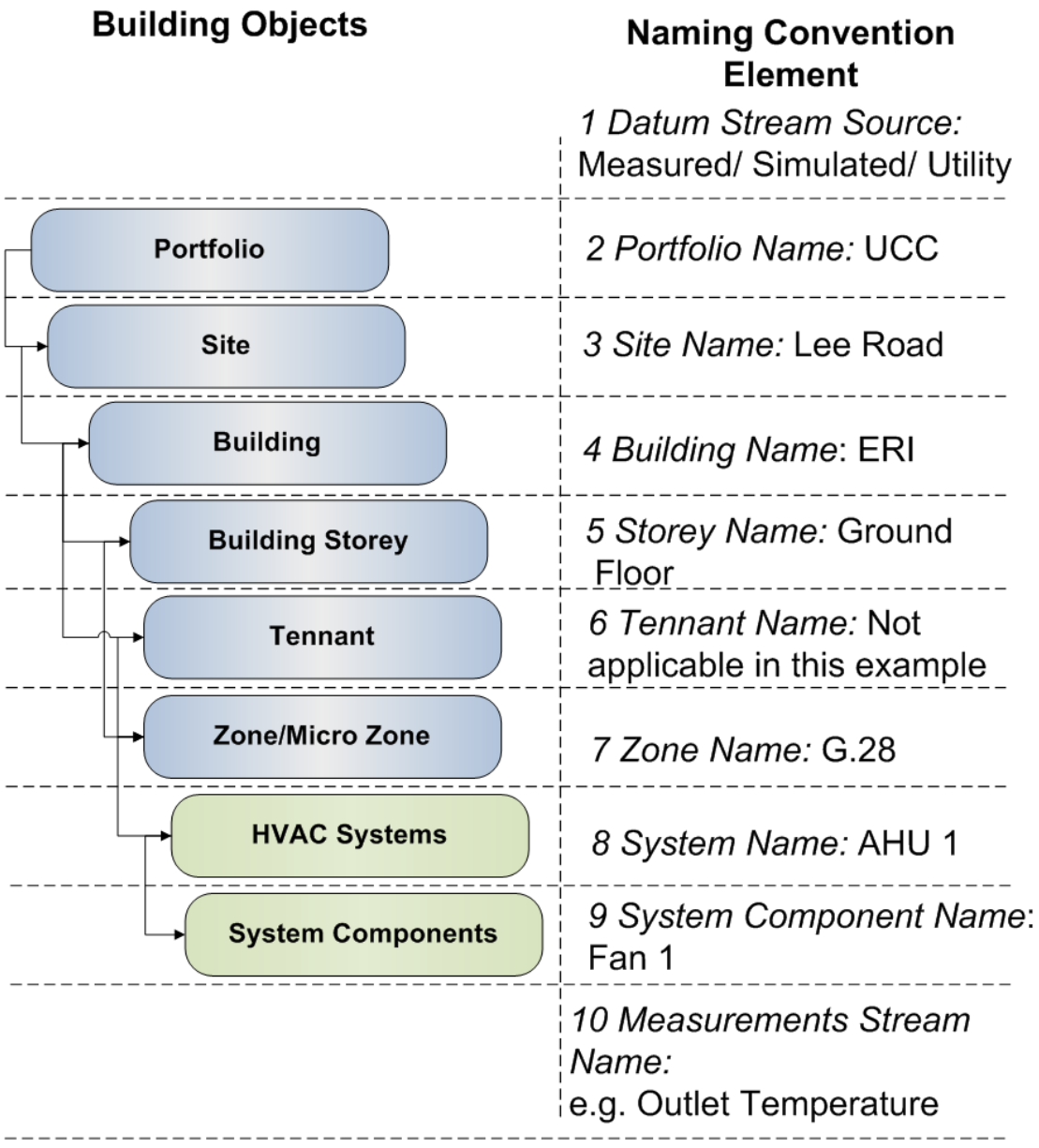


Figure 5.3: *Systematically Structured Naming Convention for Datum Points based on the Building Object Hierarchy*

Gillespie et al. (2006) suggests the optimum method of data storage. Each data value must correspond to a single time stamp. Table 5.4 illustrates this concept. A scenario where a single time stamp and stated time interval represents 24 hours of data is not recommended. The data storage mechanism is not specified but Comma Separated Variable (CSV) file type, data base, on-line data base etc. are common options used. A years data stored in 64 bit format at 15 minute intervals requires

Table 5.4: *Specification of Format for Ideal Building Raw Datum Sources*

Date/Time	**Measured/UCC/ Lee Road/ ERI/ Roof/ / /AHU 1 /Fan 1/Dry Bulb Temperature**	**Virtual/UCC/ Lee Road/ ERI/ Roof/ / /AHU 1 /Fan 1/Dry Bulb Temperature**	**Measured/UCC/ Lee Road/ ERI/ Ground Floor/ / G.28/ / /Dry Bulb Temperature**
Date/Time	Value1	Value 11	Value 21
...	...	...	...
Date/Time	Value j	Value 1j	Value 2j

approximately 2.25 MB of storage space (Bruton 2003). The Ideal Building data storage requirement would be 33.6 MB of disk space per measurement stream, per year if the data are stored in 64 bit double format at 1 minute intervals (Equations 5.1 & 5.2).

$$64bits \times 60minutes \times 24hours \times 365days = 33638400bits \tag{5.1}$$

$$33638400bits \div 8,000,000bites/Megabyte = 4.2Megabytes \tag{5.2}$$

Data storage was traditionally an issue however large volumes of data may now be stored inexpensively with current data storage technologies.

5.4 Specification of Ideal Datum Sources

The datum source specifications are dictated by the requirements of the Ideal Set of Performance Objectives and Metrics. Simply stated the Performance Metric inputs are the datum stream outputs. It is critical that the inputs are accurate, assumptions are stated and inadequacies are noted for each datum stream. Potential sources of error and inaccuracy also need to be resolved so as to enable Ideal Building Operation. This section describes the content of data from each datum source. This generic data description ensures that these data are accessible by all profiled end users of the Ideal Building and especially Energy Managers. The three datum sources used by the Energy Manager of the Ideal Building are:

- Whole Building Energy Simulation Models Output data;

- Measured Sensor and Meter data;
- Utility Provider data.

It is imperative that data from all three sources adheres to the systematically structured naming convention developed in Section 5.3. The naming convention also facilitates consistent data transfer between the BIM and all domain specialists. For example a zone *Building Object* in the BIM will have the same name when it is transferred to a whole building energy simulation model. The Ideal Building requires an *up to date, virtual, 'ideal' building performance benchmark* for a one-to-one comparison with measured datum streams and utility provider data (Section 2.4). Correctly developed whole building energy simulation models can quantify the performance of all Building Objects across the entire BLC through systematically developed Performance Objectives and Metrics. Effective use of Utility pricing data can ensure that holistic environmental and energy management is incorporated into overall organisational objectives. The requirements for simulation model output, measured data and utility data are discussed under the following headings:

- Strengths;
- Assumptions regarding these inputs;
- Weaknesses with the data from this source.

5.4.1 Optimum Benchmark: Energy Simulation Models

Requirements: Strengths and Weaknesses

The predictive capabilities of well developed energy simulation models make it one of the most important tools at the disposal of design engineers[3] (Augenbroe 2002). However it is recognised that certain systems/system configurations are not supported by simulation programs (Crawley et al. 2005). This weakness must be removed for widespread implementation of the Ideal Building philosophy.

The Ideal Building requires that performance related decisions can be made in real time (Chapter 8). Therefore Ideal Performance benchmarks as generated by

[3]For a comprehensive list of whole building simulation packages and their features refer to Crawley et al. (2005).



whole buildings energy simulation models must also be available in real time. Regardless of the model type (design or inverse model) the modeller requires a high level of user skill and knowledge in both simulation and practical building physics. Default values as assigned by simulation programs may have no resemblance to reality (Clarke 2001). Inevitably situations arise where a modeller must assign values for uncertain parameters. Consequently the model is highly dependent on the personal judgement of the analyst carrying out the calibration (Sun 2004). The knowledge and experience of the simulation specialist are of paramount importance. If incorrect assumptions are made when constructing the model, the results may be grossly inaccurate. Consequently the Ideal Building requires that the 'ideal' benchmark is developed by appropriately qualified professionals.

The key to reliable whole building energy simulation model output is validation of the input data. Important input data are: Building, Geometry, HVAC Systems, Internal Loads and Scheduling. The Ideal Building requires that these input types are continuously updated across the building life cycle. An up to date simulation model ensures a one-to-one comparison with measured data during the commissioning and operation phases of the BLC.

Janak (1997) observed that the differences between five minute and hourly illumination data could result in prediction variations approaching 40%. The Ideal Building requires weather files that incorporate measurements at one minute intervals to avoid inaccuracies associated with interpolation of hourly data and that these data are also available in real time. This resolution of data also facilitates a reliable and robust one-to-one comparison with measured datum streams.

Requiremnts: Assumptions

Presently virtual buildings approximate actual buildings. Differences exist between sensor measurements and simulation output for a variety of reasons. These simulation assumptions include algorithms used to account for thermal bridges in building envelopes, fans are assumed to operate exactly to the curves specified at design, zone average temperature is accurately represented by a node etc.. Utmost care must be taken in relation to simulation program default values. For example heating capacity of a heating coil. The Ideal Building requires that present simulation tools inadequacies are addressed to ensure delivery of an accurate and

reliable up to date representation of ideal operation.

The most sophisticated programs are unable to exactly model reality. As a result empirical validation is expensive and only used on selected large budget projects (Claridge et al. 2003). Implementations of the Ideal Building could expedite the calibration process and reduce associated calibration cost as all required information would be stored centrally in a Building Information Model (Chapter 4) and in the format specified in Section 5.3. Calibration using sub-hourly data may require an unjustifiably large time and cost overhead (Waltz 2000). Correct model validation requires calibration[4].

> "*Historically, actual calibration has been an art form that inevitably relies heavily on user knowledge, past experience, statistical expertise, engineering judgement and an abundance of trial and error*"

(Haberl & Bou-Saada 1998)

More recent research on the calibration process has focused on comparing hourly measured data with simulation output (Sun & Reddy 2006, Sun 2004, Soebarto 1997). Hourly results represent the building dynamic energy characteristics in a more accurate and reliable way than using monthly average values (Haberl & Bou-Saada 1998, Bou-Saada & Haberl 1995). The Ideal Building requires that all whole building energy simulation models are calibrated by a simulation specialist.

Regardless of simulation engine or model type simulation output is typically in Comma Separated Variable (CSV) file format. The output variables must be defined according to the naming convention specified in Section 5.3. This convention enables a *one to one* comparison with BMS measurements and Utility provider data.

5.4.2 Actual Building Performance: Measured Data

Requirements: Strengths and Weaknesses

Independent of the measurement source, all datum streams must be accurate and reliable. Section 2.2.4 explains how installed sensors as specified at design do not

[4]Suggested manual calibration procedures may be obtained from Reddy & Maor (2006), Claridge et al. (2003).



reflect changes that occur to the building during construction or commissioning. Any proposed changes to the operation of the Ideal Building should be analysed using the Scenario Modelling technique. This technique utilises Performance Aspects, Building Objects and Performance Objectives and Metrics (Chapter 3). Ideal Building measurement streams must be defined by the Scenario Modelling technique as opposed to traditional controls specialists (Chapter 4).

Traditionally existing BMS may include central energy management, self-learning control algorithms such as supply air temperature reset, optimum start/stop time etc.. However under the traditional design/build/commission/operate process BMS will not optimally control and manage a building (So et al. 2005). At operation the Energy Manager may assume the BMS is representative of the commissioned building as specified in the design intent documentation. Alternatively an Energy Manager may improvise and use their judgement, experience and training in an attempt to derive information that is not measured (Chapter 8). The accuracy of this process is dependant on the individual Energy Manager. Emerging technologies could deliver additional cost effective retrofitted measurement streams to the Energy Manager (Jang et al. 2008, Keller et al. 2007, ennovatis 2007, Federspiel 2006). Such technological advances bring the Ideal Building a step closer to reality and also the installation of a certain level of measurement in all buildings.

Inadequate calibration of measurement devices and maintenance procedures are other potential sources of error. Sensor and meter accuracy and maintenance requirements must be specified at design. Table 5.5 specifies the required sensor accuracy for the Ideal Building measurement streams (Gillespie et al. 2006). The table illustrates that non-critical zone conditions require an accuracy of 0.2 ^{o}C. An accuracy of within 2^{o}C is not acceptable for absolute control on large energy consuming devices such as heating coils (Klaassen 2001*b*). Table 5.5 indicates an accuracy of 0.1^{o}C is essential in this situation. In this case upgrading to a higher standard of sensor may be necessary[5] [6]. Some general guidelines and considerations for *correct* sensor placement may be obtained from Klaassen (2001*a*) and a comprehensive reference is available in ASHRAE Applications (ASHRAE 2003*b*, Section 46.19).

[5]Klaassen (2001*b*) contains a comprehensive investigation of sensor accuracy and reliability.

[6]Uncertainty regarding sensor accuracy may be addressed using the techniques found in (Barley et al. 2005, Appendix C).

Table 5.5: *Suggested Resolution of Measurements (Courtesy of (Gillespie et al. 2006))*

Measurement Point or Metric	**Accuracy Goal**
Outside ambient temperature (^{o}C)	.1^{o}C
Outside ambient wet bulb temperature (^{o}C)	.1^{o}C
Zone temperature (^{o}C)	.2^{o}C
HVAC electric only energy use (kWh)	1.5% of actual value
Chilled, hot water temperature (^{o}C)	.1^{o}C, if $\geq 5^o$C delta T
Chilled, hot water delta temperature (^{o}C)	2% of actual value
Chilled, hot water flow (l/s)	2% of actual value, > 20-1 turndown
Natural gas flow (m^3)	2% of actual value, > 10-1 turndown, w/ pressure and temperature compensation; Using an average heat content of the gas to convert to kWh introduces a 2% error
Air flow (m^3/s)	5% of actual value down to 10% of full scale, > 10-1 turndown
Power (kW)	2.0% of actual value
Chiller cooling output (kW)	3% of actual value
Chiller cooling energy (kWh)	3% of actual value
Boiler heating output (kW)	3% of actual value
Boiler heating energy (kWh)	3% of actual value
Electric energy use (kWh)	2% of actual value
Total HVAC energy use (kWh) (includes air side, water side and natural gas)	3% of actual value
Chiller performance (kW/kW)	4% of actual value
ChW Plant performance (kWh/kWh)	4% of actual value
Total boiler performance (kWh/kWh) (COP)	4% of actual value
Total air handler performance (kWh/m^3)	6% of actual value
Net Usable Building floor area	2%

Requirements: Assumptions

A specified program for continued commissioning and maintenance must be incorporated into the organisational management structure if desired sensor or meter



accuracy is to be maintained (Hatley et al. 2005). A structured maintenance strategy is essential to perpetuate sensor calibration (O'Connor 2007)[7]. Ad-hoc operation results from the absence of a structured data management implementation (Morrissey 2006*b*). All environmental and energy related systems must be accessible and monitored by the central system (Chapter 7). If not, localised control of systems can lead to a deterioration of environmental conditions and consume excessive energy (Hatley et al. 2005). Missing or inaccurate performance data may only be identified during an energy audit or energy analysis. Problems such as incorrect scheduling or a damper malfunction may exist for the time periods between energy audits. Assumptions made by maintenance personnel can have a detrimental effect on operation. "*A BMS system will deteriorate down to the level of the least trained technician*" (Hatley et al. 2005). The Ideal Building also requires a specified maintenance program which is consistent with Organisational Objectives and Scenario Modelling to enable optimal holistic environmental and energy management.

5.4.3 Utility Provider Data

Requirements: Strengths, Weaknesses and Assumtions

In Ireland and Northern and Central California the Electricity Supply Board (ESB) and Pacific Gas and Electrical (PG&E) respectively offer some on-line monitoring features for their business customers through Smart Meter Technology (Ryan 2007*b*, PG&E 2006). These include bill comparison, daily load profile, cost and consumption report and a detailed reference library to assist further detailed investigation. The readings are taken at the main meter and the smallest time interval allowable is 15 minutes (ESB 2006, PG&E 2006). PG&E also offer demand response services which account for dynamic pricing information and are described in detail in Piette et al. (2005). The Ideal Building requires reliable real time utility price information at resolution specified by the Ideal Table of Performance Objectives and Metrics. Potential adjustments made to building operating strategy would be based on utility price information. It is imperative that these data streams and their contents are guaranteed by the Utility Provider.

Authenticated data are a prerequisite of the Ideal Building. Data must be mea-

[7]Each sensor should be maintained in accordance with manufacturer's guidelines.

sured and linked to the meter. It must not be estimated or interpolated. Anecdotal evidence from a site survey of the Mardyke Arena revealed a situation where the electricity bills utilised sequential estimated readings for billing periods which caused a huge spike when corrected[8] (O'Donnell et al. 2004). Estimated readings can be damaging as corrections must be made at a future date and the archive or data base is invalidated. Consequently energy use cannot be apportioned over time. Utility Providers must also account for the emission indices (Kg CO_2/GJ) and energy conversion factors (MJ/m^3) associated with different fuel types and different grades of fuel.

5.5 Chapter Conclusion

This chapter defines the datum streams or quantitative data layer that underpin the Ideal Building Framework. The Ideal Data Set supports the formally transformed data requirement by demanding accurate, consistent and reliable data to enable a one-to-one comparison between an Ideal performance benchmark, real-time measured and utility provider data. This chapter outlines the assumptions, requirements and specifications for whole building energy simulation model output data, real time measurements from sensors or meters and Utility Provider data. This chapter also includes the definition of a common datum format and systematically structured logical naming convention which is applicable to all datum sources, thus facilitating the desired one to one comparison of Performance Metrics for informed decision making.

The definition of the Ideal Measurement Set creates the possibility for all project stakeholders to use the Ideal Building Framework. Each stakeholder has a unique requirement for information, therefore customised *views* of the Ideal Building Framework are essential. Chapter 6 describes a methodology that incorporates processes from current research for enabling stakeholder *views* of the Ideal Building Framework.

[8]The utility meter was not connected to the BMS

Chapter 6

Model Views of the Ideal Building

> "*Everything that is really great and inspiring is created by the individual who can labour in freedom.*"
>
> (Albert Einstein 1950)

6.1 Chapter Introduction

This Chapter describes how an instantiation of the Ideal Building Framework can be utilised by end users responsible for building performance. *A Model View as used in this thesis is defined as a representation of the building performance data required by a profiled end user.* Therefore a *Model View* of the Ideal Building supports the analysis activities of the Energy Manager. Individual Model View definitions must match the requirements of the specific end user and corresponding Rule Sets define the Model View specific measurement streams. A generic process which is applicable for all Model Views through specific rule sets must also be defined. This Chapter describes Model Views of the Ideal Building under the following headings:

- Definition of Model View Data Exchange Requirements;
- Definition of User Profiled Based Model View Definitions;
- Methodology process, applicable during design or for as-built cases, for using a Model View and associated Rule Set with the Ideal Measurement Set;
- Specification of Rule Sets that support the definition of a particular Ideal Measurement Set Model Views.

6.2 Model View Data Exchange Requirements

This section describes the processes used for stakeholder specific data exchange. The stakeholder profiled in this thesis, the Energy Manager, requires context sensitive access to the Ideal Building Framework in the form of a Building Information Model (BIM) (Section 4.3). The process adopted to support the definition of an Energy Manager Model View data exchange requirements is applicable to all project stakeholders and is illustrated in Figure 6.1. This process is used for Industry Foundation Classes (IFC) based Model View definitions. IFC's are the only comprehensive, non-proprietary data model of buildings and have the potential to become a future industry standard (Khemlani 2005). This section will outline how the business process models and exchange requirements can be used to specify building performance data as made available by the Ideal Building Framework.

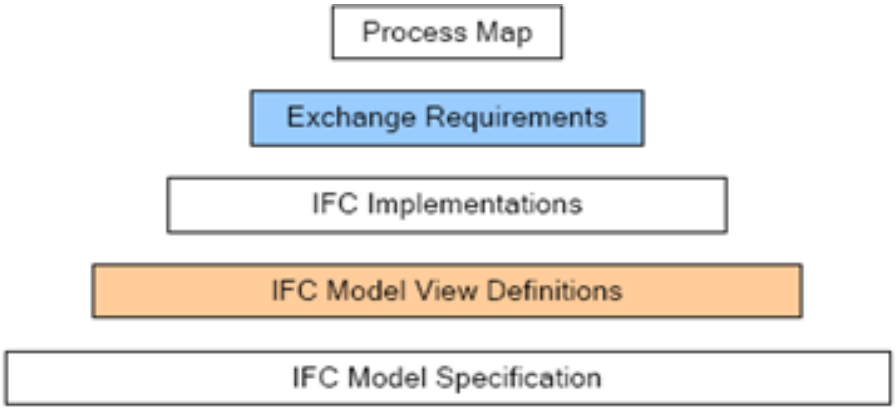


Figure 6.1: *Steps required for reaching deployment of IFC based solutions (Courtesy of (Hietanen 2003))*

The steps required for reaching deployment of IFC based Model View Definitions are illustrated in Figure 6.1. These are (Hietanen 2006):

- **IFC Model Specification** is the entire IFC schema and its documentation;
- **IFC Model View Definitions** document how the IFC Model Specification is applied in the data exchange between different application types which may or may not be stakeholder specific;
- **IFC Implementations** are the IFC import and export capabilities of software applications;



- **Exchange Requirements** document the information that must be passed from one business process to enable another to happen;
- **Process Map** gives and overview of the end user process, describing its objective and describes the stages in a project at which the process is expected to be relevant.

The complete data model of buildings is too large for practical use by all project stakeholders. Model Views enable stakeholder specific data access. This section focuses on the data and information exchange requirements of the Energy Management domain. However, Model View data cannot be exchanged using a non proprietary data model such as IFCs before the corresponding capabilities and data model implementations exist in software (Hietanen 2006). There is a current dearth of post CAD IFC software applications, which are represented by the "IFC Implementations" layer of Figure 6.1 and consequently limit the penetration of IFC with respect to practical project use. This thesis does not define an IFC based model view as it cannot be validated through software at the time of writing this thesis.

The Energy Management process map must incorporate traditional and proposed domain specific activities. The outlining parameters of the Energy Manager data exchange requirements process map are elicited from Chapters 1 and 2 which describe the *tools, techniques, data* and *information* typically used. Chapter 3 outlines the *Scenario Modelling* and *Performance Metric Combinations techniques* and Chapters 4 and 5 detail the life cycle Ideal Building Framework and data required to realise these benchmarking techniques. Cumulatively Chapters 1 to 5 specify the current and ideal requirements of the energy management domain. Appendix F lists the entire set of Energy Manager exchange requirements in an object based manner to mirror the object based nature of Building Information Models (BIM). The Building Objects as defined in Chapter 2 are a subset of the data transfer requirements, of which a summary includes:

- Day to day operation activities;
- Maintenance activities;
- Performance Benchmarking activities;

- Legislative compliance activities;
- Logging activities of all events.

It is proposed that in time these exchange requirements will form the basis of the Energy Manager IFC Model View Definition. This Model View definition could in turn be used to elicit stakeholder specific datum streams for performance analysis.

6.3 User Profiled Based Model View Definitions

This section is based on the assumption that the data exchange requirements of respective project stakeholders have been expanded to incorporate full Model View definitions. Model Views of the Ideal Building Framework enables stakeholder specific access to a subset of the Ideal Measurement Set, as defined in Chapter 5, which ultimately forms the basis of required Scenario Models.

The availability of context sensitive formally transformed data is one of the key objectives of this thesis (Section 1.5). Model View selection should also be accompanied by context sensitive resolution (high detail, medium detail or low detail). This selection would determine a subset of the Ideal Measurement Set and in turn determine the subset of Ideal Performance Objectives and Metrics which are used in Scenario Modelling (Figure 6.2). The end user driven approach is consistent with the datum stream definition detailed in Chapters 4 and 5.

This currently undefined Model View definition process must be generic in order to account for all stakeholders with a particular interest in building performance information. The process can be used with the 'Energy Manager Model View' and highlights the relevant datum streams of the Ideal Measurement Set (Figure 6.2). The process is applicable for all end users interested in accessing building information. Apart from the Energy Manger other end Model Views include:

- Energy Auditor Model View;
- LEED Accreditor Model View;
- Financial Controller Model View;
- Control Specialist Model View;

- Mechanical/Civil/Electrical Engineer Model View;
- Plumber Model View.

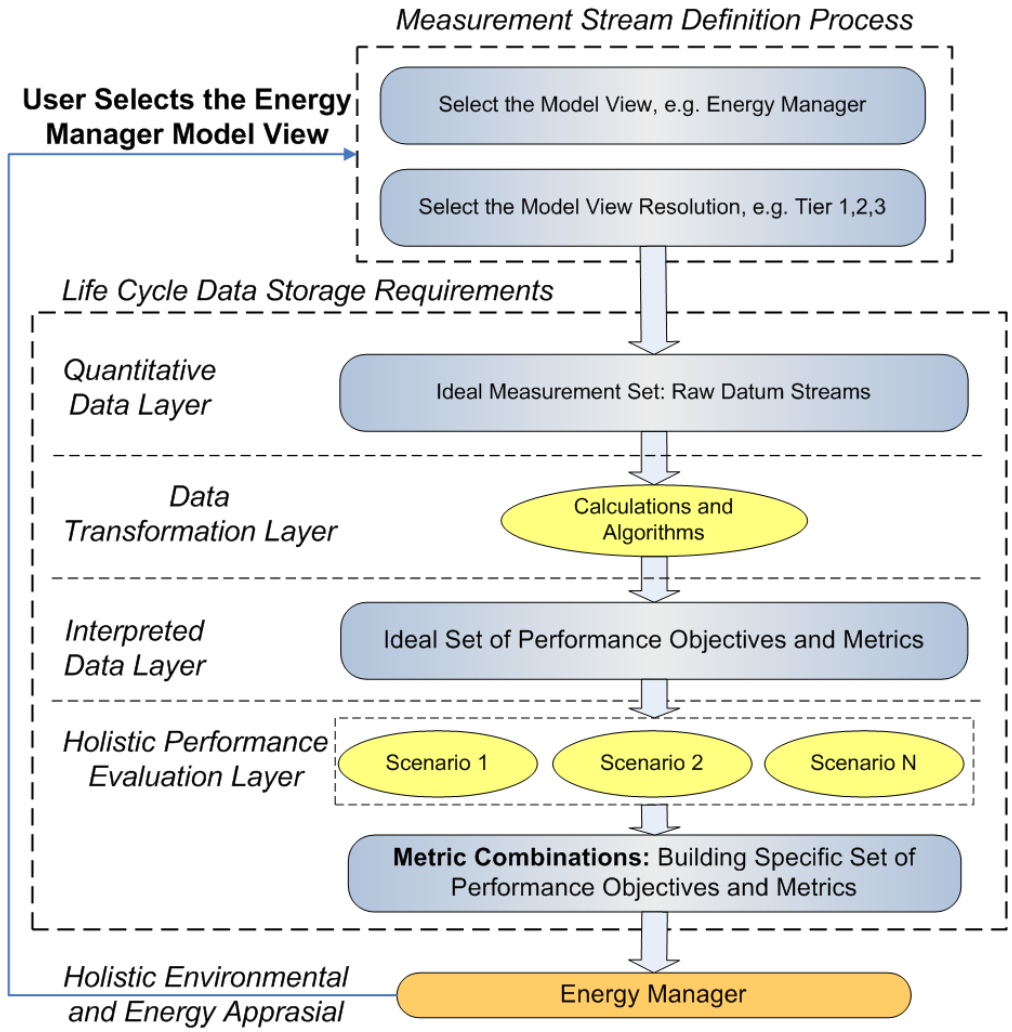


Figure 6.2: *High Level Overview of the Automated Process and Rule Set Relationships as applied with the Ideal Building Framework*

Different levels of resolution are required for each defined Model View and definition of these levels of resolution would further assist profiled end users.

6.3.1 Specification of Model View Resolution

Access to the data provided by a complete Model View definition may not be appropriate for the context specific purposes of the end user. For example an

overview of building operation may be hindered by presentation of unnecessarily detailed information. The Model View resolution concept further filters the Model View data for the specific task at hand. This concept can be illustrated by using the Energy Management Model View[1]. It is proposed that three tiers of resolution should exist for filtering the Ideal Measurement Set based on the profiled activities of Energy Managers (Neumann & Jacob 2007, Gillespie et al. 2006). Tier 1 is based on the BuildingEQ definition of the minimum measurement set (Neumann & Jacob 2007) and Tier 1 as defined by Gillespie et al. (2006). Tier 2 is based on the Tier 2 recommendations as defined by Gillespie et al. (2006) and Tier 3 is based on the requirements of Ideal Building Operation and Gillespie et al. (2006) Tier 3 definition (Chapter 4). The three tiers detail are defined as follows:

- Tier 1: High level overview to gauge overall building and system performance through appropriate benchmarks. This tier is particularly appropriate for a basic level of performance analysis by non-technically qualified Energy Managers with restricted time. This level could also be used by tactical management to determine overall building performance;
  - Building function (Important zone temperatures);
  - Weather Conditions;
  - Chilled water plant overview;
  - Hot water plant overview;
  - Renewable systems overview;
  - Air System supply temperature.
- Tier 2: Day to day operation which enables an intermediate level system by system overview that facilitates performance appraisal for all system components. This tier definition recognises better resourced energy management departments as established in Chapter 2 and is applicable for Energy Managers with qualifications in a related field;
  - Standard air system diagnostics, duct static pressures;
  - Standard plant system diagnostics, pipe static pressures;

[1]A complete set of exchange requirements for the Energy Manager Model View are included in Appendix F



  - Temperatures, humidities and Lux levels for all environmentally controlled zones;
  - Zone Occupancy Signal;
  - Building Occupancy Level;
  - Energy Use Category Meters (e.g. heating, cooling etc);
  - Heat Meters on all water sub loops;
  - System Control signals.

- Tier 3: Detailed systems analysis to facilitate in-depth investigation of identified inefficiencies. The requirement for Ideal Building operation (Chapters 3 & 4) and well resourced energy management departments are recognised. Tier 3 data would be most appropriately used by appropriately qualified technically qualified Energy Managers.

  - Sub meter breakdown;
  - Other zone measurements: temperature; humidity; Lux and air flow rate at the micro zone level;
  - Component Control signals;
  - Zone Occupancy level.

The process that provides the relevant end user data must now be defined.

6.4 Model View and Rule Set Process

This section explains a process for determining a *Model View* of the Ideal Measurement Set at the user selected resolution for a specific as-built building representation. This process is outlined by Figure 6.3 and is incorporated in the text for illustration purposes. A fully functional interactive image with accompanying rule sets are available in Appendix G. It is important to note the process results in a set of defined measurement streams. In the context of this thesis the definition of these measurement streams is through spreadsheets. An example of the measurement stream definition for a cooling coil object is illustrated in Table 6.1. When the Interactive version of Appendix G is used, the process should result in a spreadsheet identical in layout to Table 6.1. Each spreadsheets contain filters for different resolutions of measurement stream.

Table 6.1: *Energy Manager Model View of a Cooling Coil Building Object.*

Building Object	**Measurements Required**	**Unit**	**Interval**	**Energy Manager**	**Tier 1**	**Tier 2**	**Tier 3**	**Performance Objective**	**Performance Metric and Unit**
Cooling Coil	Air Inlet Temperature	°C	1 Minute	1		1	1	Minimise Required Energy Transfer Rate	Cooling Coil Energy Use (kWh)
Cooling Coil	Air Outlet Temperature	°C	1 Minute	1		1	1	Maximise Efficiency	Cooling Coil Efficiency (%)
Cooling Coil	Air Flow Rate		1 Minute	1			1		
Cooling Coil	Water Inlet Temp	°C	1 Minute	1	1		1		
Cooling Coil	Water Outlet Temp	°C	1 Minute	1	1		1		
Cooling Coil	Supply Temperature Setpoint	°C	1 Minute	1	1	1	1		
Cooling Coil	Operating Schedule	Time	1 Minute	1	1	1	1		
Cooling Coil	Water Flow Rate	m^3	1 Minute	1	1		1		
Cooling Coil	Coil Valve	%	1 Minute	1		1	1		
Cooling Coil	Coil Valve Signal	%	1 Minute	1		1	1		



The important steps for using the Automated Process and Rule Set methodology are discussed in turn and include:

- Zonal Model of a building;
- Object Identification and Categorisation;
- Model View Selection;
- Rule Set Application;
- Specification of Resolution;
- Measurement Delivery.

A building representation in the form of a **zonal model** is a critical requirement for this process. Ideally this zonal model would be object oriented in nature but this is not essential. In the context of the Ideal Building a zonal model is automatically described in the life cycle BIM (Section 4.3). However, this zonal information could also be determined when BIM is not available. In such cases whole building energy simulation models that output the ideal performance benchmark (Section 5.4) could act as the zonal model. An object oriented model would demand a one-to-one relationship with defined Building Objects (Chapter 2). For example a physical zone would be represented by a zone Building Object from the model. Furthermore this object oriented model can be proprietary or non proprietary in nature. A spreadsheet type model could be used in the absence of a zonal model. EnergyPlus is an example of a zonal model and Dwelling Energy Assessment Procedure (DEAP) is an example of a spreadsheet model (US-DOE 2006, SEI 2006*a*).

The automated process identifies each relevant Building Object in the model used and defines a **Building Object Hierarchy** of these objects that reflects the identified in Section 4.4.

The manual process '**View Selection**' allows the user to input their role with respect to building performance. This Model View Selection would be from a predefined set of Model Views such as for an Energy Manager, an Energy Auditor or a Financial Controller etc. Additional Model Views may be manually defined if required for other parties interested in building performance.

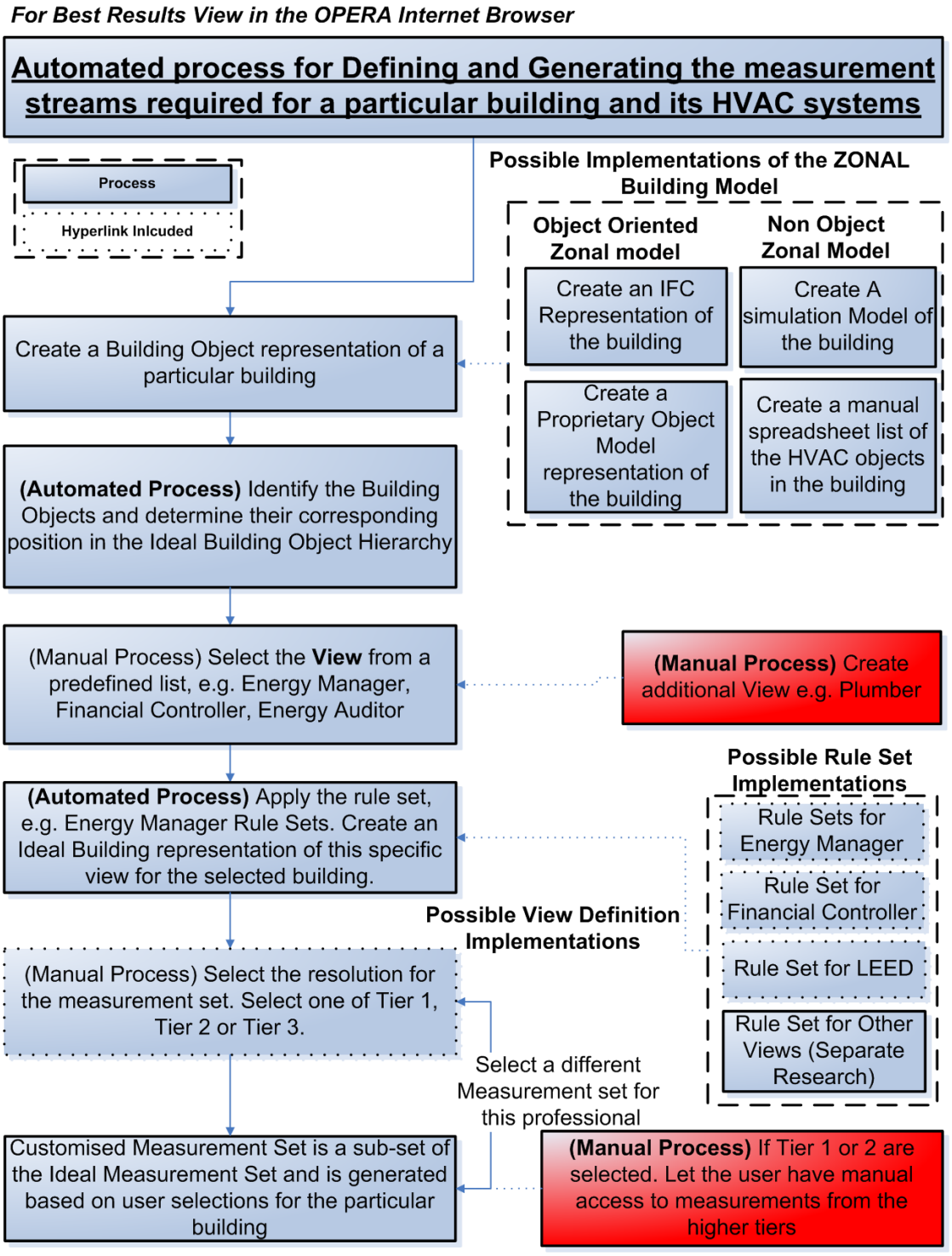


Figure 6.3: *Process for Defining a Model View for a Specific Measurement Set of a Particular Building. Appendix G contains a fully interactive image.*



The automated process '**Apply the Relevant Rule Set**' utilises a unique predefined rule set that defines the previously selected Model View. The rule sets are described in detail in Section 6.5. Each unique rule set identifies the Building Objects in the Building Object Hierarchy that are relevant to this particular Model View (Section 6.2).

Each rule set allocates measurements based on individual Building Objects and the Building Object Hierarchy but these measurements are modified in accordance with:

- Building and HVAC System Configuration. For example, in the case of the Zone Building Object, a mechanically conditioned zone would require a different measurement set compared with the measurement set for a naturally ventilated zone;

- The Rule Set Definition for that Model View. For example an Energy Manager may require high resolution of measurements for a zone and an Energy Auditor may not.

When the rule sets have been applied the user must **select the resolution** of the Model View required. The resolution should reflect the specific need of the end user. For example an Energy Manager may need an overview of building operation or a detailed analysis of building operation. For an Energy Manager this would be a Tier 1, 2 or 3 selection. In the context of the LEED Model View this selection could be on a credit by credit basis, a group of credits or all credits relevant to the context of this thesis.

This output of the entire process is a context sensitive, tiered, Model View representation of the Ideal Measurement Set.

6.5 Model View Rule Set Specification

Rule sets have been explicitly defined for an Energy Manager Model View, LEED Model View and a Financial Controller Model View. Each respective sample rule set is defined by a flow chart (Figures 6.4-6.7 inclusive) and the table contained in

Appendix D[2]. The flow charts identify the Building Objects and the Appendix D Table defines the measurements for each Building Object in the particular Model View. Performance Objectives and Metrics are specified at the Building Object level (Section 3.4), as are the underlying measurement streams (Section 4.2).

It stands to reason that measurements defined by the rule sets should be associated with individual Building Objects. The set of measurements associated with each object can vary depending on building and HVAC system configuration. The conditions for these dependencies are described in the comment column of Appendix D. The user may also manually adjust the measurements associated with each object at any stage of the process. These rule sets are described in turn starting with those for the Energy Manager.

Rule Set: Energy Manager

The Rule Sets for the Energy Manager are characterised for conditioned zones (Figure 6.4) and for non-mechanically conditioned zones (Figure 6.5). The measurements identified by both rule sets are combined to deliver the Energy Manager Model View of building performance. Each rule set defines the necessary *zone* measurements and subsequently the measurements for the other Model View specific Building Objects. These are the mechanically or naturally ventilated systems that service that zone. Rule Set 1/2 then describes the measurements for the *plant systems* that supply the systems servicing each *zone*. The *utility* measurements, *building* measurements and *site* measurements are identified in turn. At each stage in the process the *energy use categories* are noted and updated to account for building specific systems.

Energy Manager rule set 2/2 defines the measurements for unconditioned *zones* which are categorised as "naturally ventilated zones", a typical "unconditioned zone" such as a storage area or an "unconditioned zones that influence a conditioned zone". Measurements associated with naturally ventilated zones or zones that affect other zones are automatically assigned to the relevant *building* or *system* Building Object.

[2]A fully interactive and interlinked series of images is available in Appendix G. This appendix includes an interactive version of the process for defining a Model View (Figure 6.3), sample rule sets (Figures 6.4 & 6.5 & 6.7) that this process could use and an interactive version of Appendix

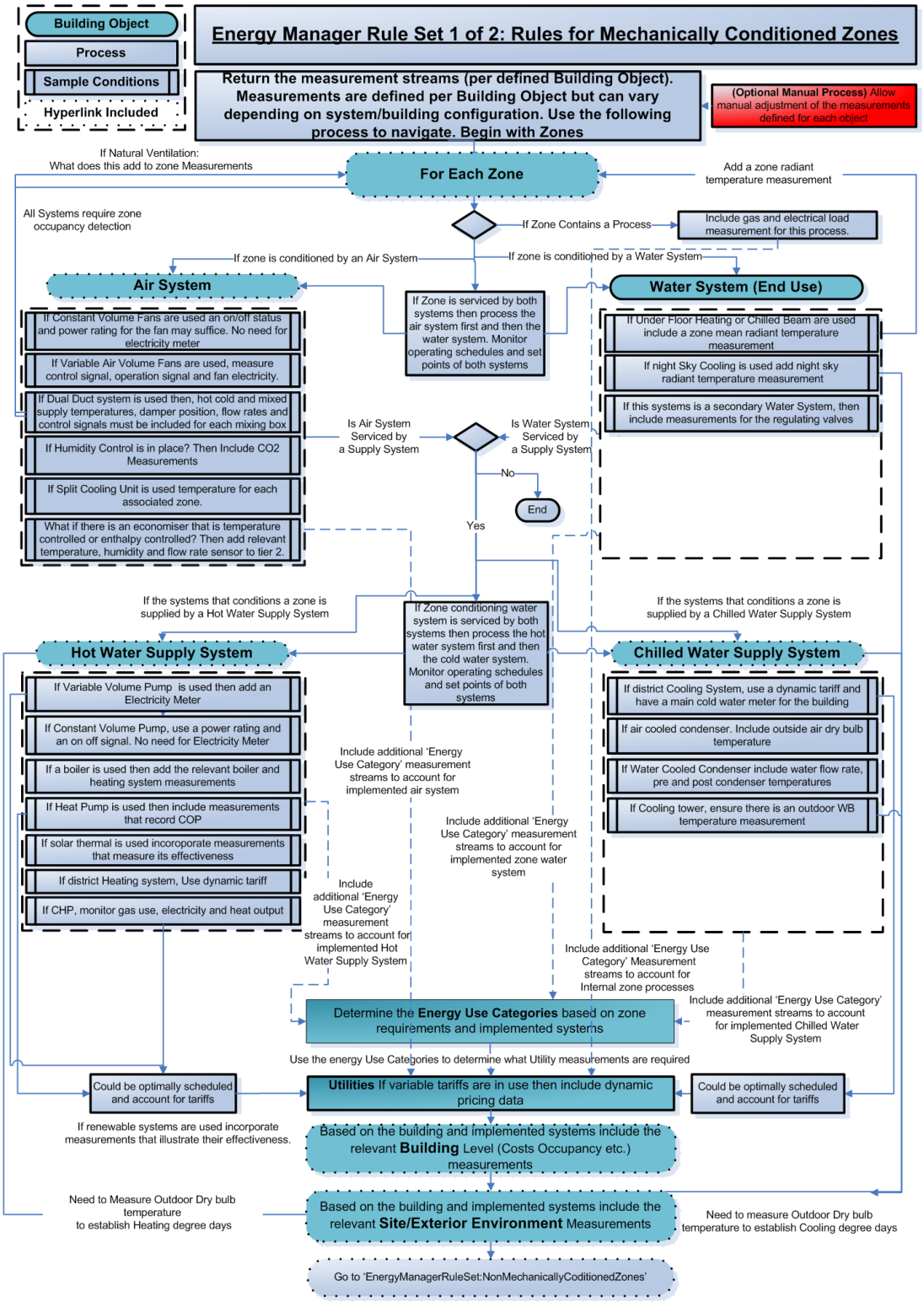


Figure 6.4: *Energy Manger Rule Set for Mechanically Conditioned Spaces. Appendix G contains a fully interactive image.*

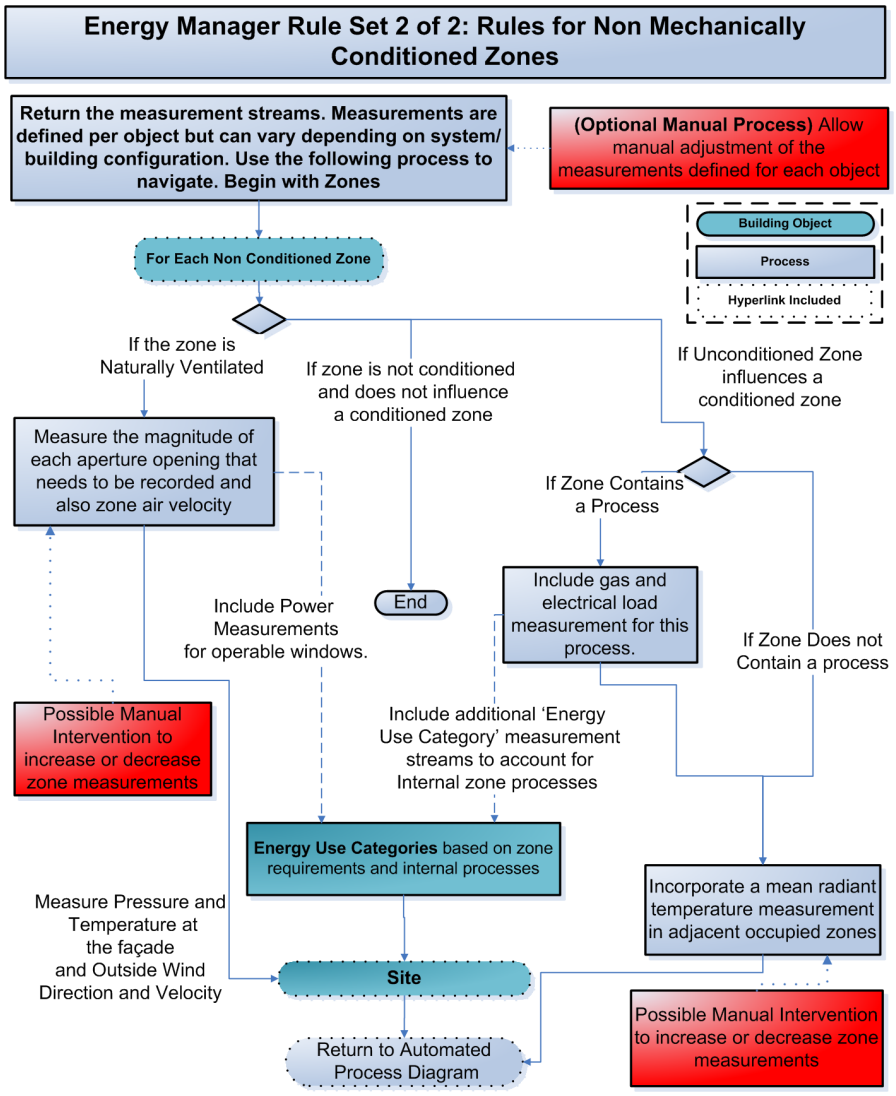


Figure 6.5: *Energy Manager Rule Set for Non-Conditioned Zones. Appendix G contains a fully interactive image.*

Table 6.1 demonstrates the Energy Management Model View of a Cooling Coil Building Object. These measurements are applicable to the cooling coil contained in Scenario 1 (Section 3.5). Table 6.1 also includes tiered measurements for three resolutions of the Energy Management Model View. The identified measurements are associated with Performance Objectives and Metrics which are also identified for the *cooling coil* Building Object (Section 3.4).

D to highlight Model View specific measurement streams

Rule Set: LEED Accreditor

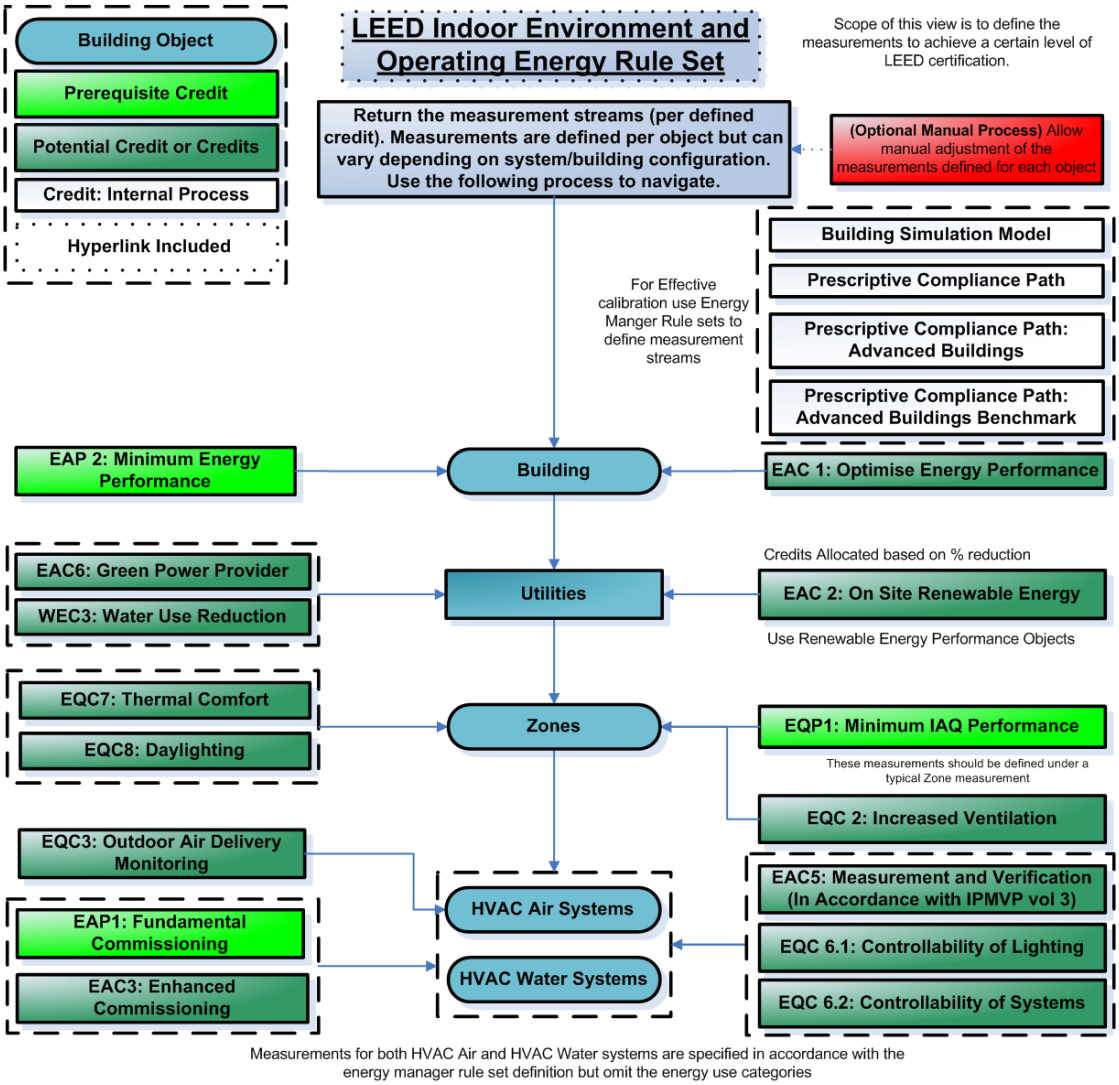


Figure 6.6: *The LEED Rule Set for Credits that Relate to the Scope of this Thesis. Appendix G contains a fully interactive image.*

The LEED rule set outlines the measurements for the LEED V2.2 credits that are within the scope of this thesis[3]. The credits are categorised as a prerequisite or optional in accordance with LEED labelling and are assigned to Building Objects as defined in Section 2.4. The flow chart illustrated by Figure 6.6 defines the process for identifying the relevant Building Objects for each building instance.

[3]As of writing this thesis the EPBD has not yet implemented a methodology for rating commercial buildings. A EPBD rule set could be developed to define the building specific measurements required for an energy rating

The table contained in Appendix D includes the measurement streams for each Building Object in Figure 6.6 on a credit by credit basis.

Table 6.2: *Sample Measurements for LEED Credit 'Energy and Atmosphere Credit 1: Optamise Energy Performance' at the Zone Building Object*

Building Object	**Measurement**	**Unit**	**Frequency**
Zone	Zone Temp	^oC	1 Minute
Zone	Zone Temp Setpoint	^oC	1 Minute
Zone	Zone Relative Humidity	%	1 Minute
Zone	Zone Relative Humidity Setpoint	%	1 Minute
Zone	Occupancy Signal (CO_2or PIR)	CO_2 PPM	1 Minute
Zone	Zone Air Velocity	m/s	1 Minute
Zone	Zone Mean Radiant Temp	^oC	1 Minute
Zone	Metabolic Rate	W/m^2	1 Minute
Zone	Doors/Windows Closed (Yes/No)	Yes/No	1 Minute
Zone	Magnitude of opening for each door or window	%	1 Minute
Zone	Zone Lux Level	Lux	1 Minute
Zone	Zone Occupancy	People	1 Minute
Zone	Zone Lighting load	kWh	1 Minute
Zone	Zone Plug Load	kWh	1 Minute

Table 6.2 displays an example of measurements required for the LEED Accreditor Model View of the Ideal Building. The example illustrates that for the 'Energy and Atmosphere Credit 1: Optamise Energy Performance', the *zone* Building Object requires the measurements illustrated in Table 6.2. A LEED Accreditor can now analyse the measurement streams required on a credit by credit basis if the illustrated example is extended to incorporate the entire building and its systems. This concept is demonstrated in Section 9.3.2.

Rule Set: Financial Controller

The Financial Controller Model View is included to demonstrated the scope of the Model View concept. A Financial Controller controls the accounts for a building, a campus, an organisation, a country and so on. A sample rule set has been created for the Financial Controller of a building who oversees the day to day operation of the building's finances. Rule Sets for this domain should be defined by an appropriately qualified person or group such as a facilities management

organisation. In a manner similar to the rule sets developed for an Energy Manager the Financial Controller rule set identifies the relevant Building Objects and their associated measurement streams. The process is outlined in Figure 6.7. A complete Financial Controller Model View is defined in Appendix G.

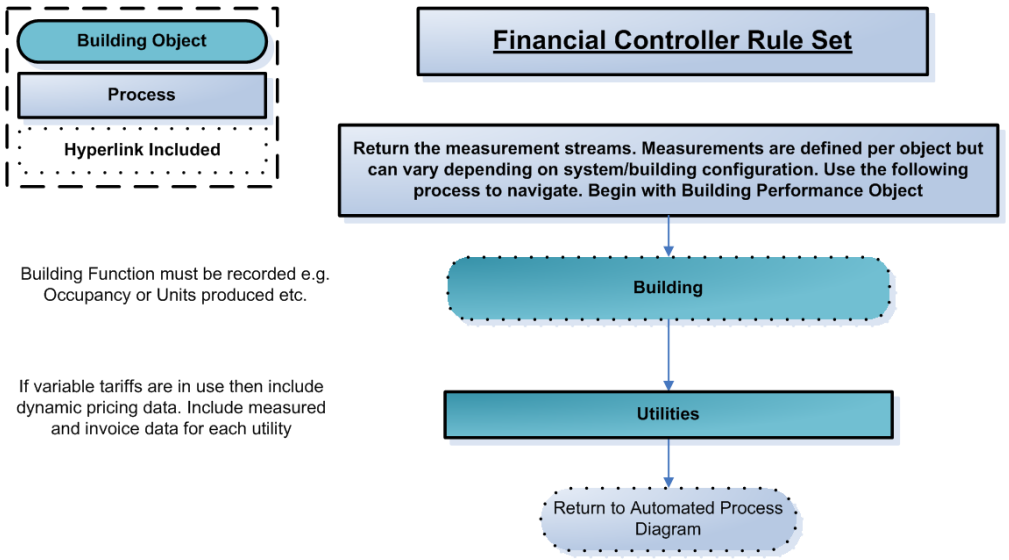


Figure 6.7: *Rule set for Financial Controllers. Process for Defining a Model View for a Specific Measurement Set of a Particular Building. Appendix G contains a fully interactive image.*

6.6 Chapter Conclusion

This Chapter defines the data and information exchange requirements for the Energy Manger Model View. The defined requirements are communicated in an object oriented nature to facilitate future adoption in object oriented Building Information Models. A formally structured generic process for identifying the data needed by profiled end users is also outlined. This Model View methodology utilises rules sets for each Model View and the returns a unique measurement set of datum streams. In essence this Model View specific data set would be a sub set of the Ideal Measurement data Set developed in Chapter 5. The end user may also select the resolution at which he intends to use the Model View specific data set. A carefully defined three tier structure is proposed for the Energy Manager Model View and is contained in Appendix E.

This chapter completes the definition of data required by the life cycle Ideal Building and the definition of context sensitive formally structured data transformations (Chapters 1-6 inclusive). However information generated by the Ideal Building Framework needs to be presented to a defined end user such as the Energy Manager. A software environment that enables the storage, tracking and visualisation of performance information across the entire building life cycle must also be developed. Chapter 7 specifies the requirements for an Information Delivery Tool that incorporates the requirements of the Ideal Building Framework.

Chapter 7

Specification of Information Delivery Tool

> "*The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.*"

(Mark Weiser 1997)

7.1 Chapter Introduction

An Information Delivery Tool must incorporate the requirements, principles and components of the Ideal Building Framework as laid out in previous chapters. A user friendly Graphical User Interface (GUI) interface must account for the established profile of the end user, in this case the Energy Manager, in conjunction with the principles of best practice user interface design. This chapter details the following:

- Specifications of Screen Layout;
- Specifications of Interface Navigation and Use;
  - Specification of Performance Data Display;
  - Specification of Report and Save Options.

7.2 Specifications for Screen Layout

Software tools demand a systematic approach to their development. The requirements of the Information Delivery Tool include:

- Profiled End User and Identified Domain Criteria (Chapter 2);
- Scenario Modelling using Benchmarking and the Metric Combinations techniques (Chapter 3);
- Generic and building specific Performance Metrics (Chapter 3);
- Ideal Set of Performance Objectives and Metrics that underlie the required benchmarking technique (Chapter 4);
- Ideal Measurement Set (Chapter 5);
- Views of the Ideal Measurement Set for profiled end users (Chapter 6).

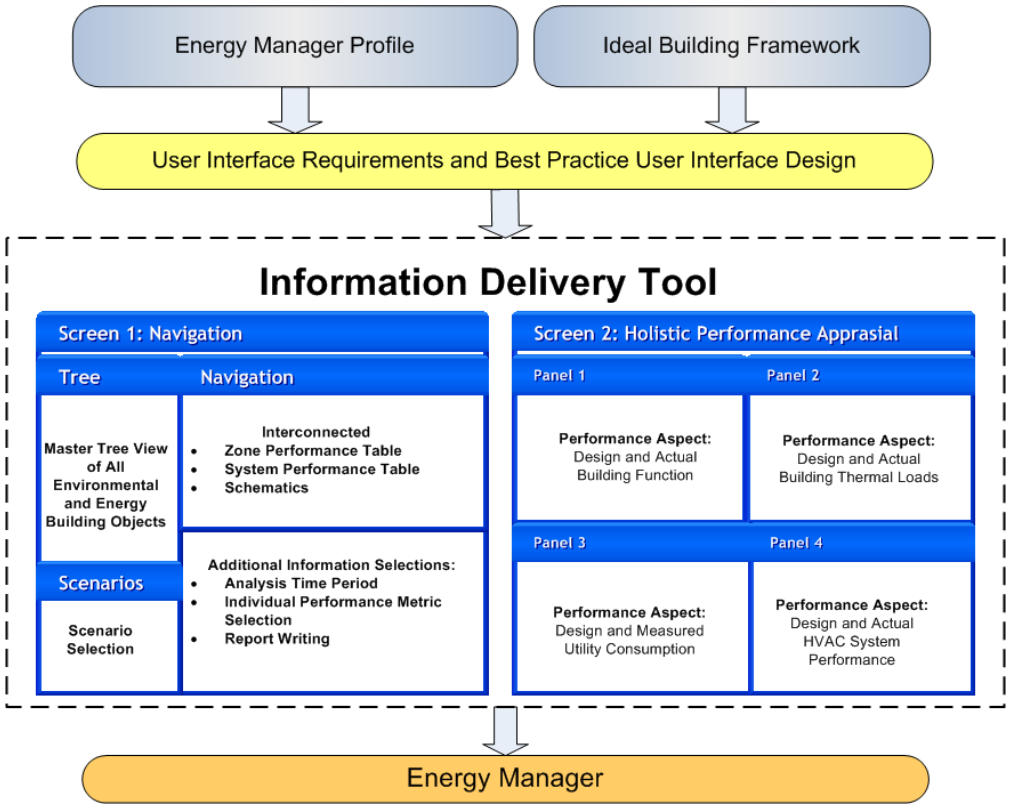


Figure 7.1: *Considerations for an Information Delivery Tool.*



The requirements outlined above contribute to the design of the Information Delivery Tool and in turn contribute to optimum building performance. It is essential that the requirements fit in with the relevant concepts outlined in this thesis (Figure 7.1). It can be clearly seen that tool development is dependant on the abilities of the end user as defined in Chapter 2 and the Ideal Building Framework representation of Scenario Models as defined in Chapters 3 and 4.

The specifications for screen layout incorporate the principles of best practice user interface design (Section H.2), the semantics of user interface specification (Section H.3) and an analysis of current interface technology alternatives (Section H.4). Only necessary functionality is to be included in order for minimal user selections.

It is imperative that an Information Deliver tool is defined using a standardised formal approach. The GUI recommendations are detailed in Appendix H. The specifications are for tool design but do not include implementation[1]. The design of screen layout focused on the full information requirements of the Energy Manager as defined in Chapters 2-6. For this reason a desktop interface was chosen as the ideal layout option. Further research could be conducted on selected subsets of this information set that could be accurately conveyed through portable hand held devices and mobile computing equipment.

7.2.1 Screen Layout

The chosen design is a two screen interface customised specifically for the established profile of Energy Managers that facilitates both navigation and visualisation of performance data. The generic specifications for each screen are illustrated in Figure 7.2. 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. Two screens were chosen to avoid information overload (Section H.2), excessive information retention and so that the navigation screen always acts as a reference when performance data are viewed.

[1]The development of class diagrams leading to a working prototype should be the topic of additional research

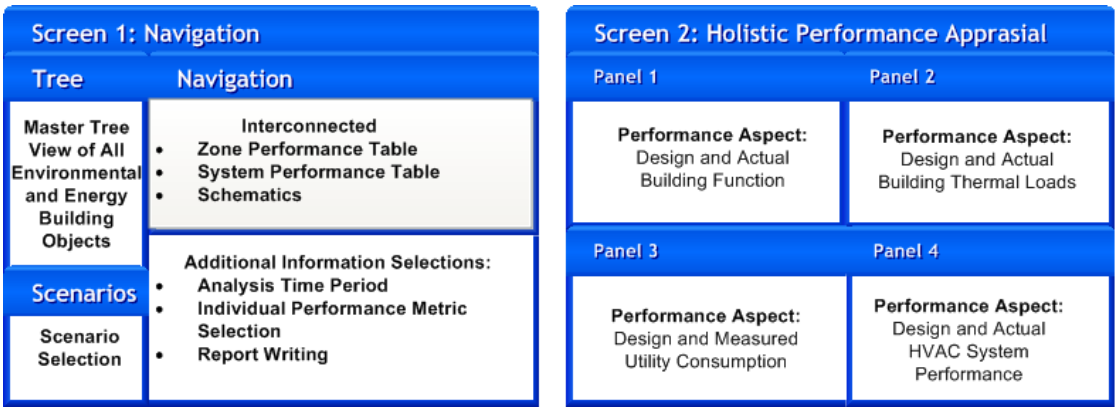


Figure 7.2: *Specification of Screen Layout for an Information Delivery Tool. Physical Screen 1 enables Navigation of Building Performance Objects and Physical Screen 2 enables Holistic Building Performance Evaluation.*

'Screen 1' is specified in accordance with the proposed use of an Information Delivery Tool (Figure 7.3). Requirements specification for 'Screen 1' (Figure 7.2) include panels to display navigation information to assist building performance as defined in Section H.3. These are:

1. Master Navigation Tree of Building Objects (Screen 1: left side, top panel);
2. Scenario Selection (Screen 1: left side, bottom panel);
3. Zone Performance Table defined in Section 7.3 (Screen 1: right side, top panel);
4. System Performance Table defined in Section 7.3 (Screen 1: right side, top panel);
5. Additional Information and Report Writing (Screen 1: right side, bottom panel).

The specifications for the right lower panel include the display of performance objectives and metrics for selected individual performance objects and a tab for report writing. Unambiguous layout coupled with on screen instructions enables intuitive use of the interface and minimise users memory load (Section H.2).

It is proposed that legislative requirements will be implemented as Performance Objectives and Metrics and will in turn be evaluated for individual Building Objects (O'Donnell et al. 2005). For example "Reduce *Building* Energy Consumption



by 3%" would be the appropriate Performance Objective applied to the Building Performace Object. The Screen 2 panel layout is identical to the Scenario Layout introduced in Section 3.5 and is composed of the following Performance Aspects:

- Design and Actual *Building Function* (Panel 1);
- Design and Actual Building *Thermal Loads* (Panel 2);
- Design and Actual *Energy Consumption* including Utility pricing and tariffs (Panel 3);
- Design and Measured *System Performance* (Panel 4).

The 'Screen 2' layout reflects holistic performance categorisation (Figure 7.2). The objective is to support multiple views of performance through effective scenario display on a single screen. Energy Managers have the ability to select or deselect relevant metrics in each of the four window panes. The navigation screen has undergone detailed specification but the performance screen must also be outlined.

7.3 Specification of Interface Navigation and Use

Projected software usage scenarios assist specification of the Information Delivery Tool. The intended sequence of actions as depicted in Figure 7.3 was chosen to reflect the principles of Ideal Building operation and these are:

- Screen 1: Choose the Building;
- Screen 1: Choose the Model View and resolution (Chapter 6);
- Screen 1: Choose the analysis time period. Common analysis is performed based on an annual, monthly or weekly basis (Chapter 2);
- Screen 1: Choose the inefficient Building Object from the Zone Performance Table (Perspective A), System Performance Table (Perspective B) or the Master Tree (Perspective C). Time constraints identified in the Energy Management role dictate that the inefficiencies must be automatically highlighted (Chapter 2);

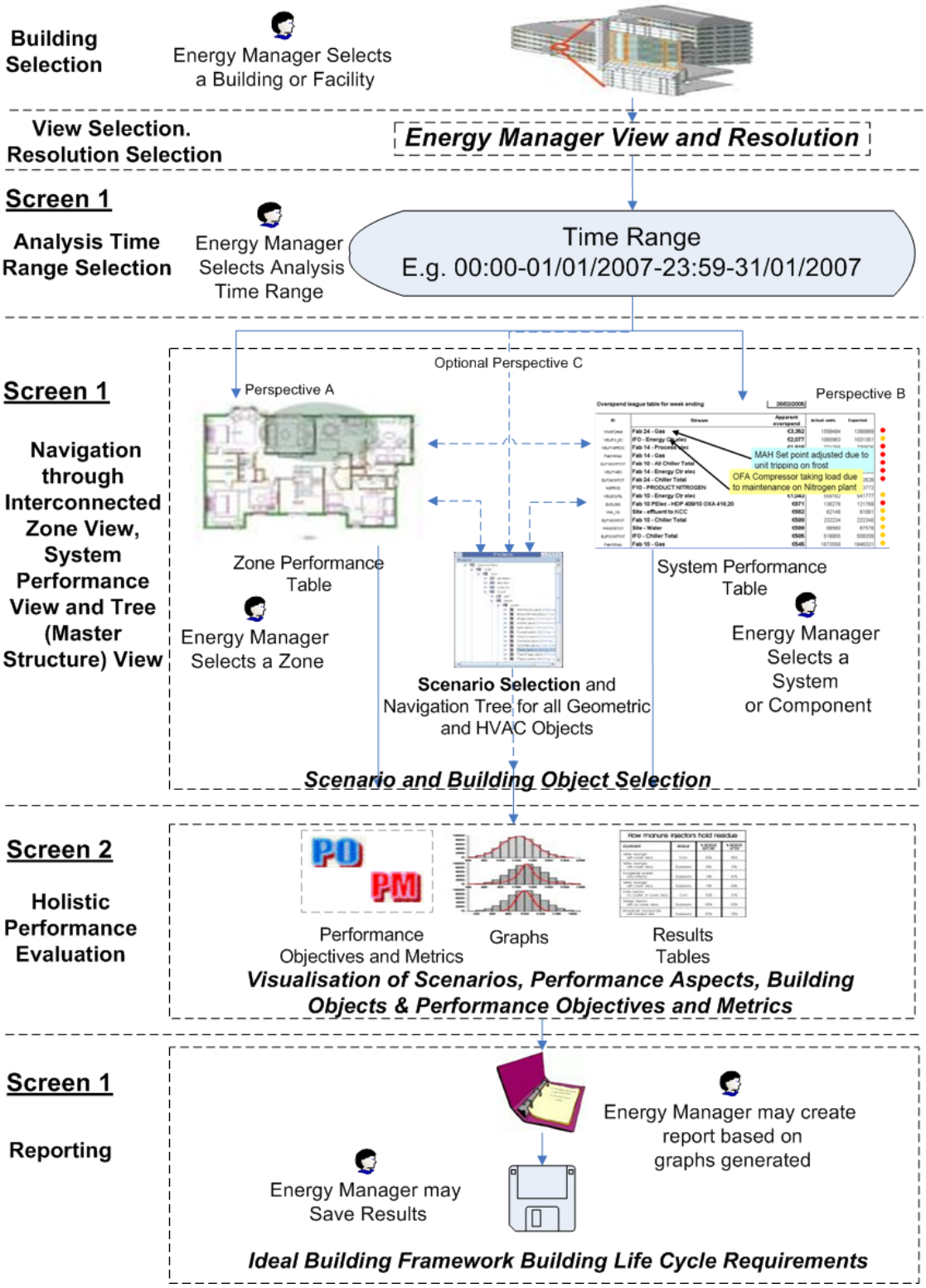


Figure 7.3: *Proposed Logical Sequence for Navigating the Information Delivery Tool*



- Screen 2: Perform holistic environmental and energy performance analysis using building specific Scenarios, Performance Aspects, Building Objects and standardised Performance Objectives and Metrics (Chapters 3 and 5);
- Screen 2: Generate a report and save for future reference. This functionality supports and continues the life cycle approach to holistic building management defined in Section 1.5.

Each section is specified in detail and an example walk through is offered. This example is based on Scenario 1 of Section 3.5. The example illustrates how the end user or Energy Manager would interact with the interface. To recap the following are the key pieces of information for Scenario 1:

- The Trigger event is a change in zone temperature setpoint from 21^o to 19^o;
- The important Building Objects are Zone, Cooling Coil, Chiller, Energy Use Category Cooling and Electricity Use.

The user selections for each stage in the process are highlighted in red for each example interface.

7.3.1 Screen 1 Navigation

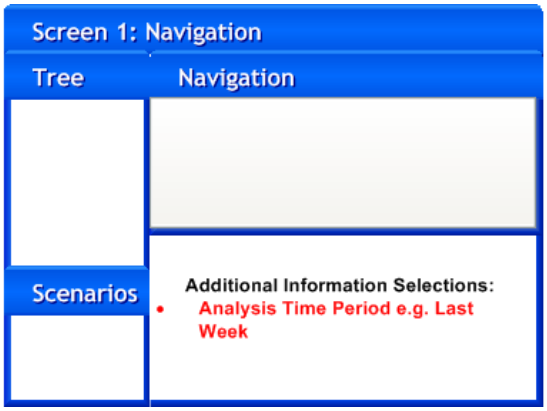


Figure 7.4: *Interface Example Step 1: Select Time*

The Energy Manager *selects the building, the Energy Manager View and analysis time period.* For example today or July 1 to July 31 of this year. The default view is real-time. An example of the interface used for time selection is depicted

in Figure 7.4.Based on the building and time period selections the Energy Manger is presented with three different performance views from which a specific aspect of performance is selected. For example select Virtual/UCC/Lee Road/ERI/Roof/ / /AHU 1 /Fan 1/ which is named in accordance with the specifications in Section 5.3.

The center (navigation) portion of Figure 7.3 depicts three *views* of building performance. Perspectives A and B are the *Zone Performance Table* and the *System Performance Table*. These *techniques* are specified to guide the Energy Manager toward improper indoor environmental conditions and inefficient system operation respectively, thereby removing the time overhead associated with traditional building performance analysis as described in Chapter 2. Table 7.1 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. Zone names are listed in accordance with the systematically structured format specified in Section 5.3 but are simplified in Table 7.1. The indicator type is predefined for each metric and is an average over the time period or percent of time it lies outside a certain tolerance range. The Actual, Ideal and Error columns use the benchmarking *technique* to quantify the variation between ideal and measured performance.

Table 7.1: *Specification for Zone Performance Table*

Zone Performance for DD/MM/YYYY HH:MM to DD/MM/YYYY HH:MM					
Building Object: Zone	**Performance Metric**	**Indicator %**	**Actual (Unit)**	**Ideal (Unit)**	**Error (Unit)**
Hall	Zone Temp	14	24	21	3
Office	Zone Humidity	—	50	50	0
Z3:Toilet	Zone Comfort	-30	-2	0	-2

The objective of an Information Delivery Tool is to enable optimum building performance. This goal has been decomposed for the Energy Manager through Table 7.1 and the System Performance Table (Table 7.2). Energy consumption and associated financial costs are crucial deliverables for the success of an Information Delivery Tool. The HVAC System Performance View (Table 7.2) would enable rapid investigation of inefficient systems and system components. This technique enables Energy Managers to rank offending components according to cost or energy

values. The indicator would be the percentage total difference in energy consumption or cost for the user specified time period. The Actual, Ideal and Error columns quantify the variation between expected and measured performance.

Table 7.2: *Specification for System Performance Table*

Inefficiencies for DD/MM/YYYY HH:MM to DD/MM/YYYY HH:MM					
Building Object	**Performance Metric**	**Indicator %**	**Actual (kWh)**	**Ideal (kWh)**	**Cost (€)**
Boiler	Boiler Energy	20	2400	2000	32.00
Heating Coil	Heating Coil Energy	6	85	80	00.40
Heat Pump	Heat Pump Energy	—	40	40	00.0

The specification of the Zone Performance and the System Performance Tables would enable selection of the most appropriate Performance Metrics for building operation. How performance metric selection is incorporated into tool layout and how to optimally present quantitative information for Energy Managers requires further discussion. Perspective C of Figure 7.3 is a Master Tree of all building specific Building Objects. This tree can act as a navigation tool for experienced users or as a reference point for all users. End users may also select predefined building specific scenarios or scenarios that relate to selected Building Objects. The end user interaction with the Information Delivery Tool with respect to Scenarios, Building Objects, Performance Tables and individual Performance Objective and Metric Selection is highlighted by Figure 7.5.

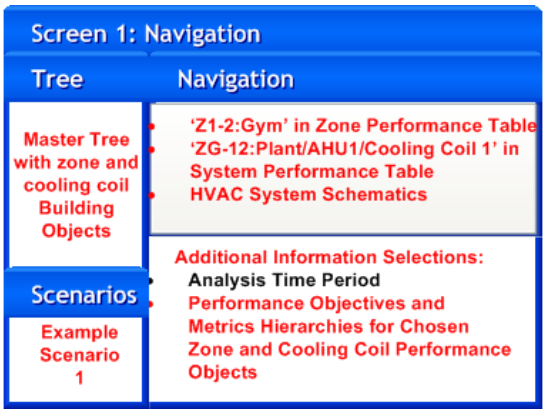


Figure 7.5: *Interface Example Step 2: Select Scenario or Building Object from Performance Tables or Master Tree. Individual Metric Selection for chosen Building Object is also available.*

Specifications for interface navigation were based on the principles of software

design outlined in Section H.2 and the navigation requirements required by Section 2.4. These combined requirements conclude that the Energy Manager must have unambiguous guidance when a selection is necessary (Section H.2). The established user profile stated a preference for diagrammatic navigation *technique* (Section 2.3.1). Where possible selections should be assisted by informative interactive schematics for the following Building Objects: Site layout, Building floor, Floor plan and HVAC Systems. These interactive schematics have clearly labelled, well defined boundaries and incorporate active links e.g. each zone should be clearly defined on a floor plan or a building on a site plan and clicking on the zone or building should activate that selection.

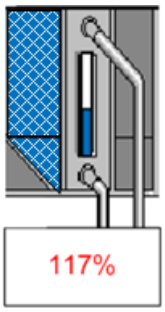


Figure 7.6: *Example of a Cooling Coil Icon Illustrating a 17% Excess when Compared with 'Ideal' Energy Consumption*

An Information Delivery Tool should focus the Energy Manager's attention on anomalies in operation. A visualisation approach should incorporate an unambiguous consistent mechanism for highlighting inefficiencies (Section H.2). Energy Managers can learn from, improve and optimise operation by analysing archived performance metrics. This benchmarking technique incorporates comparing actual or measured performance with *ideal* or benchmarked performance (Chapter 5). The example illustrated by Figure 7.6 illustrates how actual energy consumption relates to benchmarked (ideal/simulated) energy consumption for a cooling coil. These percentage readings are displayed on all Building 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 (Sections H.2 & A.3). An Information Delivery Tool offers Energy 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 Energy Manager towards the Building Objects consuming the largest unnecessary amount of energy and not just the most inefficient components. For example a 150 kW cooling coil using 110% of intended consumption (15kW) should take precedence over a 30 kW cooling coil consuming 120% of intended energy use (6kW).

The intuitive and repetitive nature of tool navigation for purposes of building performance analysis would reduce the reliance on end user memory load. The generic process outlined by Figure 7.3 would be used for all performance analysis sessions and for all appropriate buildings. 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.

Report and Save options allow the user to create an analysis archive which could be retrieved at any future point (Section 7.3.3). Again experienced users could return to a point of previous analysis without remembering all previously chosen options. The user profile highlighted that the time allocated for energy management is of paramount importance. The save and restore function would expedite analysis.

7.3.2 Specification of Performance Data Display: Screen 2

This section specifies the graphing display *techniques* that the Information Delivery Tool uses to display Performance Metrics. The primary function of information graphics is to describe the behaviour of the data, and in the case of the Information Delivery Tool, to also highlight discrepancies between benchmarked ideal performance and measured actual performance. This is appropriately emphasised by Tukey (1977):

> "*There cannot be too much emphasis on our need to see behaviour . . . . . Graphs force us to note the unexpected; nothing could be more important*"
>
> *(Tukey 1977)*

Presentation of holistic building performance data is critical for a clear understanding of operation. Prazeres & Clarke (2003) state *"To be understood, graphics*

must first be accurately perceived". Data must be presented clearly and unambiguously leaving no doubt in the user's mind as was previously profiled in Section 2.2. The integrity of the data must be maintained and, contrary to standard industry practice, the augmentation of 2-D data with 3-D effects is not recommended[2] (Tufte 2001). General specifications for graphs that depict building performance include (Tufte 2001):

- Grey grid;
- Active grid lines;
- Range frame (frame that begins and ends at the minimum and maximum values respectively);
- Graphs must be at the correct magnitude;
- Eliminate Lie Factor (a value to describe the relation between the size of effect shown in a graphic and the size of effect shown in the data);
- Option to turn grid on and off;
- Golden rectangle (ratio of length to height of approximately 1.6:1);
- Labelling should be clear and helpful and not of vertical orientation;
- Maximum number of data streams is six;
- Font should be SansSerif.

Three dimensional graphs incorporating a third axis offer potential for advanced data display. In certain circumstances these complex graphs are difficult to comprehend. Considering the established user profile three dimensional features should not be included in the specification for an interface delivery tool. In its stead the ability to include additional variables on a second Y axis would expedite analysis. The interface specifications require a 'tool tip' or feedback feature from the principles of user interface design. For example, move the mouse over a point on a graph and the summary of information for that point is displayed in text format back to the user.

[2]A comprehensive list of graphing techniques and features are available from Prazeres & Clarke (2003), Tufte (2001, 1990), Tullis (1988).

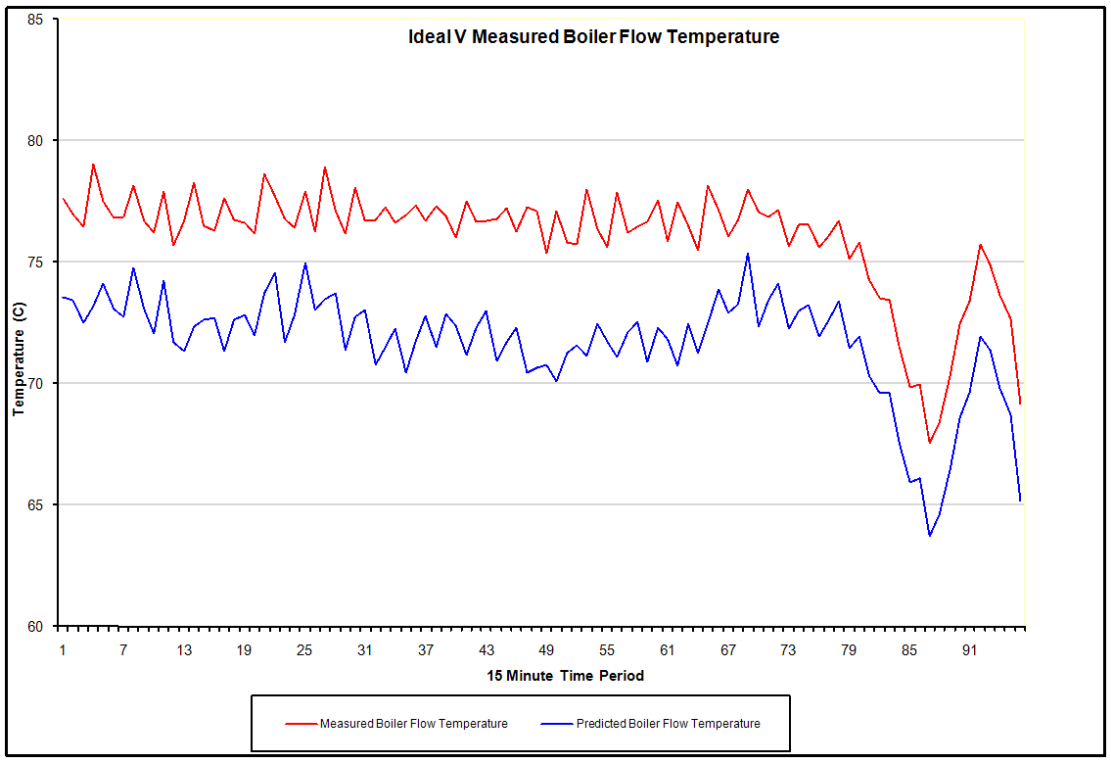


Figure 7.7: *Example Plot of a Boiler Flow Temperature Performance Metric for the Profiled Energy Manager*

Graphs must reflect the *frequency* and *resolution* of changes to building operation and relay this information to an Energy Manager. A large hall, as an example, will have a significant time delay before a change in supply temperature will be reflected in zone temperature. However an increase in fan speed would have an instantaneous effect on volumetric flow rate.

Gillespie et al. (2006) recommends time series graphs (segmented curves) and XY-plots for the display of building performance related information. The interface specifications also include automatic selection of chart type based on Performance Metric and Time Period of analysis, Figures 7.7 & 7.8 illustrate two distinct Performance Metrics. The former highlights an example of benchmarked ideal performance and measured actual performance for 'Boiler' Building Object, 'water flow rate' Performance Metric. The later illustrates an example of ideal and actual performance for gas consumption over a 12 month period. Specifications account for the fact that these graph types are ideally accompanied by a a short summary of results which include:

- Maximum or peak value;
- Minimum value;
- Cumulative total for the time period in question.

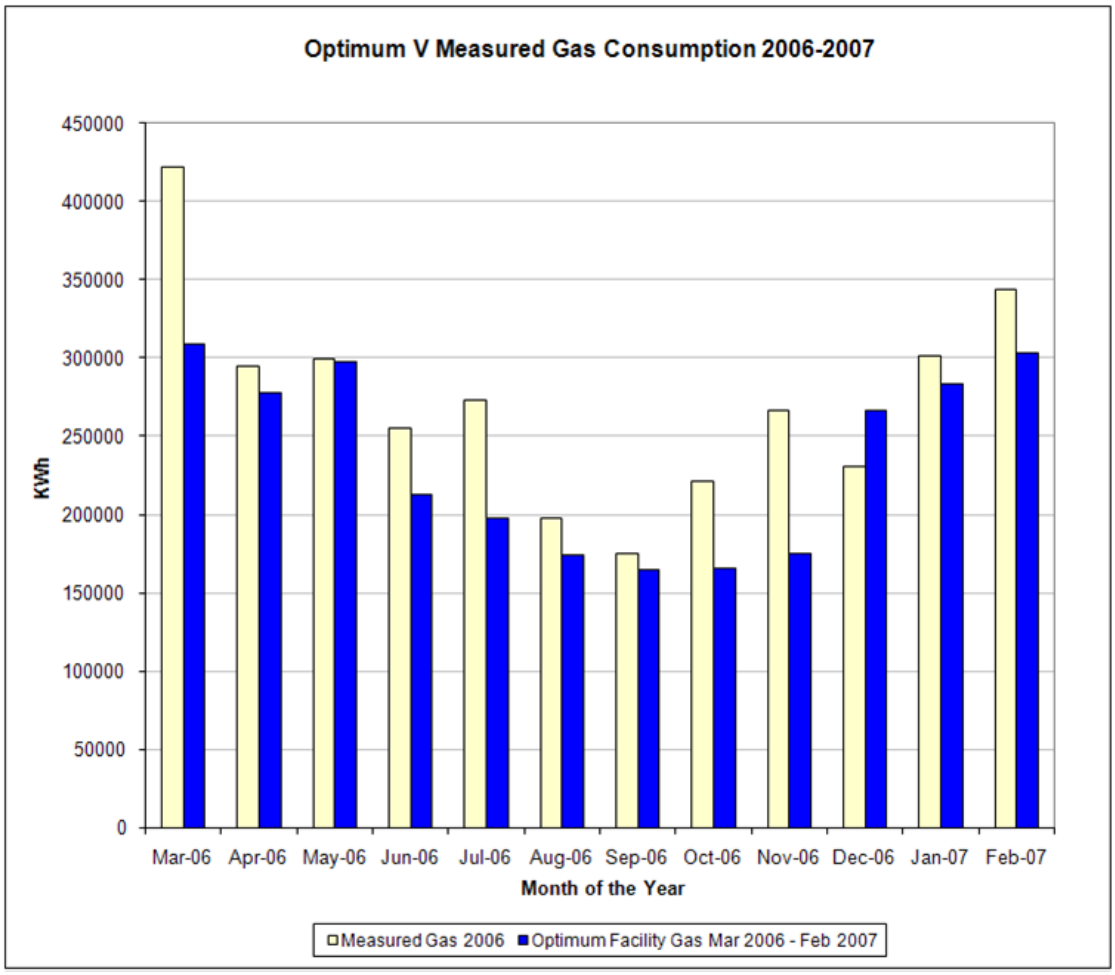


Figure 7.8: *Example of Building Gas Consumption for the Profiled Energy Manager*

Isakson & Eriksson (2004) use carpet plots (Figure 7.9) and scatter plot matrices accompanied by histograms to communicate operational information. Understanding scatter plot matrices can prove to be problematic with Energy Managers and so have been omitted from the Information Delivery Tool specifications. However carpet plots display patterns in large volumes of data and also large time periods of data e.g. hourly temperature readings over a 12 month period. Histograms are not recommended for large data sets (Tufte 2001) and are only included in the

graphing specifications for a time resolution of less than one month and are more suitable for graphing monthly values over a 12 month period.

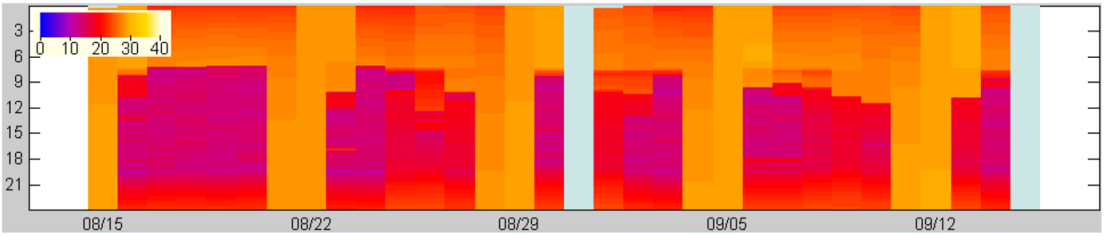


Figure 7.9: *Sample Carpet Plot that is to display Performance Metrics for the Profiled Energy Manager(Courtesy of Isakson 2004)*

Specifications also include the ability to view interrelationships between variables over a set time period. For example, select one or a number of data points on 'Graph A' and the same values are automatically highlighted on all other relevant graphs. This *technique* is extremely useful when analysing predefined metric combinations. The ability to add a linear fit to the data on scatter plots is a powerful energy management tool (SEI 2006*b*). Important trends and patterns that would otherwise go unnoticed are available to the Energy Manager. Specifications for linear regression algorithms are as depicted in Devore (1995). All Performance Metrics, highlighted by bullets, will be presented to the end user under the Performance Aspect headings (Figure 7.10).

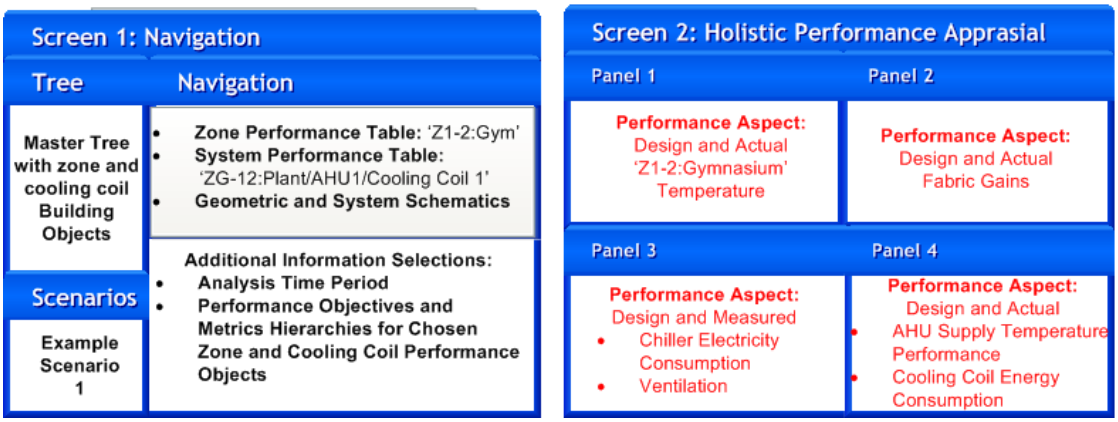


Figure 7.10: *Interface Example Step 3: Performance Metric Display using the Specified Graphing Techniques for Scenario 1 Information (Section 3.5).*

This subsection has specified the requirements for display of building performance data in the form of standardised Performance Metrics. However a mechanism for saving analysis projects and recording observations is also necessary.

7.3.3 Specification of Save & Report Options

Functionality that allows analysis to be saved as a project and returned to at a later time would expedite analysis and increase efficiency of the Energy Manager. A report feature that is quickly accessible at any point when the program is open would offer the Energy Manager the ability to record his findings in real time. The facility to store snapshots of graphs generated would form the basis of such a report. In essence the report would be a text window with additional functionality that allows graphs generated to be stored. The format of such reports would be standardised to include the following headings:

- Date;
- Person;
- Project;
- Summary of overall analysis;
- Commentary on analysis in text format and where required include snapshots.

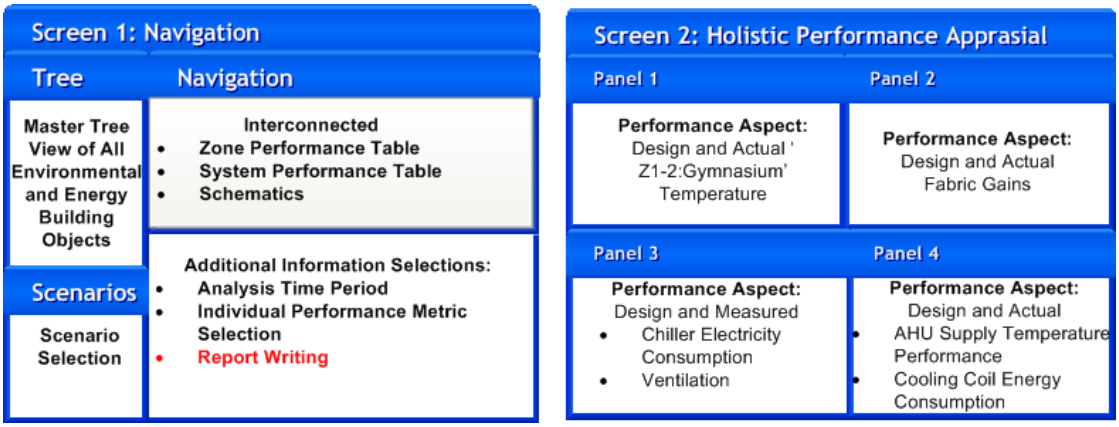


Figure 7.11: *Interface Example Step 4: Report Writing Based on Observed Performance.*

A quick export function would allow the user to email the contents of the report with graphs in-line. The end user would write up a report in the highlighted section of Screen 1 based on a performance analysis session, the location is highlighted in Figure 7.11.



7.4 Chapter Conclusion

This chapter described the specification of a context sensitive Information Delivery Tool for the explicit purpose of holistic Environmental and Energy Management in buildings. The development considerations include the Scenario Modelling and Benchmarking techniques, the Ideal Building Framework, the established profile of the Energy Manager and the principles of software design. The customised dual screen user interface is shown to adhere to best practice user interface design.

The Information Delivery Tool, encapsulates the Ideal Building Framework and could create new decision making capabilities for the profiled end user. It is the authors opinion that a non-prescriptive process for decision making is supported for a number of stakeholders involved in building performance evaluation. Chapter 8 specifies a decision assistance framework.

Chapter 8

Assisting Decision Making

> "*A decision is the action an executive must take when he has information so incomplete that the answer does not suggest itself*"

(Arthur William Radford 1958)

8.1 Chapter Introduction

First cut at what needs to be supported. Preliminary simplified to approach to decision support to demonstrate the feasibility of the overall concept. The thesis recognises that substantial research in the fields of AI and decision support should be brought to bear to formalising and underpinning the decision support elements of the proposed hypothesis.

This Chapter describes:

- The decision making environment in which an Energy Manager typically operates and defines the boundaries of this research thesis, i.e. clarifying decision support as opposed to automated decision making;
- A proposed process that includes the Scenario Modelling and Benchmarking techniques to underpin holistic environmental and energy management to assist decision making;
- An example of how the decision assistance process could operate.

8.2 Scope for Decision Assistance

Conventional building management as described in Chapter 2 is in essence a *problem solving* process. The knowledge and experience of Energy Managers can vary dramatically. This variation is coupled with traditionally fragmented data and information from Building Management (BMS) and Energy Management (EMS) Systems. Many problems will continue indefinitely if maintenance is based only on occupant complaints and system alarms. An end of the month retrospective analysis may uncover problematic areas while others remain undiscovered. Chapter 3 specified performance benchmarking through Scenario Modelling as the most appropriate technique for Energy Managers. The Information Delivery Tool, underpinned by the formally transformed data from the Ideal Building Framework, detailed the most appropriate context sensitive presentation techniques for communication of scenario modelling information (Chapter 7). Throughout operation and across the entire Building Life Cycle (BLC), the ideal energy consumption as determined by up-to-date calibrated simulation model output, reflects changes to the building or building use thus enabling a meaningful comparison with actual measured data (Chapter 5). Guesswork on the Energy Manager's behalf is eliminated entirely and replaced by a formal decision assistance process. The differences between traditional decision assistance and proposed structured decision assistance with respect to environmental and energy management in buildings is outlined in Figure 8.1.

Data provided by traditional BMS or the Ideal Building Framework requires human or expert-based analysis for intelligent judgements (So et al. 2005). Any issue such as an occupant complaint requires *information, knowledge and time* in order to be solved effectively. Energy Managers can either accept the provided information blindly or they can interpret it. However in interpreting the information the Energy Manager may often question or transform the information and base decisions on individual judgement and experience. This process of unconstrained data manipulation may transform the information presented to give it a different meaning. Decision making is potential flawed in the absence of formally transformed data as provided by the Ideal Building Framework (Chapter 4). The requirements to support effective informed decision making must be investigated[1].

[1]The attitude of the Energy Manager can have a substantially affect productivity (Ram & Jung 1991) but accounting for attitude in energy management is beyond the scope of this thesis.

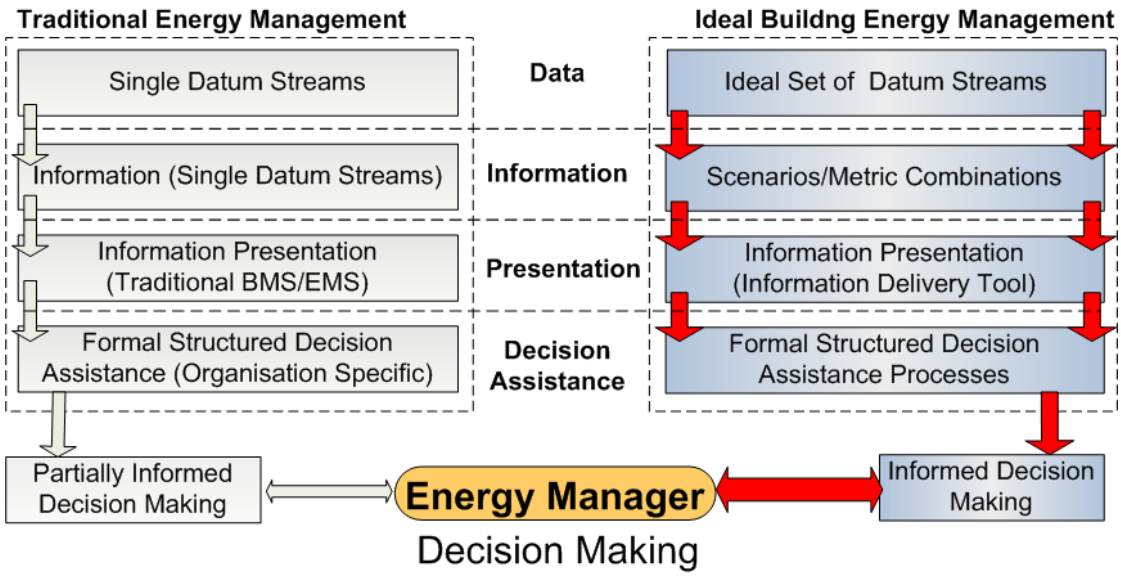


Figure 8.1: *Comparison of Decision Making Environment for Traditional and Ideal Building Energy Management*

This work is limited in scope as it relies on the Energy Manager to make effective decisions based on the information at hand. This thesis does not propose to provide an alternative to fault detection and diagnosis within buildings such as described by Katipamula & Brambley (2005) or Salsbury & Diamond (2001). Instead it is a preliminary simplified approach of decision support to demonstrate the feasibility of the overall concept.

An Energy Manager needs to be aware immediately of the existence of a problem and the nature of this problem. RPS (2007) stressed the limited time that could be allocated to solving any particular problem on the basis of cost benefit. The Energy Management role is not typically an organisational priority (Chapter 2) and as a result the scope for problem investigation is consequently reduced. Energy Managers therefore require an automated process for retrieving and presenting context sensitive data as specified in Chapters 4 and 7. Structured but non-restrictive analysis processes will also expedite building performance appraisal.

8.3 Proposed Decision Assistance

The Information Delivery Tool presents the Energy Manager with Scenario information in the form of Performance Metrics, which can in turn indicate that

a problem exists in relation to a particular Building Object. It will not detect the problem or diagnose the nature of the problem and it will not offer possible solutions. The hypotheses presented in Chapter 2 are dependant on the logical reaction of an Energy Manager to a problem once it has been identified through Scenario Modelling and Performance Metric Benchmarking information. A prescribed approach to solving categories of problems is not consistent with design philosophy or to the usage environment of the Ideal Building Framework and an Information Delivery Tool.

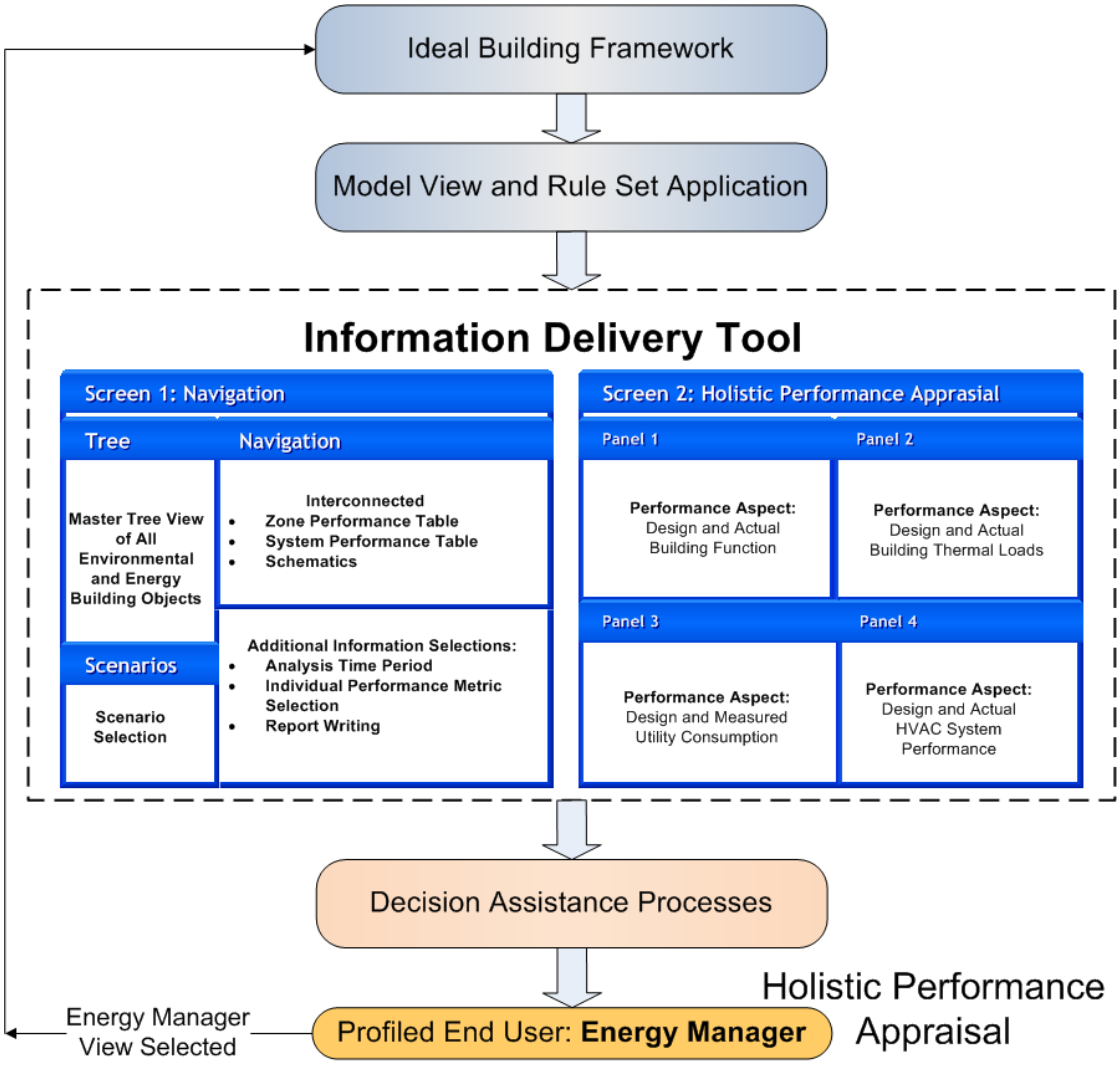


Figure 8.2: *Effective Decision Making is Dependant on Ideal Building Framework Information Presented by the Information Delivery Tool*

The Ideal Building Framework coupled with the Information Delivery Tool, as described in Chapter 7, creates an opportunity for informed decision making. Tra-

ditionally energy management is an energy reduction process (Ahern 2006, RPS 2007). In industrial cases where energy management is a well resourced activity, the emphasis is on production as the manufactured product is of significant monetary value (Geoghegan & Fenner 2007, O'Connor 2007). Therefore industrial energy management can also be described as an energy reduction process. Energy Managers typically utilise Energy Use Intensities (EUI) as a building performance indicator and for further investigation decompose energy use into its constituent categories. This *top down* approach or the alternative *bottom up* approach are explained in IEA (1996). The Ideal Building Framework, through presentation of predefined Scenarios in the Information Delivery Tool for a profiled end user, has created an environment capable of supporting holistic building performance appraisal (Figure 8.2).

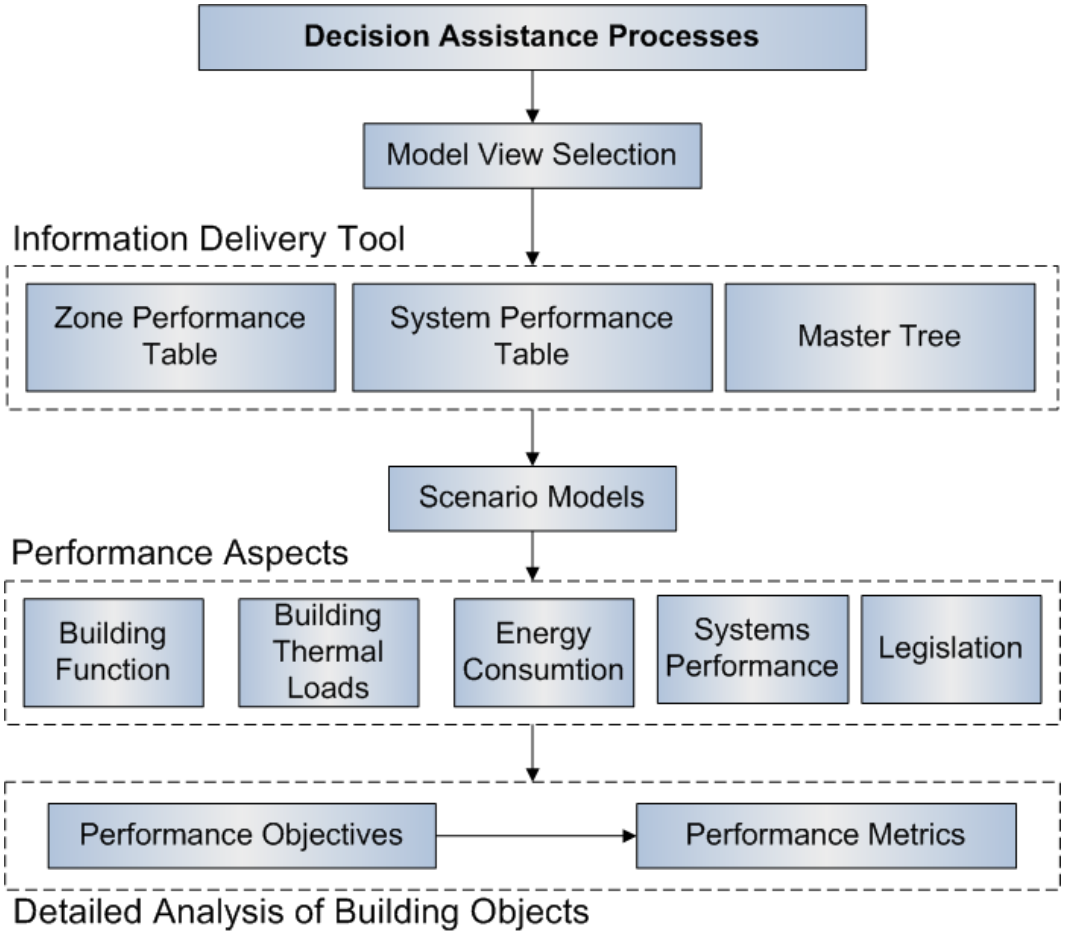


Figure 8.3: *General Decision Assistance Process which Complements the View Methodology and Ideal Building Framework*

The Proposed Logical Sequence for Navigating the Information Delivery Tool (Section 7.3) is a generic tool navigation process. It stands to reason that a generic decision assistance process (Figure 8.3) would complement the generic tool navigation process and utilise the components of the Ideal Building Framework, View methodology and Information Delivery Tool. Logically the generic decision assistance process is underpinned by the formally transformed data available which is dependant on the end user Model View (Chapter 6). Therefore the end user or Energy Manager will only have access to the relevant information through the Information Delivery Tool. The Zone and System Performance Tables guide the Energy Manager to inefficiently operating Building Objects. It is proposed that through the decision assistance process illustrated in Figure 8.3 that the Energy Manger would analyse the inefficient Building Object independently and also as part of the relevant Scenarios. Standardised Performance Objectives and Metrics would be used to qualify and quantify all aspects of performance.

8.3.1 Decision Assistance Example

An example of how the generic decision assistance process would work is illustrated in Figure 8.4 and utilises Scenario 1 (Section 3.5.1) to demonstrate the concepts proposed in Section 8.3.

The supported View is that of the Energy Manager who is presented with the Zone and System Performance Tables based on the selected analysis time period (Section 7.3). The Systems Performance Table (Section 7.3) assists decision making through identification, ranking and presentation of inefficient Building Objects. The Energy Manager can select the inefficient Zone Building Object or the System or component Building Object from these tables. An independent analysis of the Building Object is now possible but the thesis philosophy is to examine Building Object performance in the context of a Scenario. The holistic interconnected approach empowers the Energy Manager with the *information* required for optimal operation thus enabling better performance related decisions. Therefore the Energy Manager should select Scenario 1 to enable holistic environmental and energy analysis. The Energy Manager is presented with qualitative and quantitative Performance Objectives and Metrics information for the established Performance Aspects (Chapter 3).

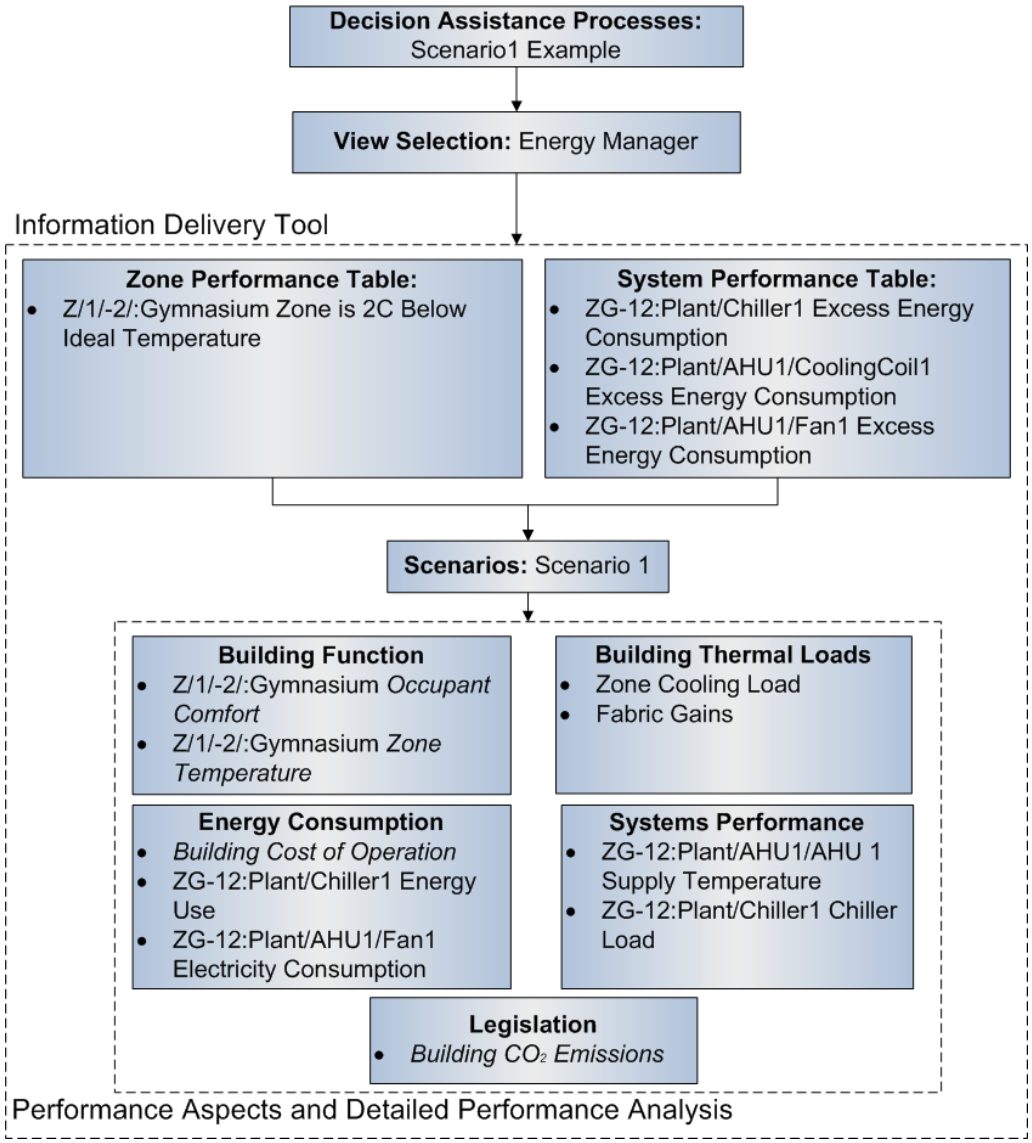


Figure 8.4: *Decision Assistance for a Scenario Illustration Depicting the Effects of a Manual Change in Zone Temperature Setpoint.*

8.4 Chapter Conclusion

This chapter described the significance of holistic informed decision making environment for Energy Managers. The volumes of formally structured data generated by the Ideal Building Framework and presented by the Information Delivery Tool require a structure through which an Energy Manager can make informed decisions. This is a preliminary simplified approach for decision support that demonstrates the feasibility of the overall concept. The decision assistance pro-

cess diagram illustrates a defined procedure for analysing building operation and is supported by: Stakeholder Specific Model View definitions, The Ideal Building Framework, Performance Aspects, Building Objects, Building Object Hierarchy, Ideal Set of Performance Objectives and Metrics, Ideal Measurement Set, Model View Methodology and the Information Delivery Tool.

This chapter demonstrates that a decision support process may be coupled with the intended use of the Information Delivery Tool to provide informed decision assistance for profiled Energy Managers, ultimately resulting in buildings that perform optimally. The environment that provided information for the Information Delivery Tool and the decision assistance process outlined in this chapter require evaluation on an existing building. Chapter 9 describes a demonstration of the overall philosophy using the ERI at University College Cork, Ireland as the demonstrating building.

Chapter 9

Demonstration of Philosophy

> "*In any moment of decision, the best thing you can do is the right thing, the next best thing is the wrong thing, and the worst thing you can do is nothing*"

(Theodore Roosevelt)

9.1 Chapter Introduction

This chapter illustrates a sample demonstration of the Ideal Building Framework (Chapter 4) as applied to the Environmental Research Institute (ERI) at University College Cork, Ireland. The demonstration applies the *Model View and Rule Set Methodology* for the chosen building and it's state of the art Building Management System. The demonstration describes:

- The Environmental Research Institute at University College Cork;
- Application of the Model View and Rule Set Methodology using the demonstration building. The selected Model Views are:
  - ERI Building: Energy Manager Model View and Rule Set which outputs an Ideal Building measurement set representation of the ERI;
  - ERI Building: LEED Accreditor Model View and Rule Set which outputs the required measurements with regard pertinent LEED credits.
- The Scenario Modelling and Benchmark techniques used to assist Informed Decision Making as presented by the Information Delivery Tool.

9.2 ERI Description

The Environmental Research Institute (ERI) building, located at University College Cork (UCC), Ireland was designed as a green flagship building and a low energy research facility (Kennett 2005). The Performance Aspects associated with the ERI are emphasised in Italics for the section. It's *Building Function* includes a combination of both laboratory and office spaces requirements. Such facilities are often dismissed as too complex and specialised for employing a sustainable design approach. Operation of these facilities while managing low levels of *Energy Consumption* is notoriously difficult to achieve (Federspiel et al. 2002). High levels of *Energy Consumption* are magnified during the operational phase of the Building Life Cycle as it is extremely difficult to qualify the effectiveness of energy use in buildings with disparate functions such as office space, laboratories, cold temp rooms, toilets and conference rooms.



Figure 9.1: *South Faade of the ERI Building at University College Cork, Ireland*

The ERI building was designed as an ongoing experiment in green building design and operation with a particular emphasis on an increased knowledge of downstream performance (Kennett 2005). As a result, a *state of the art BMS* was installed to facilitate monitoring of:

- The *integrated hybrid heating and cooling system* (Figure 9.1);
- Building energy use;
- Indoor environmental conditions.

The Benchmark objective for the ERI is an Energy Use Intensity (EUI) of

100 kWh/m^2/year compared to a good practice figure of 240 kWh/m^2/year. The energy efficient features as described by Kennett (2005) include:

- High thermal mass;
- North-south orientation to maximise daylighting in office spaces;
- Natural ventilation of office spaces;
- Airtightness of 5 m^3/h at 50 Pa;
- Advanced thermal bridging to minimise *Thermal Loads*;
- A hybrid integrated heating and cooling system (Figure 9.2);
- Renewable technologies include an aquifer sourced heat pump and solar thermal panels.

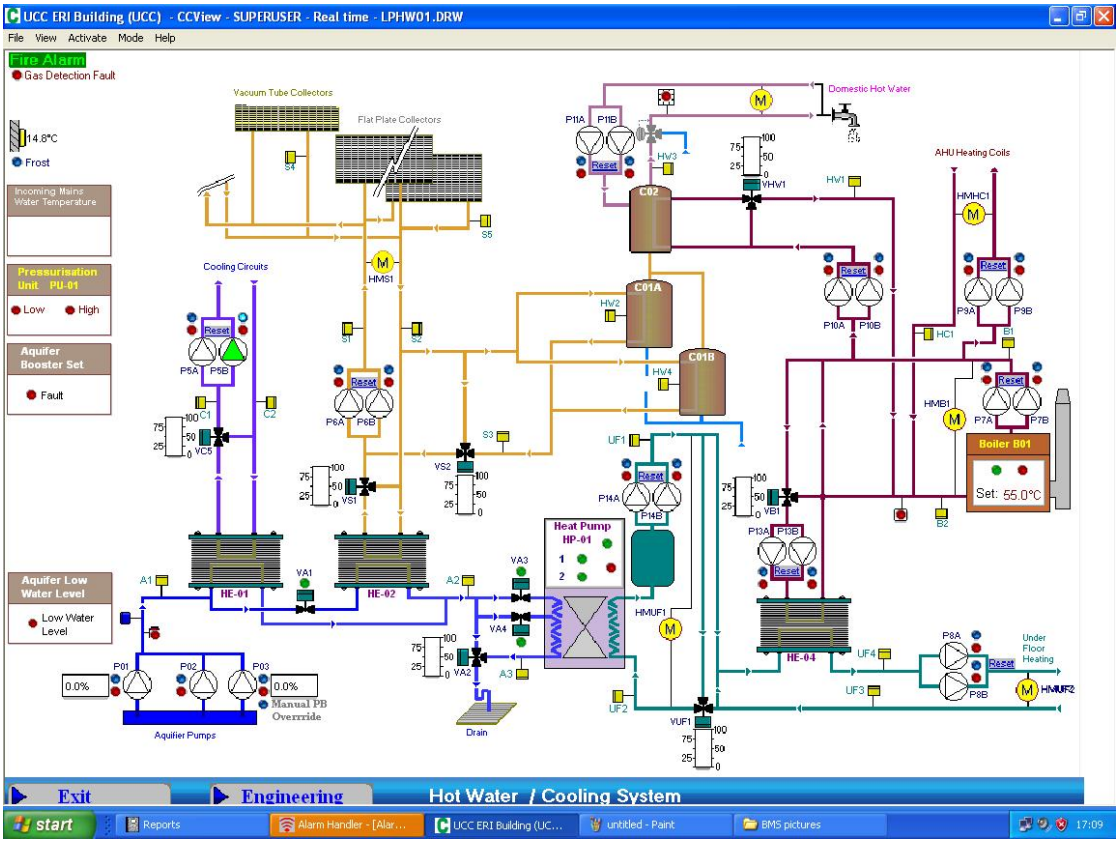


Figure 9.2: *Screen Shot Image of the ERI BMS Illustrating the Integrated Hybrid Heating and Cooling System*

The EU Energy end use and Services Directive is not implemented at the time of writing of this thesis and subsequently the building was not required to conform to any national or international *Legislation*.

Application of the *Model View and Rule Set Methodology* must now be undertaken using the ERI building (Section 9.4). Current IFC compliant software does not support a full Building Object Hierarchy of the building, particularly in relation to HVAC system components (Bazjanac & Maile 2004). The ERI Building Objects are therefore represented in a spreadsheet model contained in Appendix I. The following section describes an application of the Model View and Rule Set Methodology using the demonstration building.

9.3 ERI: Model View and Rule Set Methodology

This section describes and evaluates the implementation of the automated process using the Energy Manager Rule Sets for the ERI building. The objective of the Energy Management Model View is to specify the ideal measurement representation of the prototype building (Section 9.2) and to illustrate the scope and resolution of where the current measurement set is inadequate[1]. The consequences of missing measurements are also outlined for each level of resolution.

The Energy Manager Model View and LEED Accreditor Model View (Section 9.3.2) is discussed under the following headings:

- Application of the automated process (Figure 9.3) to a specific building using a particular rule set;
- The impact on the different data measurement streams resulting from the selection of different resolutions of data;
- Discussion of the resulting measurement sets.

The automated process is applied to the ERI building and a spreadsheet zonal representation of the building was created for the purpose of this demonstration

[1]In the context of the Ideal Measurement Set the BuildWise project has identified numerous shortcomings in terms of data acquisition, reliability of data and data archival with the installed BMS. The project will remedy current inadequacies through installation of appropriate wireless sensors (Keller et al. 2007).

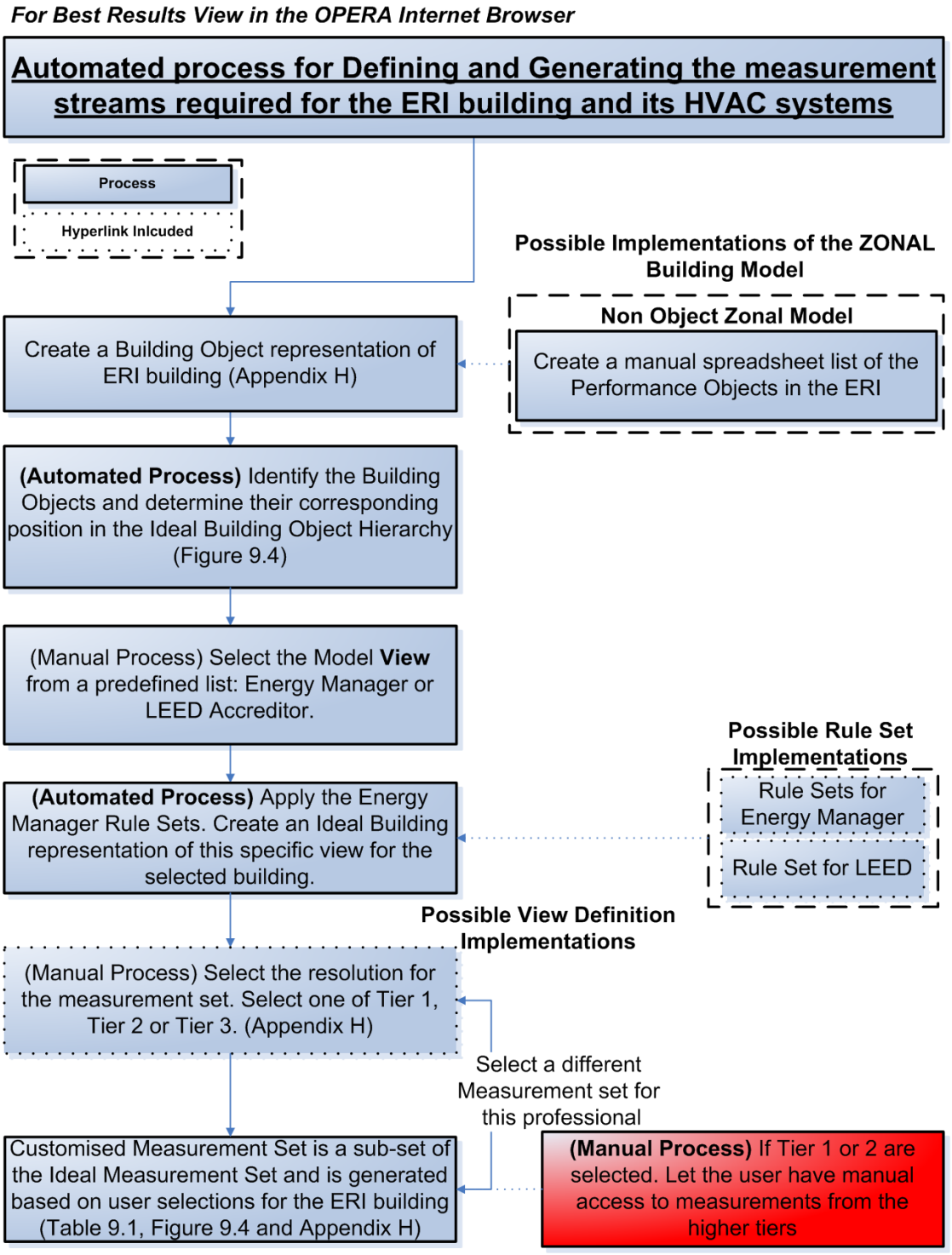


Figure 9.3: *Process for Defining an Energy Manager of LEED Accreditor Model View Specific Measurement Sets for the ERI Building (Section 6.4)*

(Appendix I). A hierarchy of possible performance objects that represent Holistic Environmental and Energy Management is illustrated in Figure 9.4. The application of an Energy Manager rule set and LEED Accreditor rule set (Section 9.3.2) are discussed individually.

9.3.1 ERI: Energy Manager Rule Set

This section demonstrates the automated process using the Energy Manager rule set. The outcome of the automated process (Figure 9.3) using the Energy Manager Rule Set is a tiered Ideal Building measurement set representation of the ERI. The Automated Process in Figure 9.3 takes the spreadsheet representation of the ERI Building Objects and creates a Building Object Hierarchy for the ERI (Figure 9.4).

The Energy Management rule sets define the 'Ideal Measurement Set' for the ERI building. However the automated process enables manual selection of measurement resolution, for example Tier 1, 2 or 3 which represent the Important, Useful and Helpful categories respectively. It is important to note that the measurements have been separated for the purposes of illustration. If Tier 2 resolution is selected by an Energy Manager Tier 1 measurements would also be included. Similarly if Tier 3 is selected this measurement set would include Tier 1 and Tier 2 measurements. A complete table that lists each unique measurement is included in Appendix I. The measurements at each resolution are presented in Table 9.1. Tier 3 Measurements are also illustrated in comparison with the existing ERI measurements in Figure 9.4. The following colour codes apply to the measurement streams associated with each Building Object:

- Existing measurements exactly matching the Model View definition measurement description: Green;
- Some existing measurements matching the Energy Manager Model View definition measurement description: Orange;
- Absence of measurements when compared with the Energy Manager Model View definition of measurements: Red;
- Duplicate object: White.

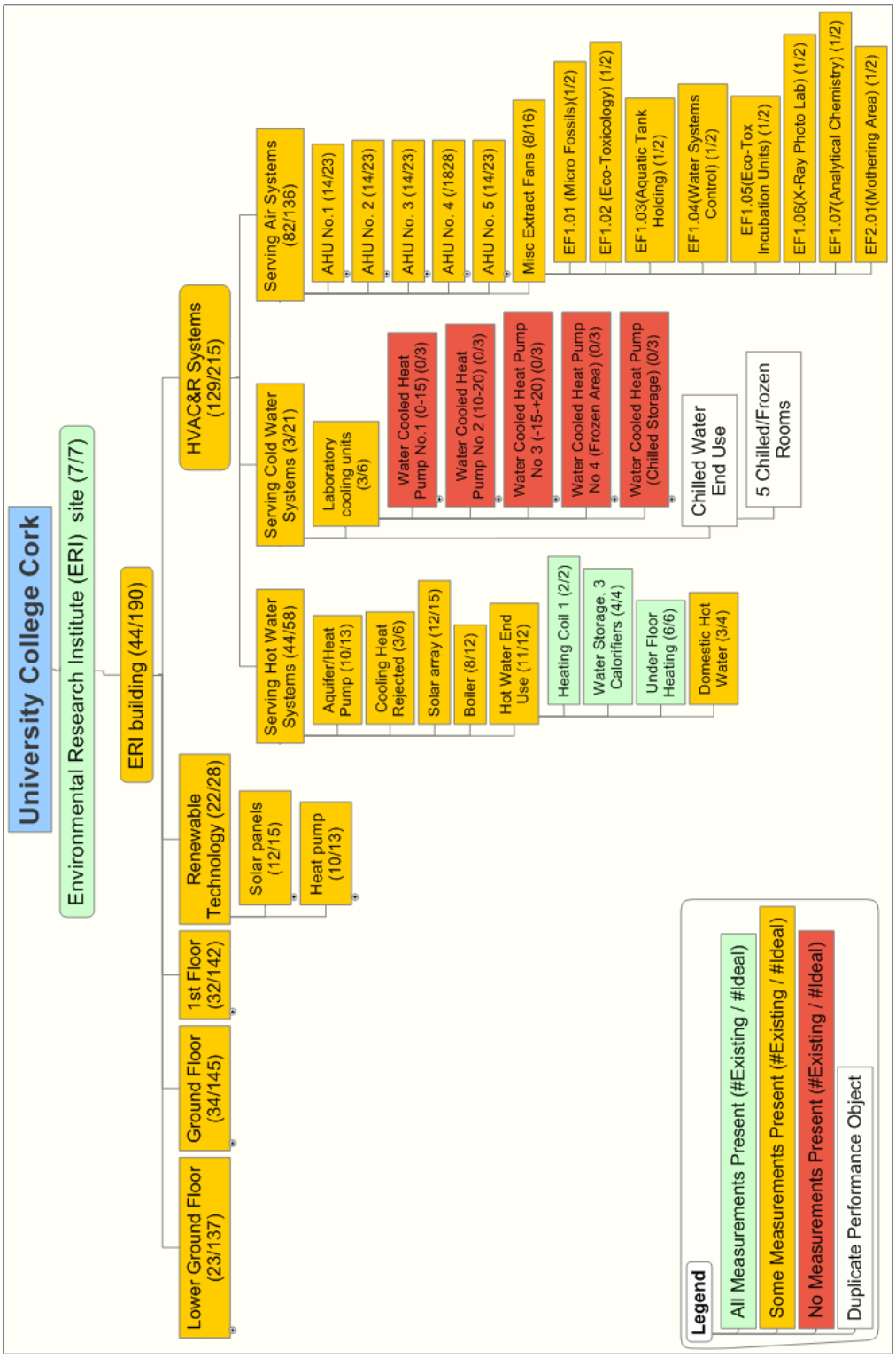


Figure 9.4: *ERI: Building Object Hierarchy illustrating the discrepancy between Ideal and installed measurements. A complete interactive ERI Building Object Hierarchy is contained in Appendix I*

Table 9.1: *Results from Application of the Automated Process using the Energy Management Rule Set*

	Required	**Existing**	**Missing**	**Existing Measurements %**
Total	861	283	578	33
Tier 1	120	106	14	88
Tier 2	346	99	247	28
Tier 3	395	78	317	20

Existing measurements account for only 283 of the required 861 measurements in the ERI building (Table 9.1). It is immediately apparent that the building only contains 33% of the required measurement streams as defined by this Energy Management Model View. Table 9.1 demonstrates that a current best practice, 'design award' winning building does not contain the measurements required for optimal operation. Further analysis requires investigation of the measurement streams at the three stated levels of resolution.

Tier 1 measurements are defined as datum streams that are essential for building operation (Chapter 6). It is observed that 106 of 120 or 88% of measurement streams are present. A fundamental understanding of builing performance, HVAC system operation, energy consumption and energy end use is not attainable without the missing 14 datum streams.

Tier 2 measurements are defined as datum streams that are necessary for normal building operation (Chapter 6). It is observed that 99 of 346 or 28% of required measurements streams are present. The absence of 72% of the necessary measurment streams prohibit an Energy Manager from fully understanding HVAC system operation and a breakdown of building energy use.

Tier 3 measurements are defined as datum streams that are helpful or useful for low level diagnostics of building performance (Chapter 6). It is observed that 78 of 395 or 20% of required measurements streams are present. The absence of 80% of the necessary measurment streams prohibits an Energy Manager from fully understanding HVAC component operation, detailed building energy use by category or end use at the zone level.

9.3.2 ERI: LEED Accreditor Rule Set

The objective of this section is to illustrate the required measurement streams for a 'LEED Credit' Model View and to identify what measurements are missing in the prototype building. This rule set would be used with the process illustrated in Figure 9.3.

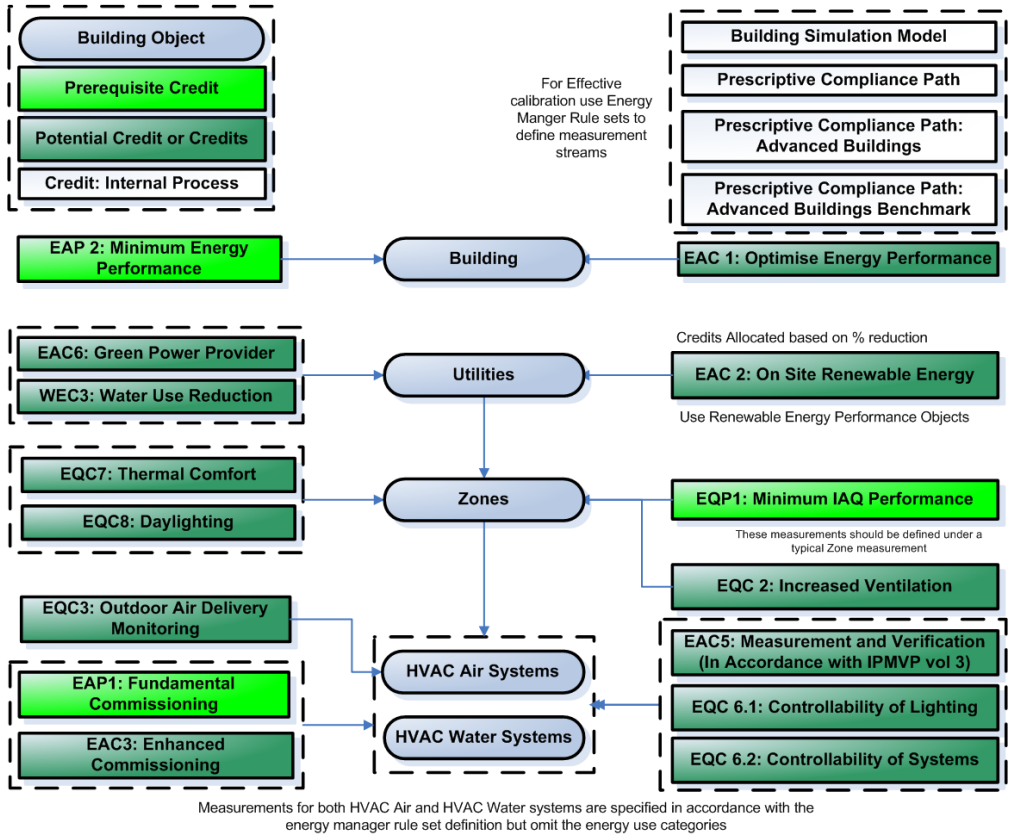


Figure 9.5: *Overview of the LEED credits and the Building Objects with which they are associated*

The scope of the LEED Model View with respect to the Ideal Measurement Set that underpins the Ideal Building Framework is illustrated by Figure 9.5. The relevant Building Objects to which the Credits are linked are listed below:

- Building;
- Utilities;
- Zones;
- HVAC Air and Water Systems.

Building

EA Prerequisite 2: Minimum Energy Performance: This Credit requires compliance with the mandatory provisions and prescriptive requirements of Standard 90.1-2004 ASHRAE/IESNA (Illuminating Engineering Society of North America). In order to evaluate minimum energy performance fossil fuel use and electricity use need to be quantified at design. Building floor area is also required. The operational equivalent of this Credit is attainable through existing measurements.

EA Credit 1: Optimise Energy Performance: The measurement streams defined by the Energy Management Rule Set are required for this Credit but the datum source must be a whole building simulation model output. The number of points allocated for this Credit (1-10 points) depends on a percentage reduction of projected energy consumption when compared with the standard prescriptive evaluation of the same building.

Table 9.2: *EA Credit 2: Relevant Measurement Streams for Renewable Energy Building Objects*

	Required	**Existing**	**Missing**	**Percentage**
Total	30	17	13	56.66
Tier 1	6	2	4	33.33
Tier 2	9	6	3	66.66
Tier 3	15	9	6	60.00

Utilities

EA Credit 2: On-Site Renewable Energy: This Credit requires measurement streams for the on-site renewable energy components. The renewable technologies in the ERI are flat solar panels, evacuated tube solar panels and an open loop water source heat pump. Table 9.2 illustrates that 56% of the measuremets required for on-site renewable energy are present.

EA Credit 6: Green Power: The utility provider data are required and present. The utility provider details, building electricity meter and tariff information are available.

WE Credit 3: Water Use Reduction: The utility provider data are required and present. The provider details, building water meter and tariff information are available.

Zones

EQ Prerequisite 1: Minimum IAQ Performance: This Credit is used at the design stage. During operation the equivalent measurement streams are the volume of fresh air and number of occupants over time. The building incorporates a swipe card entry system but occupancy is not counted. The air flow rates for the mechanical and natural ventilation systems are not measured.

EQ Credit 2: Increased Ventilation: This Credit utilises identical measurement streams as EQC1. However compliance with stricter air flow rate standards is required.

EQ Credit 7.1: Thermal Comfort: Design, EQ Credit 7.2: Thermal Comfort: Verification: This Credit requires the Energy Management Model View, Tier 3 zone measurement streams.

EQ Credit 8.1: Daylight & Model Views: Daylight 75% of Spaces, EQ Credit 8.2: Daylight & Model Views: Model Views for 90% of Spaces: This Credit requires the Energy Management Model View, Tier 3 zone measurement streams.

HVAC Air and Water Systems

EQ Credit 1: Outdoor Air Delivery Monitoring This credit requires the "*installation of permanent monitoring systems that provide feedback on ventilation system performance to ensure that ventilation systems maintain design minimum ventilation requirements. Configure all monitoring equipment to generate an alarm when the conditions vary by 10% or more from setpoint, via either a building automation system alarm to the building operator or via a visual or audible alert to the building occupants*" (USGBC 2005).

Measurements for this Credit are not present.

EA Credit 3: Enhanced Commissioning and *EA Credit 5: Measurement & Verification*: This Credit requires the Energy Management Model View, Tier 3 measurement streams.

EA Prerequisite 1: Fundamental Commissioning of the Building Energy Systems: This emphasis for this Credit is on a recorded and structured process. When applied to building systems the process requires Energy Management Tier 2 measurement streams for all HVAC systems and the zones which they service.

EQ Credit 6.1: Controllability of Systems: Lighting, EQ Credit 6.2: Controllability of Systems: Thermal Comfort: This Credit requires the Energy Management Model View, Tier 3 measurement streams at the zone level.

The Energy Manager Model View and the LEED Accreditor Model View are now specified for the building. Informed Decision Assistance requires the Scenario Modelling Technique and the The Ideal Building Framework to support transformed data. The quantitative data layer, which underpins the Ideal Building Framework is defined by the Energy Manager Model View. The following section investigates Informed Decision Assistance using a Scenario Model using the operating ERI building.

9.4 ERI: Ideal Building Framework

The application of Energy Manager Model View with the automated process has resulted in the Ideal Set of Datum Streams for the ERI building (Section 9.3). This demonstrator emphasises Informed Decision Making using the Scenario Modelling technique and also an appropriate expert decision assistance process as depicted in Figure 9.6. However the Ideal Building Framework representation of the ERI must initially be created.

Application of the Ideal Building Framework for the ERI includes the following steps (Figure 9.6):

- Choose the Building (ERI)(Section 9.2);
- Choose the Energy Manager Model View (Section 9.3.1);
- Apply the Model View and Rule Set Methodology to obtain the ERI specific Ideal Measurement Set as defined in Section 9.3.1;
- Implement the Ideal Building Framework and its constituent layers;
  - Develop an ERI prototype Scenario (Section 9.4.1);
  - Demonstrate informed Decision Assistance using the ERI prototype Scenario Model as would be presented by the Information Delivery Tool (Section 9.4.2).

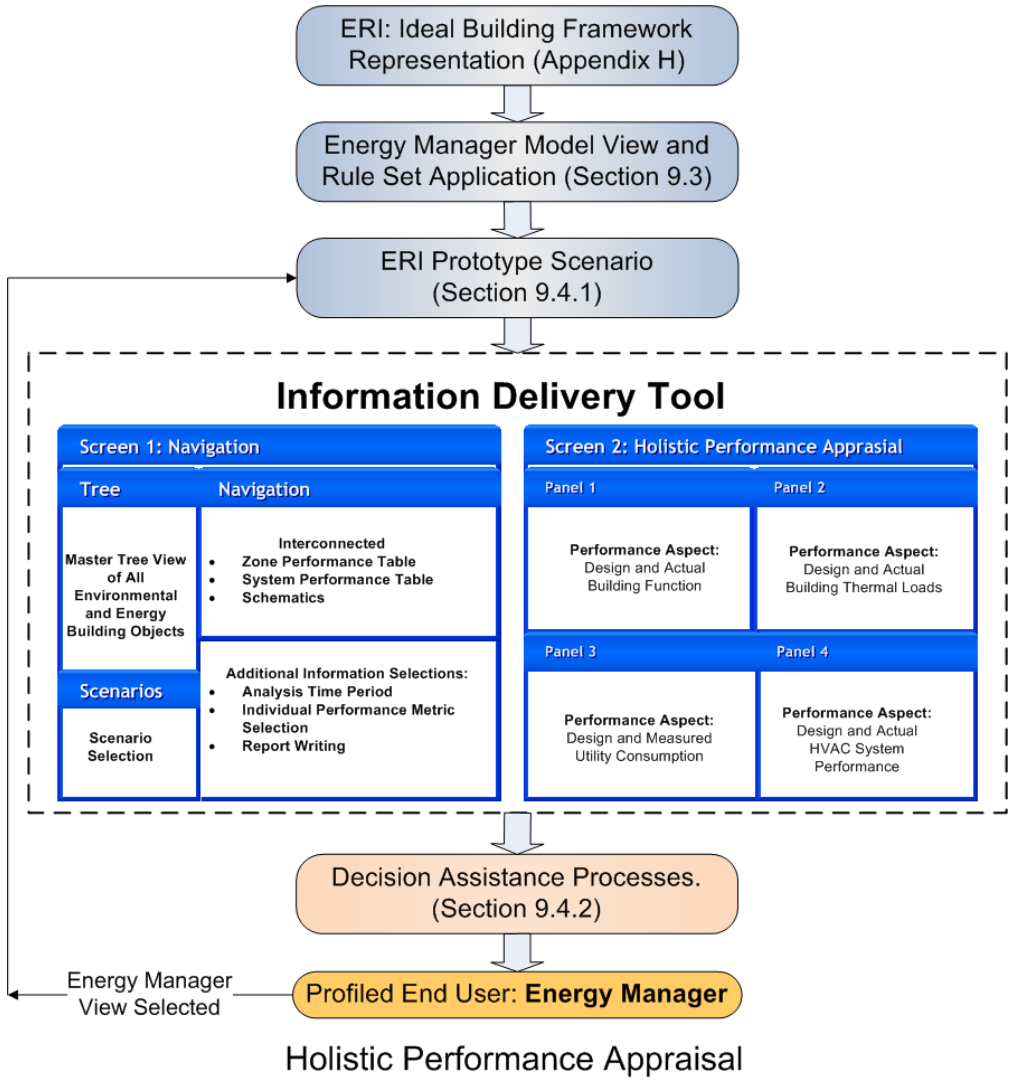


Figure 9.6: *Informed Decision Making as Used with the Prototype ERI Building*

9.4.1 ERI: Scenario Modelling

The ERI demonstrator requires a test scenario to illustrate the applicability of the Ideal Building Framework to real buildings. The Scenario trigger event is that the heat pump has been manually adjusted and current operation is not in accordance with updated design intent. The trigger event, the Performance Aspects, Building Objects, Performance Objectives and Metrics and the major downstream implications of this change to building operation are clearly labelled in Figure 9.7. The measurement streams required for this scenario are included in Appendix J. A snapshot of prototype Scenario measurement streams are included

in Table 9.3.

Table 9.3: *Example of ERI Prototype Datum Streams. The Full Set is contained in Appendix I*

Building Object	**Performance Objective**	**Performance Metric**	**Unit**	**Formula and Data**
Site	Monitor Temperature	Outside Air Temperature at LGF level	^{o}C	Outside Air DB Temperature
Boiler	Minimise Energy Consumption	Gas Consumption	m^3	Boiler Gas
Heat Pump	Optimise Operation	Electricity Consumption	kWh	Compressor Electricity Consumption
Heat Pump	Maximise COP	COP	-	Condenser Loop Heat Meter / Compressor Electricity
UFH Manifold 0.02	Maintain Intended Supply Temperature	Supply Water Temperature	^{o}C	Supply Water Temperature
G05: Immunology Lab	Maintain Air Temperature Setpoint	Air Temperature	^{o}C	Zone Temperature

This scenario clearly identifies that the Performance Aspects: *building function, thermal loads* and *system performance* are unaffected. However the *energy consumption* and *legislation* Performance Aspects indicate, through Performance Metrics, significant changes in terms of the utility consumption, cost of operation and CO_2 emissions. Table 9.3 demonstrates the relationships between the different layers of the Ideal Building Framework when applied to a Scenario in a real as-built context. Building Objects are connected to Performance Objectives and Metrics which are in turn supported by measurement streams and formulae.

The effectiveness of this scenario with respect to Informed Decision Making must now be validated through the recommended decision assistance process and secondly through the expert decision assistance process.



Figure 9.7: *Prototype Scenario Illustrating the Building Function Performance Aspect, Test Zone Building Objects and Performance Objectives and Metrics.*

9.4.2 ERI: Informed Decision Assistance

Informed Decision Assistance is initially tested with the recommended decision assistance process. Information is discusses as if it is presented by the Information Delivery Tool (Chapter 7).

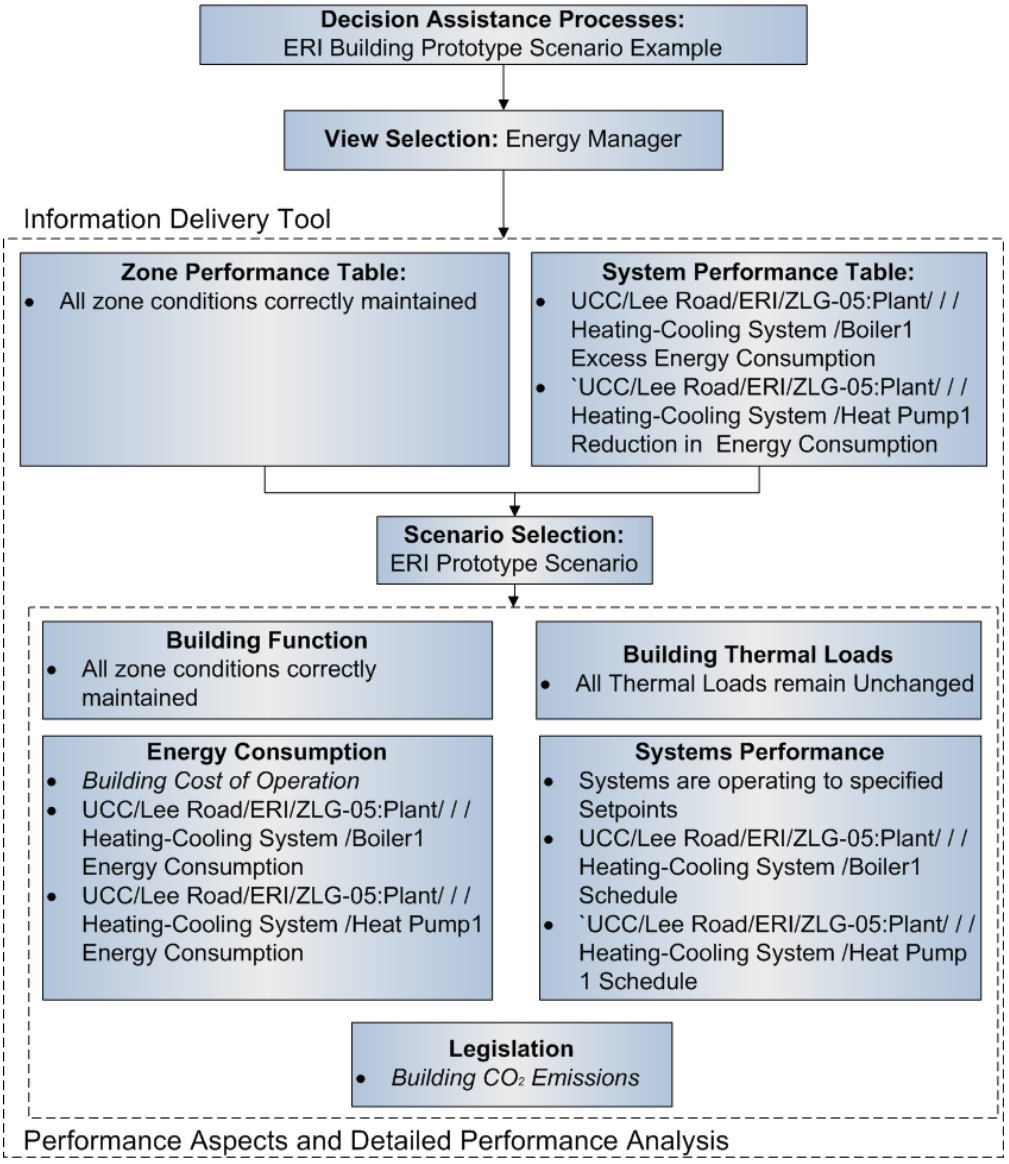


Figure 9.8: *Decision Assistance for the ERI Prototype Scenario. System Operation is not in Accordance with Updated Design Intent*

The prototype example indicates how the generic decision assistance process developed in Chapter 8 is applied to a scenario from the ERI building in Figure 9.8. The selected Model View is that of the Energy Manager who is in turn pre-



sented with the Zone and System Performance Tables (Section 7.3) in screen 1 of the Information Delivery Tool. Using this process the Energy Manager may select the offending 'UCC/Lee Road/ERI/ZLG-05:Plant/ / /Heating-Cooling System /Heat Pump1' or 'UCC/Lee Road/ERI/ZLG-05:Plant/ / /Heating-Cooling System /Boiler1' Building Objects from the Systems Performance Table. The Boiler has an increase in energy consumption when compared with its ideal benchmark equivalent. Conversely the Heat Pump registers a decrease in energy consumption when compared with its ideal benchmark equivalent.

All zones are correctly maintained within predefined environmental parameters. An independent analysis of the Building Object is now possible but the thesis philosophy is to examine Building Object performance in the context of a Scenario. The Energy Manager would then select the Prototype scenario. Energy Manager could use screen 2 of the Information Delivery Tool to analyse the Performance Metrics for the Building, 'UCC/Lee Road/ERI/ZLG-05:Plant/ / /Heating-Cooling System /Heat Pump1' or 'UCC/Lee Road/ERI/ZLG-05:Plant/ / /Heating-Cooling System /Boiler1' Building Objects (Figure 9.8).

Using this holistic scenario approach the Energy Manger can make Informed Decisions based on the following transformed data available from the formal decision assistance process:

- Cost of building operation is in excess of ideal operation cost;
- Reduction in the cost of 'UCC/Lee Road/ERI/ZLG-05:Plant/ / /Heating-Cooling System /Heat Pump1' operation as a result of modified scheduling and resulting reduction in electricity consumption;
- Increase in cost of 'UCC/Lee Road/ERI/ZLG-05:Plant/ / /Heating-Cooling System /Boiler1' operation as a result of modified scheduling and resulting increase in gas consumption;
- Building Function is not affected;
- Increase in building related CO_2 emissions due to additional 'UCC/Lee Road/ERI/ZLG-05:Plant/ / /Heating-Cooling System /Boiler1' gas consumption.

Informed decision making has now been successfully demonstrated using the recommended decision assistance process.

9.5 Chapter Conclusion

This chapter demonstrates an application of the Ideal Building Framework for the Environmental Research Institute at UCC. The chapter describes an application of the Model View and Rule Set Methodology using the Energy Manager and LEED Accreditor Rule Sets.

The application of the Model View Methodology and Energy Manager Rule Set to the Environmental Research Institute found that only a fraction of the measurement streams defined by the Energy Manager Rule Set and therefore required by Energy Managers was implemented in the state of the art BMS.

The application of the Model View Methodology using the LEED Rule Set illustrates the measurement streams that are required per relevant LEED credit. Only a fraction of the measurement streams were implemented for all of the relevant LEED credits. This rule set facilitates the optimum selection of sensors and meters to satisfy LEED credit requirements.

This chapter also demonstrates an application of the Scenario Modelling and Benchmarking techniques incorporated in the Ideal Building Framework and presented by the Information Delivery Tool. The Model View Methodology and Energy Manager Rule Set generated the Ideal Measurement Set for the ERI building which was in turn used to underpin the ERI representation of the Ideal Building Framework. The ERI implementation of the Ideal Building Framework supports the application of the Scenario Modelling technique and demonstrated the effectiveness of the information provided with respect to decision support. Informed decision making was demonstrated through recommended decision assistance process defined in Chapter 8.

Chapter 10

Research Results

"*Things should be made as simple as possible, but not any simpler.*"

(Albert Einstein)

10.1 Research Conclusions

This thesis developed and tested a framework to support informed decision making by the established profile of Energy Managers, working at the operational level of organisations. The solution is proposed in response to the weaknesses in current building operation practice with respect to:

- *External drivers* which are the key factor for organisational energy management. The implementation of *internal drivers* is organisation dependant but if deployed require a payback period of 2-3 years;
- *Role* and resources of each Energy Management department which are dependant on the *internal* organisational drivers. The profile of Energy Managers can vary dramatically under the headings of education, experience and knowledge;
- Energy Managers who have ad-hoc access to *data* and *information*. Transformation of raw data is dependant on the profile of the Energy Manager. Decision making is based on the results of this *data* transformation;
- *Tools* that are used by each Energy Manager are not context sensitive and do not support holistic environmental and energy management of buildings;

- Employed *Techniques* fail to recognise the Energy Manager profile. Analysis against an ideal performance benchmark is not conducted.

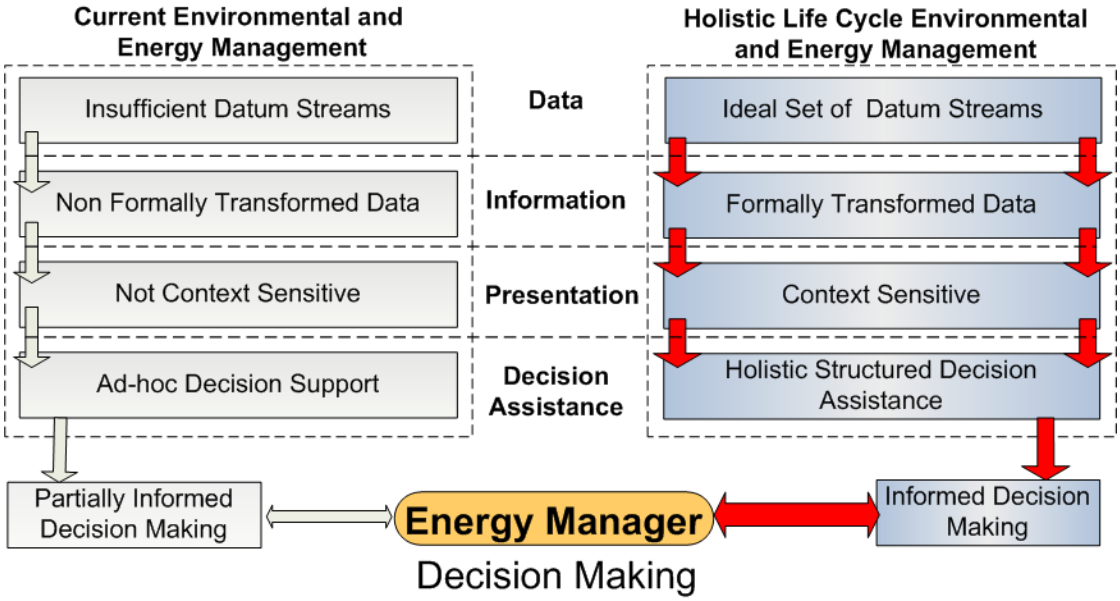


Figure 10.1: *The Proposed Solution to the Identified Weaknesses in the Environmental and Energy Management of Buildings by Profiled Energy Managers*

This thesis proposes to resolve present inadequacies in current building operation (Section 1.5) by *enabling informed decision making*, Figure 10.1), through a formal decision assistance process used by the established profile of Energy Managers. Within organisations the solution would ideally be applied at the operational level of building management. The developed solution focuses on quantitative descriptions through which an Energy Manager can identify and close the gaps between measured and ideal building performance. The approach is applicable for all Building Objects and removes the need for ad-hoc prescriptive comparisons against past performance or the performance of similar buildings. The results of performance analysis at the operational level can also be passed to the tactical and strategic levels of facility management. Formal decision assistance as defined in this thesis requires all the components of Figure 10.2 which are: Stakeholder Specific Model View definitions, The Ideal Building Framework, Performance Aspects, Building Objects, Building Object Hierarchy, Ideal Set of Performance Objectives and Metrics, Ideal Measurement Set, Model View Methodology and the Information Delivery Tool.



Profiled Energy Managers require that the descriptive *data* and *information* used for decision making is *presented* in an appropriate context. This thesis specified a customised dual screen interface to present required *context sensitive Scenario Model information* and is based on the principles of best practice user interface design. The specifications also account for the established profile of Energy Managers, Holistic Environmental and Energy Management and the Ideal Building Framework (Chapter 7). Quantified benchmarking of ideal performance as specified by a whole building simulation model against measured actual performance is undertaken using the tool's many customised features. The *formally transformed data* presented in the *context sensitive* Information Delivery Tool removes the need for present ad-hoc *data transformation* procedures. The underlying component of the solution is the *Ideal Data Set* which is capable of quantitatively measuring the performance of any building.

It is imperative that the Ideal Data Set is formally accessible to all project stakeholders. A Model View is defined as only the data relevant to a particular project stakeholder. The absence and corresponding need for an Energy Manager Model View is described in Chapter 6. The current and future operational processes as determined by Chapters 2-4 establish the global data exchange requirements for the Energy Manager Model View. It further develops a process for extracting stakeholder specific Model Views of Ideal Building operational data based on formal stakeholder specific *rule sets* (Chapter 6). This generic process identifies the relevant Model View data for a particular building. Each individual Model View definition is based on a rule set, two of which have been defined in detail for Energy Management and the LEED Rating System. This particular measurement generation process accompanied by defined View would filter and expedite access to performance data for all stakeholders involved in building performance.

The Model View and Rule Set Methodology define the measurement streams required for ideal operation of buildings. The Ideal Building Framework underpins the datum stream definitions used by the Energy Manager Rule Set. This descriptive as-built performance framework achieves optimum building operation by benchmarking measured performance against up-to-date ideal performance established by whole building energy simulation tools. This approach far exceeds traditional prescriptive comparisons against past performance or the performance of similar buildings. The developed layers of the Ideal Building Framework are:

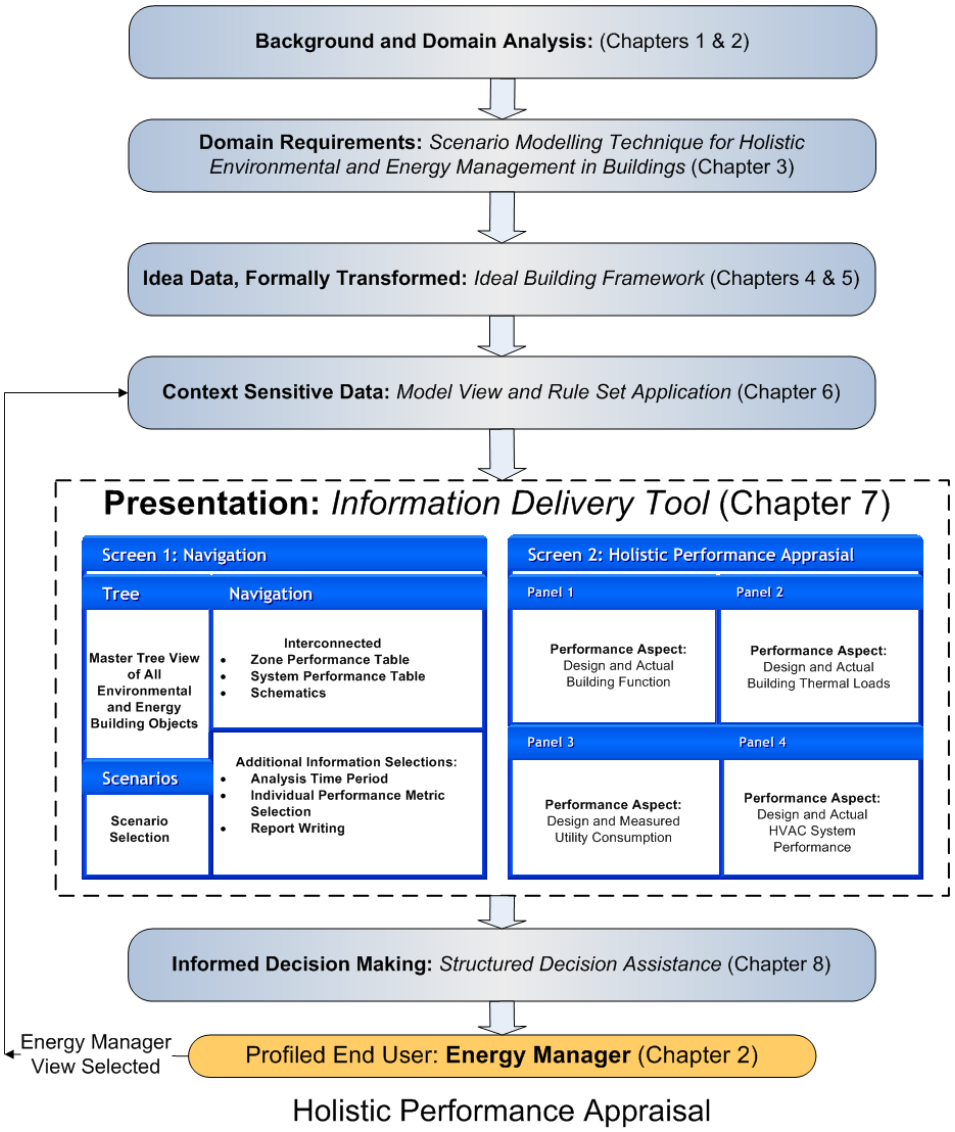


Figure 10.2: *Research Results and Thesis Review*

- Holistic Performance Evaluation Layer which is defined by the Scenario Modelling technique (Section 3.5). Each Scenario is described by:
  - A trigger event;
  - Developed Performance Aspects which account for *internal and external drivers*;
  - Developed Building Objects organised in the Building Object Hierarchy;
  - Standardised Performance Objectives and Metrics;



- Interpreted Data Layer which is defined by the Ideal Set of Performance Objectives and Metrics (Section 4.5). These qualitative and quantitative descriptions are capable of describing the performance of any building;

- Data Transformation Layer which is defined by algorithms included in the Ideal Set of Performance Objectives and Metrics (Section 4.5);

- Quantitative Data Layer which underlies the Ideal Set of Performance Objectives and Metrics. This layer is defined by the Ideal Measurement Set (Chapter 5);

- Interoperable Life Cycle Data Storage Framework to store all performance related data across the entire project life cycle (Section 4.3).

The developed Scenario Modelling technique requires predefined quantification of performance targets which in turn form the basis for analysis. Such quantification as incorporated in the Ideal Set of Performance Objectives and Metrics enables each performance criterion to be calculated in an identical manner by using both ideal or measured data. Therefore enabling a one-to-one comparison for the Energy Manager.

The developments in this thesis create the possibility for future research. The potential topics are now discussed in the following section.

10.2 Future Research

The important components of this work focuses on the development of the data exchange requirements for the Energy Manager Model View but current barriers exist for non-proprietary data model implementations, non-proprietary Model View definitions and subsequent data model specifications. All Model View developments should be conducted in accordance with the IFC Information Delivery Manual (IDM), the process defined in Gökçe (2008) and deployed for testing and validation in real projects (IRUSE 2007, 2008). Other deployments are required to develop the exchange requirements of other Model Views such as a Facilities Manager or a building performance rating system specialist. In time, and with the development of numerous Model Views, additional rule based processes that

identify the direct and indirect consequence of a change to an object in the building product model would greatly assist stakeholder integration. Systems as such would help to remove, current communication barriers and expedite the design process.

The Automated Process and Rule Set methodology should also be developed in a non-proprietary object oriented environment as opposed to the spreadsheet implementation in Chapter 9. Such examples would highlight the widespread and cost effective applicability of the process and how it could be adopted for the EU Energy Performance of Buildings Directive, the Energy end use and Services Directive and other international building performance frameworks such as LEED. Other stakeholder rule sets should also be developed and validated to increase efficiency with respect to data acquisition.

Further work could assist effective implementations of the Ideal Building Framework. Existing BMS systems are not robust, malleable and cost effective sensor technology platforms. It is the authors opinion that wireless sensor networks could provide a solution to expensive retrofits of existing buildings and widespread implementations with respect to new buildings (IRUSE 2007, 2008). The Ideal Set Performance Objectives and Metrics could also be extended for the specific purposes of performance monitoring of industrial facilities. The Ideal Measurement Set could also be extended based on identified Industrial Performance Metrics.

Significant developments must also occur in the domain of whole building energy simulation as shortcomings currently exist. Advancement of existing simulation engines and their input and output interfaces is currently required. Seamless transfer of data between the BIM and simulation engines is essential (Bazjanac 2008). The naming convention proposed in this thesis could provide a formal means of matching the data streams from BIM and simulation tools. The author acknowledges that Global Unique Identifiers (GUID) are contained within present non-proprietary BIM but this is not a user friendly data format when used by domain specific software. Standards for the use of whole building energy simulation must be developed if they are to be adopted as a performance based benchmark for implementations of the Ideal Building. A predictive model will have different input variables when compared with a retrospective model. These input types

must be standardised for three different model types which include:

- Future predictive analysis prior to an analysis period (e.g. week, month or year);
- Real-time analysis, instantaneous operational analysis;
- Retrospective analysis, post analysis period (e.g. week, month or year).

The scenario modelling concept could also be expanded to account for input by different professionals during the Building Life Cycle. A formal process is necessary to enable the elicitation of all stakeholder requirements at design. These requirements could be transferred to the Scenario Modelling format as available through the Ideal Building Framework thus enabling life cycle evaluation of multi-stakeholder criteria. In conjunction with this advance a rule based reasoning methodology would be required to ensure independent inputs are mutually beneficial and do not conflict with the requirements of other project stakeholders. Other independent or complementary developments would develop a generic set of Scenarios applicable to all buildings. A reasoning process that would automatically create Scenarios for a particular building would automate the development of Performance Frameworks for all buildings.

These research developments must be supplemented by parallel advances in the Information Delivery Tool which would change automatically in terms of interface layout, display and functionality depending on Model View selected. An example of alternative GUI layout would be for tactical or strategic facility management. The current specifications, detailed in Chapter 7, are not underpinned by formalised software engineering methods other than at the GUI design. Detailed class diagrams would further progress the existing specifications before actual implementation. The tool could be further advanced by incorporating a web interface so data are accessed remotely and managed centrally. Current technological advances such as the widespread availability of touch screens and WiFi could also be investigated as possible options that would enhance the productivity of Energy Managers. Other software tools such as a Scenario Modelling tool must also be developed and tested in real buildings (IRUSE 2007).

With respect to decision assistance, this thesis recognises that substantial research in the fields of Artificial Intelligence and decision support should be brought to bear with regard to underpinning, formalising and implementing the decision support elements of the proposed hypothesis.

The research presented here identifies a path toward ideal building operation. This path involves fundamental changes to the traditional design, build and operate process and for the information generated, stored and communicated by these processes.

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Appendix A

Case Studies: Interviews

The following case studies were undertaken in order to complete the background investigation into the domain of Building Energy Management. They are intended to complement and verify the information obtained from the literature review. Three Energy Managers were selected as a representative sample of building energy management in Ireland. University College Cork was chosen to provide a background into how a typical Irish university campus operates. Pfizer was chosen to investigate how energy is managed at an industrial plant. The Pfizer Energy Manager was also voted Energy Manager of the Year 2006. Intel Ireland is the third case study and was chosen as the company which incorporates the most advanced BMS/EMS in Ireland. Intel Ireland is also one of Ireland's largest electrical consumers. The choice of Energy Managers is reflective of world wide energy management for pharmaceutical, ICT and public body organisations. A supplemental but interview was conducted with the RPS Energy Engineering Department to obtain an industry wide perspective on Energy Management.

A template for analysis of the case studies was developed to incorporate and investigate the issues uncovered in the literature review (Section 2.2). The following categories were identified as the basis for critical analysis:

- Energy Management *Drivers*: Delivery of product and legislation;
  - Overall objectives of the organisation;
  - *Role* and job description of Energy Management in terms of the objectives of the overall organisation (Resources Allocated);

  - *Profile* of the Energy Manager- education, experience, training provided.

- *Information* used and the underlying *data*;
- *Tools* Used;
- Energy Management *Techniques/Strategies*;
  - Problem identification;
  - Integrated maintenance support within the organisation.
- Benchmarking *Techniques*;
  - Comparison with previous consumption;
  - Comparison with owned building stock consumption;
  - Comparison with a normalised statistical sample;
  - Comparison with a simulated ideal.
- Other relevant features.

A.1 Case 1: University College Cork

The Office of Buildings and Estates (B&E) is responsible for energy management in UCC. The primary driver is to deliver the organisational objective which is to 'provide an environment in which students can learn and in which research can be conducted'. The EPBD also requires UCC to take part in the emissions trading scheme.

B&E perform a traditional energy management *role* at UCC. The financial controllers view energy as a utility bill that had to be paid not managed. Consequently the present organisational structure is not conducive to effective utility management. Existing procurement processes provide ample evidence of how the current system is not oriented towards the needs of B&E. The Procurement Office commonly purchase systems for B&E that best suit the criteria outlined by Procurement. Only capital cost is considered while maintenance, integration with existing systems and operating costs are all considered to be part of other budget



lines. Ultimately B&E does not receive the system it requires. The inadequacies of the organisational structure are also compounded by the absence of communication between staff internally in UCC and between UCC staff and professionals on contract within UCC. The Energy Manger who is currently a *degree educated experienced* UCC employee often requests certain features in a BMS upgrade but the features recommended by the controls specialists are installed. Instead training is not provided for B&E on the new system. At present the Energy Manager is not notified of updates or upgrades to existing BMS. With the exception of a major retrofit Operation and Maintenance (O&M) manuals are not updated to reflect changes to the building.

Each weekday morning the Energy Manager compares the critical metrics for the entire campus e.g. zone temperature and humidity in the art gallery with normal operating parameters. Alarms are also checked for critical warnings. Approximately ten minutes in total is spent performing these checks. If either operational status or alarms indicate a reason for concern critical systems for the building in question are investigated. If these critical systems are not working properly a maintenance request is made. An important maintenance request is answered on the same day but others may never be dealt with. However, an appropriate *maintenance strategy* is not in place. There is no formal classification of problems or a procedure for dealing with faults to HVAC systems in UCC. Solutions to problems are at the discretion of the Energy Manager. Due to the limited resources B&E are forced to make the assumption that their buildings are operating correctly if they do not receive occupant complaints. The Energy Manager must also determine the UCC Green House Gas (GHG) emissions for the Environmental Protection Agency (EPA)[1]. Opportunities for energy management are severely curtailed by the time overhead incurred by the Energy Manager's other tasks which include security and telecommunications.

The BMS *tools* used by Buildings and Estates (B&E) UCC are Trend, Cylon and Siemens. An Energy Focus Monitoring and Targeting (M&T) system is used to monitor energy use. Different communication protocols and hardware are used and these range from copper cables to digital network cables. Maintenance and repair of many different systems consumes unnecessary resources. Problems are

[1]Calculations are for on-site generated emissions

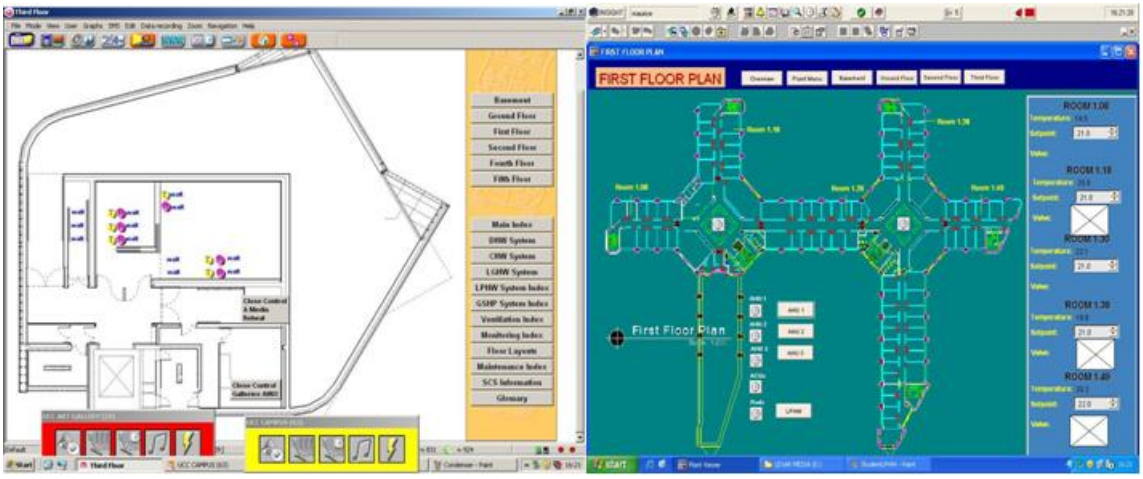


Figure A.1: *Trend and Siemens BMS that are Used at UCC.*

exacerbated by the fact that companies who design and install the BMS do not conduct the maintenance on their installations (Ahern 2006). Hatley et al. (2005) of the United States Department of Defence (DOD) recommends that no more than two BMS types should be on any particular site. The disparity and disconnect is most evident in the UCC Student Centre where the new extension has a separate BMS to the original structure. Each proprietary BMS has a different interface, two of which are shown in Figure A.1. The M&T package has yet another interface.

Techniques including EUI levels (measured in kWh/m^2/year) are the preferred metric for building energy analysis on campus. The Office of Buildings and Estates at UCC compares each building's EUI to that of the previous year and against the campus average. This benchmarking process does not normalise data for building type, occupancy profile etc..

The Office of Buildings and Estates recently acquired an M&T package which is used to monitor primary energy consumption of electricity and gas at the building and site level. Based on hourly *data* values the Office of Buildings and Estates identified that the campus night time electrical load (Figure A.2) is approximately 1/3 of the peak day time load. To demonstrate the potential of having access to the necessary *information* the Department of Civil and Environmental Engineering successfully *benchmarked* and subsequently reduced its night time load by 24%. This reduction was achieved through monitoring electrical consumption for the whole building only. In essence through the provision of some *additional infor-*

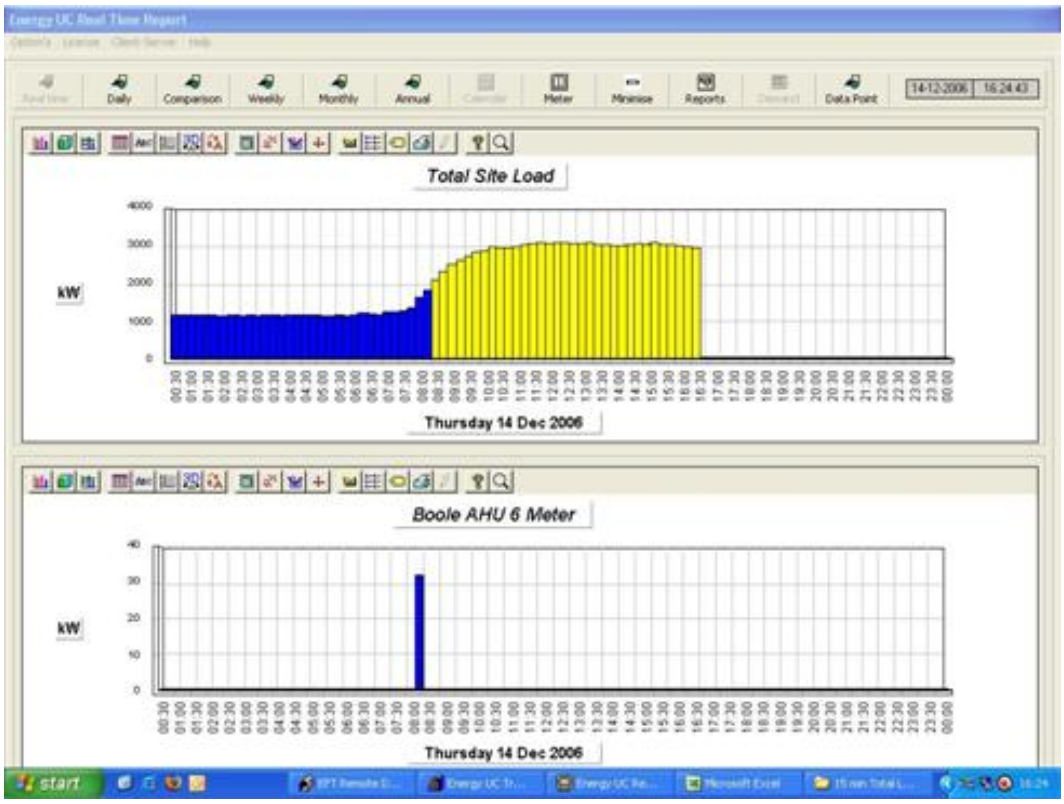


Figure A.2: *Typical College Weekday Electricity Load Profile for UCC Site. Displayed by the EnergyFocus EMS.*

mation substantial reductions in energy consumption were made possible. Further resources, sub metering (capital expense) and man power (recurring expense) are required to similarly profile and reduce energy use cost effectively within all campus buildings. A comparison with a simulated ideal energy consumption benchmark was not considered.

A.2 Case 2: Industrial Plant

The Pfizer pharmaceutical plant at Little Island is one of three plants owned by the company in the Cork area. The plant objective is the manufacture of medicinal drugs. Cumulatively the three plants have an annual energy consumption in the region of €20 Million. Breakdown by cost is approximately 75% electricity and 25% gas. The *drivers* for Pfizer energy management are financial, legislative (compliance with internation medicinal drug production standards) and environmental. The Little Island plant currently complies with the ISO 14001 Environmental

Management System (NSAI 2004). To further reduce environmental impact energy management successfully implemented International Standard IS 393 (NSAI 2005)[2]. Pfizer is the first Irish plant to be awarded this energy management standard (O'Connor 2007).

A dedicated Energy Manager is responsible for all energy related projects and outsources a considerable portion of the work to the RPS energy consultancy group. RPS have a full time presence on the site. The current Energy Manager is a *qualified electrician* with *considerable experience*. The RPS employees that work at the Pfizer plant are all *qualified engineers (civil, mechanical and marine)*. Qualifications include PhD, Masters and Degrees in related fields. The group leader has extensive experience in building energy management.

Within the Pfizer organisation, the role of the Energy Management Department is to reduce energy consumption without interfering with production. Important process related meters are calibrated weekly and non critical meters are calibrated annually. For a pharmaceutical industry Energy Manager the most critical information is a notification alarm of a fault (e.g. pump not operating etc.). Production may be compromised if such an issue is not addressed. The Pfizer Energy Manager has a *defined maintenance support network* and resources such as repair personnel at his immediate disposal.

Pfizer energy analysis is performed monthly. The EnergyFocus M&T package (EnergyFocus 2007) is used to store and access raw *data*. These raw sensor data are manually extracted from EnergyFocus and converted into *informative* metrics such as energy consumption values. Analysis *techniques* are based on Energy Performance Indicators (EPI's) and data streams are checked using six-sigma analysis for correlation with acceptable tolerance margins. Outliers require additional investigation and explanation (Lee-Mortimer 2006*a*,*b*).

Customised software *tools* (interface illustrated in Figure A.3) focus on energy

[2]IS393 is an Irish national standard developed to ensure that energy management becomes integrated into organisational business structures. The standard model elements are Energy policy, planning, implementation and operation, checking and corrective action, corrective and preventive action, monitor and measure, internal audit, management review, continual improvement. The success of the system depends on commitment from all levels and functions of the organisation, and especially from top management (NSAI 2005).

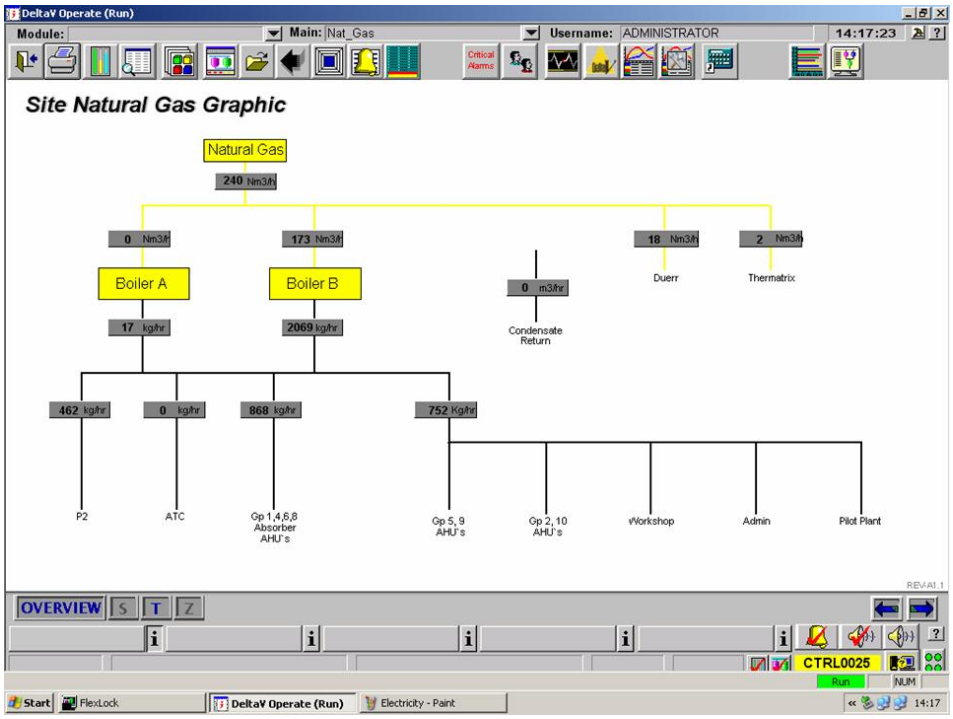


Figure A.3: *EnergyFocus Schematic of Gas Consumption for a Pharmaceutical Site*

consumption and not energy use. Energy (electricity and gas) is disaggregated by building and then to consuming components. Real time consumption values are available on screen for all levels displayed by the interface. For day to day energy management the most useful metrics are power and energy consumption values. The data required is primarily flow rate (gas and water) or power (kW). *Techniques* that establish performance and benchmark against past performance are the only pragmatic option that account for the unique nature of production processes at Pfizer. Monthly energy analysis is performed for the entire site. Energy Management would like to utilise techniques that deliver a metric of 'energy cost per unit of output' but require additional resources such as man power, sensoring and sub metering. Such an analysis will only be permitted if the cost benefit to the company can be pre determined.

In addition to energy management a structured approach was applied to energy reduction at the Pfizer site. In order to do this a site wide audit was initially conducted. Energy Management identified the major energy consumers in order of consumption. These included e.g. waste water treatment, thermal oxidiser, air

compressors, chillers, boilers etc. The components with the largest potential for gross energy savings were identified and given priority for further investigation. Adequate resources were allocated for this further analysis.

A.3 Case 3: Intel Ireland

Intel is one of the largest consumers of energy in Ireland and they employ over 4,500 people at one location (Geoghegan & Fenner 2007). The facility *objective* is the manufacture of computer chip wafers. The *drivers* for Intel's Irish Energy Management Department are in order of priority to:

1. Keep FAB operational;
2. Ensure systems reliability;
3. Energy Management activities are not to intrude on factory operation;
4. Keep work spaces air conditioned.

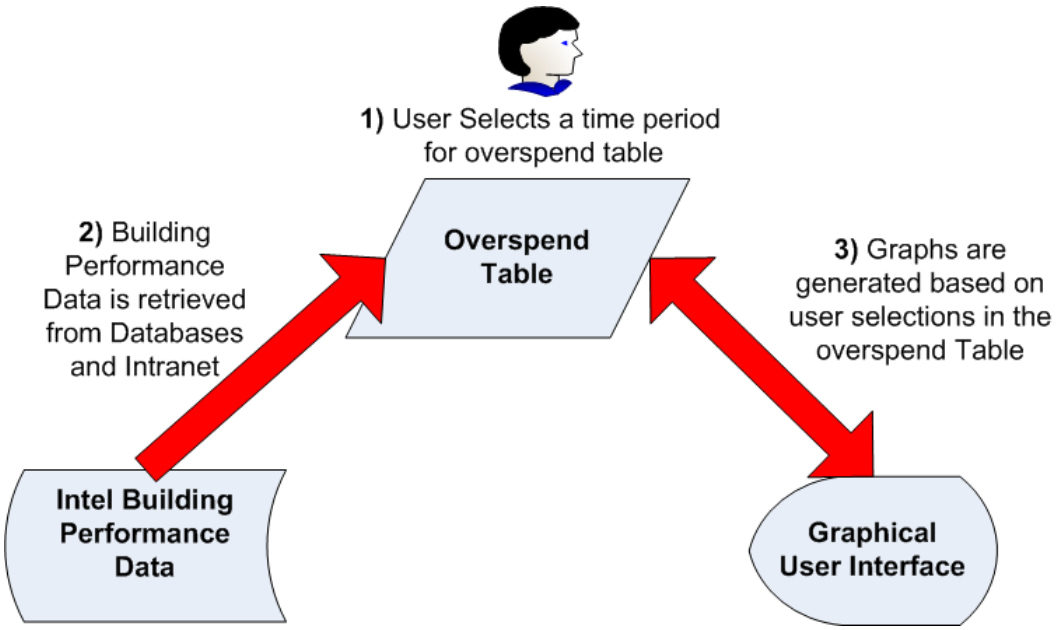


Figure A.4: *Architecture of Intel Energy Management*

As a department its internal goals are to optimise plant operation and improve budget accuracy without compromising production. The energy management per-

sonnel are qualified electrical and mechanical engineers with considerable experience in energy management. Full training is provided to staff members who operate the software tools used for energy management.

Once a week the EMS (software *tool* architecture as illustrated in Figure A.4) is used to pull data from different sources, for example electrical consumption, flow rates, weather degree days, wafer moves, etc. from databases and websites. In-house techniques deliver expected energy consumption which is normalised to *fairly* compensate for the variable effects of the weather, levels of business activity, product mix, and other external influences, and compare with actual consumption which comes from energy metering *data*. The Intel Energy Manager views this comparison through an Overspend League Table (Figure A.5) which prioritises the streams that exceed expected consumption. Red traffic light's (as displayed in the far right column of Figure A.5) indicate above expected target and tolerance for each particular stream. Summary information and performance feedback is communicated to other departments through Intranet pages. This summary includes the overspend table for the specific time period and relevant comments.

Overspend league table for week ending 26/02/2005

ID	Stream	Apparent overspend	Actual units	Expected	
VGAF24tot	Fab 24 - Gas	€3,352	1558484	1390869	
VELIFO_EC	IFO - Energy Ctr elec	€2,077	1065963	1031351	
VELF14PROC	Fab 14 - Process elec	€1,916	771756	739826	
Fab14Gas	Fab 14 - Gas				
ELF10CHTTOT	Fab 10 - All Chiller Total				
VELF14EC	Fab 14 - Energy Ctr elec				
ELF24CHTOT	Fab 24 - Chiller Total			2628	
N2PROD	F10 - PRODUCT NITROGEN			3772	
VELECUTIL	Fab 10 - Energy Ctr elec	€1,043	559162	541777	
ELPL055	Fab 10 PElec - HDP 409/10 OXA 418,20	€871	136278	121769	
WA_19	Site - effluent to KCC	€662	62146	61061	
ELF10CHTOT	Fab 10 - Chiller Total	€599	232224	222240	
WASITETOT	Site - Water	€599	68560	67578	
ELIFOCHTTOT	IFO - Chiller Total	€585	518955	509209	
Fab10Gas	Fab 10 - Gas	€545	1673558	1646331	

MAH Set point adjusted due to unit tripping on frost

OFA Compressor taking load due to maintenance on Nitrogen plant

Figure A.5: *Sample Overspend Table (Courtesy of Intel)*

Intel Energy Management are of the opinion that they are *"data rich, information poor"*. Intel Energy Management measure and store all data points required but are unsure of the optimal format for information display. A series of drop down menus is used to navigate through actual energy consumption values. Com-

piling this data into pertinent performance information is also conducted through drop down menus. Each interface is customised as required for the various types of data source. However a skilled and competent Energy Manager is required to understand and manipulate the large number of data streams measured in each facility (FAB unit) (270 logged and 60 calculated). The customised EMS software was designed to provided maximum functionality for the Energy Manager and adequate training is provided on all systems. Any anomalies detected are investigated and are normally attributed to changes in production. Intel Energy Management stated that their own productivity could be enhanced through improved communication with other Intel departments. Intel is also actively engaged in energy mitigation initiatives such as reducing the clean room air flow from 70 cubic feet per minute to 60 cubic feet per minute. All changes are cost driven. Criteria for energy efficient projects are that the return on investment must be about 3 years. The range is from 12 months to 7 years for exceptional cases.

A.4 Industry Overview Interview: RPS Group

RPS Group is an energy auditing consultancy and have extensive experience across the domain of building energy management (RPS 2007). The employees interviewed were group leader Richard Morrison, Elmer Morrissey, Ken Bruton and Dermot Walsh.

New buildings do not operate as designed. Typically buildings experience a 15% reduction in energy consumption in year 2 when compared with year 1 and a 6% reduction in year 3 when compared with year 2. Traditional commissioning inhibits operation due to the limitied perspecive of the comissioning process. System and component performance are compared with design specifications. Operating strategy or holistic building performance is not investigated. In practive Energy Managers typically spend 5-10 minutes a day focusing on energy consumption.

To solve energy related matters one needs time, resources and knowledge. When performing audits the majority of the RPS employee's work revolves around checking utility rates and tariffs, checking setpoints and schedules. For an Air Handling Unit (AHU), an RPS employee requires inlet and outlet temperatures and also valve position. However Building Manager's may just check zone conditions and no further action is performed. For Example two split systems can have two differ-

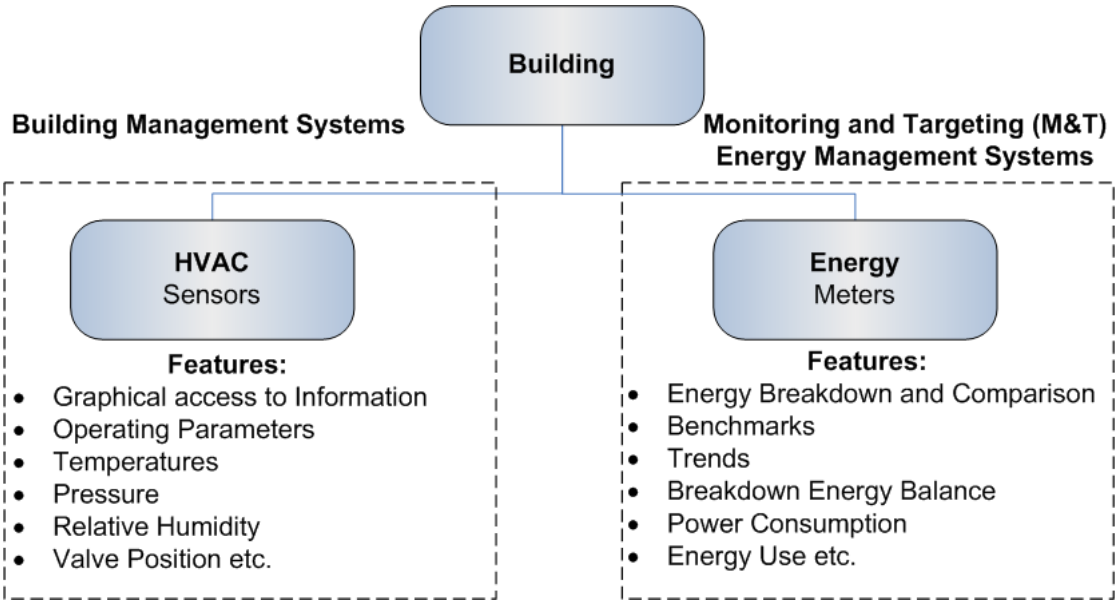


Figure A.6: *Simplified Diagram of Conventional BMS and EMS Datum Sources and Functionality*

ent setpoints, one for each zone. In this case the systems never reach an equilibrium and are have excessively high operating hours. One controller (which is capable of controlling both) would suffice. Sic sigma analysis which uses 3 times the standard deviation either side of the linear fit is used for analysing processes. Outliers are indicators of problems and are thoroughly investigated.

Building management tools (BMS and EMS) were discussed and the breakdown of functionality is illustrated in Figure A.6. Any tool that would be of benefit to building energy management must access all of the information included in Figure A.6.

The departmentalisation of design teams is a further inhibiting factor to the overall goal of an energy efficient building. These teams rely on traditional design techniques and very little innovation and advances occur as an engineers knowledge is not updated. The emphasis is on speed of design rather than energy efficiency. A client has to assume that a building is designed in an energy efficient manner but in reality it is more likely to have been designed using traditional methods. as a result a new role has emerged in the design process. Energy consultants are now used as a check for the mechanical and electrical design who then reports his findings back to the client. RPS group perform this role.

A.5 Analysis

This section synthesises the literature review and the case studies and therefore describes weaknesses in the key areas of holistic environmental and energy management. A literature review identified the key areas as:

- Internal and external *Drivers* for organisational energy management;
- *Role* of Energy Management within the parent organisation;
- *Information* and *Data* available to each Energy Manager;
- *Techniques* employed by each Energy Manager;
- *Tools* used by each Energy Manager.

A review of present practice energy management was conducted based on the literature review and a number of carefully selected case studies. An overview of the case study findings is presented in Table A.1. The notation used in the table is **O** for normal or typical practice, − for less than normal or typical practice and + for greater than normal or typical practice.

Table A.1: *Case Study Overview*

Categories	**Case 1**	**Case 2**	**Case 3**
External Drivers	O	+	+
Internal Drivers	–	+	+
Role	–	O	+
Data	–	O	+
Information	–	O	O
Tools	–	O	+
Techniques	–	O	O

The objective of the requirements analysis is to reveal the critical issues in each of the key areas. This analysis is described in the following sub sections.

A.5.1 Analysis: Internal/External Drivers

Organisational Energy Management *drivers* can be of two types 1 external (e.g. legislation or public perception of a company) or 2 Internal (e.g. effective energy management for utility bill reduction). Energy Management must be an integrated

and resourced function within enterprise management and demonstrate legislative compliance if it is to be successful. Currently all three organisations are part of the emissions trading scheme and must account for CO_2 emissions at the site level. In time with implementations of the EPBD and ESD, all 3 organisations will be required to account for energy at the building and system level respectively.

At UCC the organisation must comply with the Emissions Trading Directive where CO_2 emissions are monitored. A strategy to mitigate the use of fossil fuels and end use energy consumption is not currently in place. In 2006 energy accounted for over 5% of the annual campus budget. This threshold has alerted the UCC financial controllers of the significance of campus energy consumption.

At Pfizer Energy Management must comply with the Emissions Trading Directive. Pfizer has previously been ISO 14001 compliant and is also familiar with stringent regulations associated with the manufacture of medicines. Pfizer Ireland was ideally positioned to undergo IS 393 evaluation and is now the only Irish plant that complies with this standard. Compliance with IS 393 acknowledges the integration of energy management within the Pfizer organisation as a whole. Pfizer utilises a structured energy management strategy where a reduction in process related energy consumption is the key driver.

Intel must also comply with the Emissions Trading Directive but is also interested in the company's global public image. The Intel Ireland Energy Management Department is responsible for the LEED accreditation for a new Israeli facility. Internally the importance of cost effective energy management has been identified by the financial controllers and resources have been allocated accordingly.

A.5.2 Analysis: Role

The case studies highlight the fact that financial controllers ultimately dictate the *role* of energy management within each organisation. Intel specifically appointed qualified Electrical and Mechanical Engineers in charge of energy related activities. Traditionally Intel Energy Management were required to demonstrate the effectiveness of energy reduction initiatives. Feedback on successful implementation of specific energy mitigation efforts, as is the case at Intel, helps develop a working relationship between traditionally independent Energy Management and Financial Controllers. Holistic building performance is a complicated series of interactions. Typically financial controllers do not possess a qualification or experience in the

domain of building performance and cannot be expected to understand the semantics of the field. Therefore Energy Managers have had to effectively demonstrate cost effective energy reduction measures through a projected Return On Investment (ROI). A 2-3 year payback is normally acceptable but life cycle cost is not considered. Extreme cases have used an ROI of 7 years (Geoghegan & Fenner 2007, Keane 2007). Intel Energy Management are not permitted to negatively impact on production.

At UCC the role of energy management has been driven by legislation. The degree educated Energy Manager was appointed internally in response to the University's Emissions Trading Scheme requirements and does not have the resources to adequately investigate day to day operations.

Pfizer acknowledged the importance of reducing process related energy consumption. An appropriate candidate (an experience and knowledgeable qualified electrician) was internally promoted and subsequently voted Irish Energy Manager of the Year 2006. His scope of work includes reducing energy consumption but not to compromise the production process. Intel initiated a top down approach to energy management. The financial controllers identified energy reduction as cost effective in terms of the company's overall strategy. All the worthwhile cost effective resources were made available to the Energy Management Department. The role was to reduce consumption but not to compromise product manufacture.

A.5.3 Analysis: Data

Traditionally UCC has not prioritised *data* collection. System or individual sensor data are not used for cases other than real time spot checks. Monitoring and Targeting activities require measured metered data. Required data are in the form of monthly utility bills.

Pfizer have placed an emphasis on production related energy consumption. All process related and energy consumption data are monitored and recorded.

Intel measure all process related, energy consumption and energy end use data. The philosophy is to measure and record data for future analysis.

A.5.4 Analysis: Information

The primary data source for UCC is monthly utility bills. The *information* created from the utility bills consists of an annual energy report and annual CO_2 emissions. The Monitoring and Targeting system highlighted potential for energy savings but a greater resolution of measurements is required. Pfizer Energy Management manually manipulate their data to create meaningful information for energy consumption data. Energy end use data are not available and decomposing energy type by usage category is not possible. Reports are prepared monthly and energy consumption is linked retrospectively to the production process. Intel Energy Management describe themselves as "*data rich, information poor*". Relatively speaking Intel has access to the largest amount of energy consumption and end use information through their automated systems. It stands to reason that because Intel has access to the largest data sets that they had the greatest potential in terms of energy management. However Intel is unsure of the format of communication for this information.

A.5.5 Analysis: Tools

The *tools* used by UCC and Pfizer are restricted by the data streams measured. UCC use off the shelf BMS technologies. Numerous alternative BMS controlled campus plant and equipment. The ad-hoc implementation of integrated hardware and software environments prove to be grossly inefficient in terms of day to day operation and maintenance. Pfizer customised their interfaces but are restricted to examining energy consumption as opposed to energy consumption and end use. Numerous features are incorporated in all of the BMS/EMS examined. The most effective were found to be:

- Logical building performance navigation through the use of interactive schematics, e.g. interactive floor plans;
- Access to on-line O&M manuals;
- Data archival;
- Calendar functionality significantly improved traversing and specification of large volumes of data.

Intel BMS/EMS are custom made and most effective of the three cases as the systems monitored energy consumption and downstream energy use. The Intel EMS also incorporates useful graphing features that enabled rapid inter-navigation of generated graphs. Points selected on a particular graph automatically highlight on other graphs where applicable. Intel demonstrated the most effective energy management requires a customised BMS/EMS and an appropriately qualified Energy Manager who has received training on all systems. A standardised yet flexible navigation path capable of traversing all relevant levels of building performance could intervene where customised interfaces are not pragmatic.

A.5.6 Analysis: Techniques

The energy analysis *techniques* are not consistent between the three Energy Management Departments. UCC commission an annual energy report and comment on discrepancies between current and past cumulative consumption values. Pfizer perform a monthly analysis and account for production variances when analysing consumption. Intel use a normalised weekly benchmark based on Intel specified criteria. This method is the most effective of the case studies conducted. However the Intel system requires a number of weeks to establish a new best practice benchmark if modifications are made to system configuration. The plant has the potential to operate at below *best practice* conditions until this new baseline is established. In each case energy performance was compared against past performance whether normalised or not but comparison with a theoretical 'optimum' performance level was not considered.

Appendix B

Appendix B

Building Function

This appendix describes the complexity of data and information required by Energy Managers and also highlights how present tools are unable to covey the complexity of data required. This appendix also complements the definition of Performance Aspects in Section 3.3 by focusing on *building function*, *thermal loads* and *legislation*

B.1 Introduction

Building performance, building thermo-physical conditions and energy flows are a complicated series of heat transfers and energy balances as depicted in Figure B.1. This figure also illustrates the number of dynamic factors that influence zone conditions and the subsequent effect on building energy consumption. An Energy Manager cannot completely understand building performance if datum streams for each factor are not simultaneously accessible, as is the case with traditional BMS and EMS (Section 2.4). For example the downstream effects of an alteration to a zone condition setpoint, such as change in system operation and change in building energy consumption, are not normally accessible using commonplace tools.

Energy Manager cannot view the downstream effects of modification on energy consumption. Traditional energy management activities include visualisation and, where required, alteration of supply air conditions to moderate zone conditions. However an Energy Manager cannot view the downstream effects of modification on energy consumption. *Energy end use* or decomposition of energy end use may or may not be accessible through traditional tools, e.g. total plug load electrical

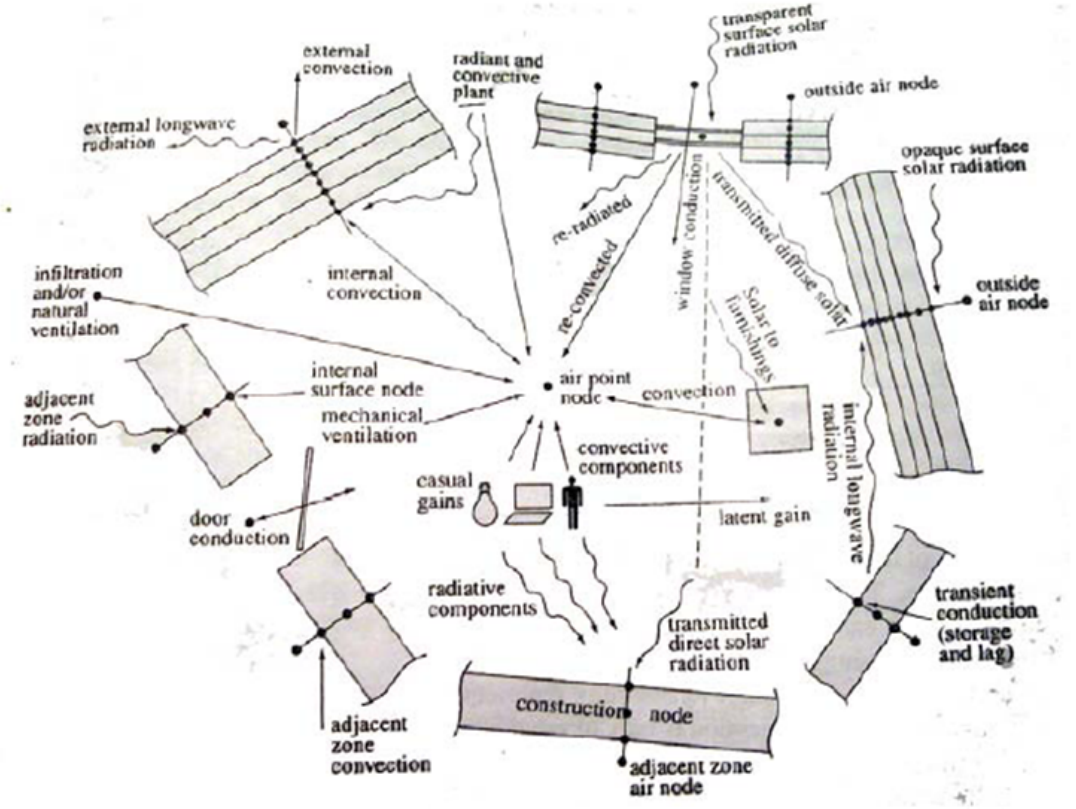


Figure B.1: *The Complexity of Building Energy Flows (Courtesy of (Clarke 2001))*

consumption. The effect of lighting on zone cooling is not considered by traditional tools. An Energy Manager must also comprehend other static and dynamic features of holistic building performance in addition to the interdependencies between a buildings heat transfers and energy balances. These are discussed in the following subsections.

B.2 Occupancy

Buildings are constructed for a purpose which may include manufacturing, education, administration, computer server warehouse etc.. In the pharmaceutical industry energy cost per unit produced is an important economic driver (O'Connor 2007). Buildings occupied by people have dynamic characteristics that are often difficult to quantify. Accurate measurement techniques that do not compromise an individual's privacy are currently under development. For example a camera

technology that quantifies people movements is currently a project at Stanford University in the US (Hengstler et al. 2007). Cameras which are ideally focused on a door use algorithms to process recorded movements. However it is acknowledged that security issues can arise for sensitive buildings (e.g. banks). Employees may object to being continuously identified and monitored.

Bulk occupancy figures for a building are comparable with gross energy consumption over time but for *ideal building operation* greater resolution is required. Knowing how many people occupy a building and where they are located is a key component of building energy management and security (Dodier et al. 2006). HVAC systems can be more tightly controlled based on occupancy levels or CO_2 measurements (Wang et al. 1999). Recent developments such as smart occupancy sensor networks that can change timing to account for activity levels have demonstrated a 5% greater saving than conventional time delay sensors (Leephakpreeda 2005, Garg & Bansal 2000). Existing tools do not illustrate the relationship between building function and energy consumption as previously outlined in Section 2.4. For example it may be impossible for Energy Mangers using existing tools and measurements to establish if cleaning crews would be more efficient, from a building operation perspective, if they cleaned on a floor by floor basis with artificial light activation/deactivation as they progressed.

A conditioned zone will unnecessarily consume energy if open windows and doors are not part of the HVAC strategy. In such cases an Energy Manager requires an alarm signal to highlight an unintended exposure of a zone to the *exterior environment*. The magnitude of aperture openings are critical measurements in cases where zones are naturally ventilated. Similar to HVAC systems, an Energy Manager requires naturally ventilated data that enables a comparison of system operating status, system performance and zone conditions (Krausse et al. 2007, Walker et al. 2004).

It is imperative that an Energy Manager can relate building function to energy consumption and associated environmental impact. This comprehensive understanding is only attainable if all the relevant information is accessible to the Energy Manager.

Current occupancy detection systems attempt to regulate the lighting in a local area (i.e. a single workstation or private office) by responding to activity occurring over a larger area (i.e. several workstations or passersby in a corridor). The zone that is viewed or monitored by any single detector (monitored space) is usually larger than the zone controlled by that detector (controlled space). For example, a single occupancy detector will often respond to the presence of passersby and/or air streams coming from office equipment cooling fans operating within the field of view of the detector. Energy savings will be compromised because the probability is low that the area viewed by a single detector will remain vacant long enough for the lights to be switched off. Consequently lights in these areas are switched off less frequently than they would be in a washroom. Further exacerbating this problem is the wide variation in office layouts which means that a generic solution using current technology is unlikely (Dodier et al. 2006).

B.3 Lighting

Zone based occupancy control, with or without time delay sensors, is not an effective solution for optimum artificial lighting or HVAC control (Mysen et al. 2005, 2003). Localised or *micro-zone* measurements are required. The intelligent workplace at Carnegie Mellon University utilises micro-zone and ambient conditions for greater HVAC energy efficiency (Hartkopf et al. 1997). Lux level lighting and thermal comfort demands are occupant specific and locally controlled. Therefore lighting and micro-zone environmental control should be occupant specific[1]. The Center for the Built Environment (CBE) at UC Berkeley developed a prototype occupant specific wireless sensor network for individual control of artificial lighting systems. Individual occupant control of lighting demonstrated a 63% saving in lighting related electricity consumption (CBE 2006). However these systems fail to minimise artificial lighting based on available natural light while simultaneously accounting for occupant thermal comfort (Inkarojrit 2005). Existing whole building energy simulation models do not dynamically account for variances in natural light (Crawley et al. 2005). When determining Lux levels, all research uses static thresholds which are not occupant specific to model occupant interference with blinds or artificial lighting (Reinhart 2004). Lighting simulation tools

[1]The German government has implemented legislation that demands optimum working conditions for all employees (Semke 2000).



are presently unable to model dynamic sky conditions. Climate files that incorporate dynamic sky conditions are not used by lighting simulation tools (Reinhart 2004). Therefore a dynamic optimum benchmark for the combination of natural and artificial light is presently not attainable.

Inkarojrit (2005) determined that the key variables for lighting thermal comfort are average window luminance, maximum window luminance, background luminance and transmitted vertical solar radiation at the window. These variables can be easily implemented in the building energy simulation tools and provide the basis for future automated window blind control systems (Inkarojrit 2005). Current IBECS sensor network technology (Integrated Building Environmental Control System) has the capability to measure localised occupancy and lighting levels and relay the information back to a control system and in turn an Energy Manager (Rubinstein & Pettler 2002).

B.4 Legislation and Utilities

Building performance must also comply with legislation. Buildings are commonly designed to minimum legislative code requirements (Section 1.4.1) but as of writing only aspects of operation must comply with legislation. For example, regulations exist regarding the use of water towers in order to prevent legionnaires disease (ASHRAE 2004*a*, 36.12). If a building, portfolio of buildings or *campus* has been incorporated in the emissions trading scheme as defined by EU Directive 2003/87/EC an Energy Manager must be able to compare actual, historical and predicted CO_2 emissions with the legally defined threshold. Efficient energy management can reduce consumption and act as an additional income stream for the organisation. The impending implementation of the Energy Services Directive (Directive 2006/32/EC) cannot at this time be incorporated in the Ideal Building (EU 2006) as the technical implementation has yet to be finalised (SEI 2007). Future domain developments must incorporate the flexibility to account for the ESD or other legislation with the minimum of alteration. Holistic environmental and energy management needs to account for utility cost especially in situations where providers incorporate dynamic pricing strategies (Piette et al. 2005).



Appendix C

BIM Environment: An Implementation Option

This Appendix describes the interoperable data and software environments required for an Information Delivery Tool. Suggested processes that populate the Building Information Model (BIM) are described in detail.

BIM is an industry term used to define 3-D, intelligent, object oriented, AEC/FM specific CAD models (Khemlani 2003). CAD vendors such as Autodesk, Graphisoft, Nemetschek and Bentley have independently developed respective proprietary data models for 3-D descriptions of geometric building form (Autodesk 2002, Bentley 2003, Graphisoft 2003). In the recent past product models could exchange geometric data but virtually no "downstream" data after CAD (Bazjanac 2004*a*). Proprietary BIM suites now include a variety of functionality such as construction scheduling (4-D) and cost estimation (5-D) functionality but information stored in a proprietary BIM is only accessible by a particular vendor's software[1].

Non-proprietary integrated product models allow ease of access for a broad range of software tools across the entire BLC. The aerospace industry has successfully implemented non-proprietary integrated product models to replace the need for physical mock-ups (Mason 2002). A similar style integrated environment could lead to increased savings for all projects stakeholders within the AEC/FM industry (Gallaher et al. 2004, Neuberg et al. 2004). Users of non-proprietary

[1]BIM functionality may be obtained from respective vendors websites (Autodesk 2007, Graphisoft 2007, Nemetschek 2007)

integrated environments are not restricted to a specific suite of software tools. Domain experts may use the most productive tools for a specific task provided an interface between a software tool and the BIM exists. Optimal design solutions are attainable through shared information as opposed to data regeneration.

Presently IFC, developed by the International Alliance for Interoperability, are the only non-proprietary, intelligent, comprehensive and globally accepted data model of buildings (Bazjanac 2003). Any tool developed for an Energy Manager should be based on the IFC data model. The IFC2x Platform Specification was officially accepted as a Publicly Accessible Specification ISP/PAS 16793 by ISO (International Organization for Standardization) in October 2004 (ISO 2004). This gave an official standard status to the IFC Specifications (Kiviniemi 2005).

BIM initiatives started with a memorandum to Public Buildings Service (PBS) Assistant Regional Administrators dated December 23 2003 from the Commissioner of the U.S. General Services Administration (GSA) (Moravec 2003). The memorandum instructed PBS Assistant Regional Administrators that for future projects (FY 2006) a BIM is required at the end of schematic design. The cooperation of the CAD vendors resulted in the development of the *IFC Space View*. The GSA can automate their spatial validation process to ensure that all designs in the Final Concept phase adhere to the spatial requirements set forth by the housing plan and PBS business assignment guide (GSA 2006). The United States is currently developing a national BIM standard (NIBS 2006). Senate Properties, the owner of Finnish Government Buildings, are following suit and as of October 2007 they require IFC based BIM for all construction projects over €2M (SenateProperties 2007).

C.1 Populating the BIM for an Information Delivery Tool

This section describes the most appropriate system architecture for an Information Delivery Tool. The required structure for instantiating a performance history object is described and the links between raw data sources and performance history objects are discussed. An Information Delivery Tool requires certain instantiated

BIM objects and the steps in the process are outlined.

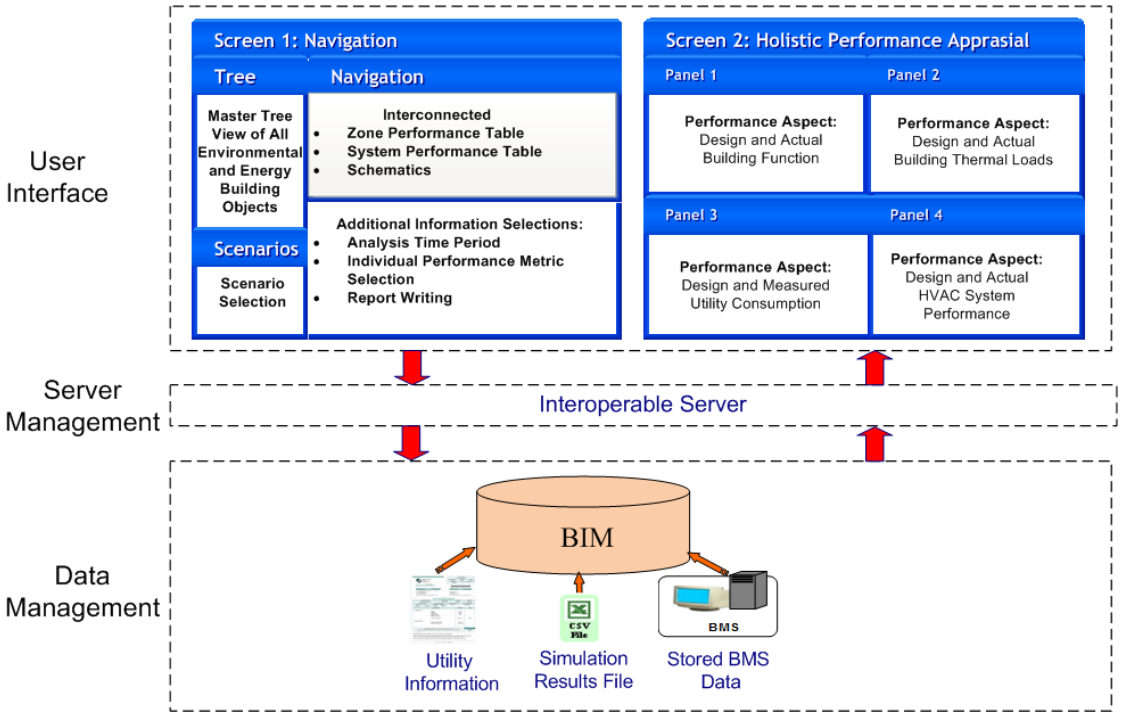


Figure C.1: *Information Delivery Tool: System Architecture*

The implemented framework is designed as a distributed three tier information system to provide flexibility, maintainability, reusability and scalability[2]. The difference between three-tier and two-tier system is the additional layer containing integration logic which enhances interoperability. The resulting performance loss is more than compensated for by the flexibility achieved through this additional tier and the support it provides to the application logic (Mourshed 2006). Tiers or Layers are depicted in Figure C.1 and are data management, process management and user interface.

The core or the bottom layer is the data representation where all project data are stored. IFC (IAI 1995) is the recommended standard for database implementation. The topological logic resides in the process management layer which extracts necessary information from the database and serves the requests from client side applications, otherwise known as domain logic. EDM server is the recommended

[2]More information on a three tier system architecture can be found in (Weijia & Zhou 2004, Langer 2000)

process management tool (EPM 2000). User system interfaces or GUI can either be stand alone or web applications. I recommend a stand alone interface due to the large file sizes typically encountered when using IFC as the data storage medium.

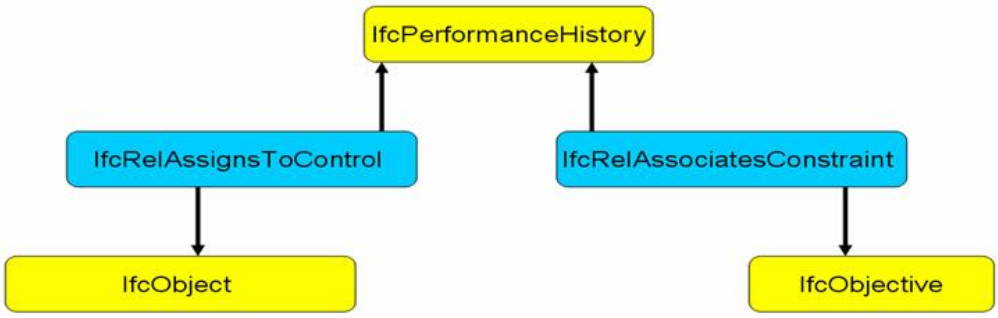


Figure C.2: *Relating Subtypes of IfcObject to IfcObjective Entities (Courtesy of (Morrissey & Hitchcock 2005))*

To date published work does not exist for storing performance history in an IFC based BIM without using IFC proxy objects. However, an informal implementers agreement describes what is required (Morrissey & Hitchcock 2005). Each performance history object should be added to the BIM in accordance with Figure C.2. Raw performance data (measurements, simulation output or utility information) can consume large amounts of data storage (multiples of the BIM). Only links to these data sources should be stored in the BIM and the raw data should be stored externally. The archive contains a pre-defined hierarchical format for referencing simulation output and BMS data which may be stored as CSV files in a database or on-line.

The IFC relationships required for storing links to data sources in an IFC based BIM (Morrissey & Hitchcock 2005) and is illustrated by Figure C.3. An Information Delivery Tool must be capable of accessing the information it needs using the relationships defined in Figures C.2 and C.3.

To populate the BIM with the information needed by a Information Delivery Tool three pre-processes are necessary:

1. Validated CAD Model;

2. Building Systems Information;

3. Energy Performance Archive.

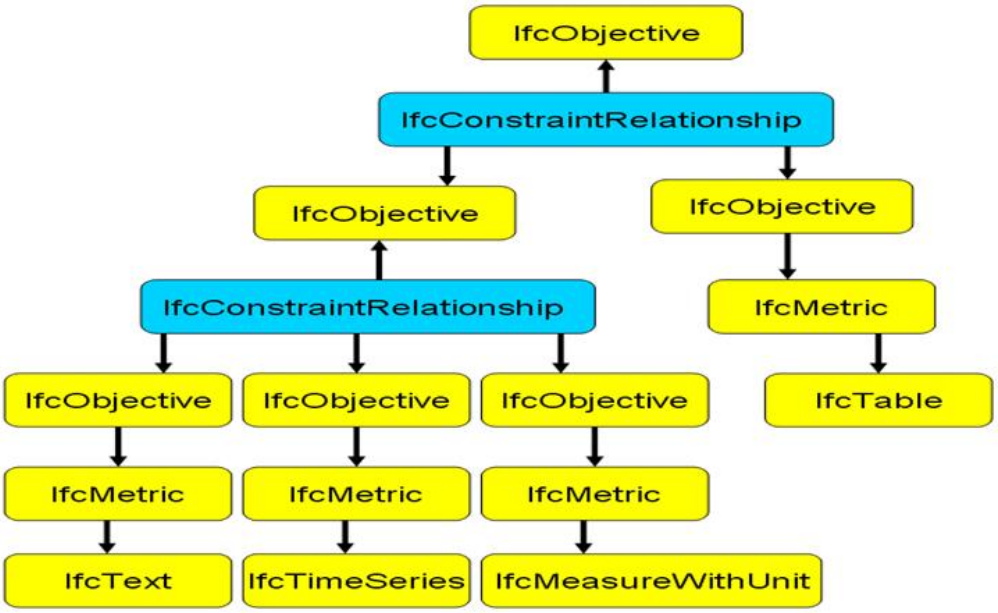


Figure C.3: *A Performance Indicator Hierarchy for a Particular IfcObjective (Courtesy of (Morrissey & Hitchcock 2005))*

Bazjanac (2005), O'Donnell et al. (2004) explain the steps required to define a building in an IFC compliant CAD package and to check the validity of the generated BIM. Traditionally up to 80% of effort in input preparation may be consumed by the definition of geometry, energy simulation requires seamless and automated data transfer from a validated BIM (Bazjanac 2001). To date EnergyPlus is the only IFC compliant energy simulation tool but the automated process (IFC to IDF) is still in Beta testing (IFCtoIDF 2001). When Virtual Building Environments (VBE) become a reality a BIM modeller with a specialised skill set will be required for this task (Bazjanac & Maile 2004)[3]. Bazjanac et al. (2006) states several Tools (Autodesks Revit, Graphisofts ArchiCAD, Nemetscheks Allplan) which may be used to export a non-proprietary description of a building in IFC format (Autodesk 2007, Graphisoft 2007, Nemetschek 2007). Solibri Model Checker is currently the only tool that incorporates checking functionality in addition to routines aimed at other specialist professionals (Solibri 2006).

In addition to geometry a simulation specialist must complete the simulation

[3]A Virtual Building Environment (VBE) is a"place where building industry project staffs can get help in creating Building Information Models (BIM) and in the use of virtual buildings. It consists of a group of industry software that is operated by industry experts who are also experts in the use of that software (Bazjanac & Maile 2004)

model input. Equipment, loads, schedules etc. are input manually or via a separate interface such as design builder or IHIT (O'Sullivan & Keane 2005). An IFC HVAC converter parses the simulation file and adds all relevant HVAC information to the original BIM. To date only one such tool exists, 'IFC HVAC Interface', and is only applicable for EnergyPlus simulation files (Bazjanac & Maile 2004). Presently only the IFC HVAC server is capable of instantiating HVAC components in an IFC file (Maile & O'Donnell 2006).

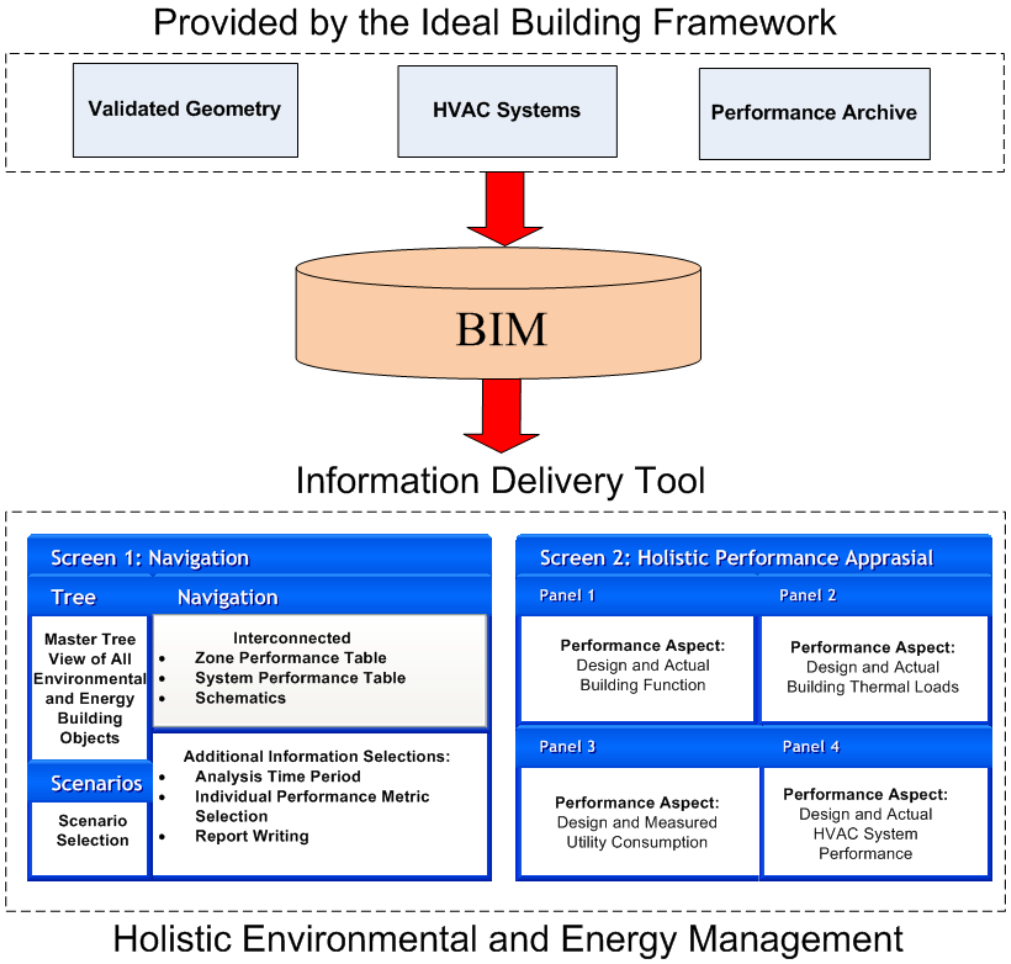


Figure C.4: *Software Environment Required for an Information Delivery Tool*

Proficient storage of qualitative and quantitative sets of information during the design and operation stages is critical and must be considered (Beller 2001). Tracking of performance metrics throughout the BLC has been documented by O'Sullivan et al. (2004b). To achieve this an archive of performance objectives and performance metrics that describe the intent behind the myriad of design and

operations decisions is required. Presently only one performance archiving tool, EArchive, exists (Morrissey 2006*a*). This tool facilitates the archiving of information in an IFC-based BIM by directly interfacing with the IFC file. The principle behind the development of the tool is to assist in documenting the design intent and to ensure an enabling repository for documentation of the design process is provided. This information is generated through the programming of a performance metric combinations (Section 3.6). Performance hierarchies are initially generated during the early design stages and may be revised, deleted or added to as the project progresses. As a result the rationale behind the myriad of design decisions made as a project evolves is archived and documented for subsequent retrieval (Morrissey 2006*a*). Access to the archive is a fundamental requirement of the Energy Manager.

Appendix D

Ideal Performance Objectives and Metrics Set

See CD



Appendix E

Energy Manager and LEED Accreditor Views

See CD

Appendix F

Exchange Requirements: Energy Manager Model View

This appendix outlines the data and information exchange requirements of the energy management domain. Table F.1 contains the entire exchange set in which information is described in an object oriented fashion. Table F.1 comprehensively describes the requirements of Section 6.2. The three categories are:

- Data Exchange Description;
- Data Exchange Object;
- Data Exchange Object Properties;

Table F.1: *Exchange Requirements of the Energy Management Domain.*

Data Exchange Description	**Data Exchange Object**	**Data Exchange Object Properties**
Geometry	*Floor Plans*	
	Walls	
	Windows	
	Doors	
	Roofs	

Data Exchange Description	**Data Exchange Object**	**Data Exchange Object Properties**
	Zones	
	Materials	
	Constructions	
	Building Area	
	Building Volume	
HVAC	*HVAC System*	Corresponds to a Performance Object, See Appendix D
		2-D System Representations
		Relationship to N Components
		Relationship to N Measurement Streams
		Setpoints
		Schedules
	System Components	Corresponds to a Performance Object, See Appendix D
		Relationship to N Systems
		Component Specifications
Scenarios	*Scenario*	Relationship to N Performance Aspects
		Relationship to N Performance Objects
		Relationship to N Performance Objectives
		Relationship to N Performance Metrics
		Relationship to N Measurement Streams



Data Exchange Description	**Data Exchange Object**	**Data Exchange Object Properties**
Performance Aspects	• *Building Function* • *Thermal Loads* • *Energy Consumption* • *System Performance* • *Legislation*	Relationship to N Scenarios
		Relationship to N Performance Objectives
		Relationship to N Performance Metrics
		Relationship to N Measurement Streams
Performance Objects	*See Appendix D for a complete list*	Relationship to N Scenarios
		Relationship to N Performance Aspects
		Relationship to N Performance Metrics
		Relationship to N Measurement Streams
Performance Objectives	*See Appendix D for a complete list*	Relationship to N Scenarios

Data Exchange Description	**Data Exchange Object**	**Data Exchange Object Properties**
		Relationship to N Performance Aspects
		Relationship to N Performance Metrics
		Relationship to N Measurement Streams
Performance Metrics	*See Appendix D for a complete list*	Relationship to N Scenarios
		Relationship to N Performance Aspects
		Relationship to 1 Performance Objectives
		Relationship to Formula, See Appendix D
		Relationship to N Measurement Streams
		Relationship to Unit
Measurements	*Measurement Stream, See Appendix E*	Measurement Stream Name
		Relationship to N Measurement Stream Sources
		Relationship to Data Resolution Level. 1, 2 or 3
		Unit
Measurement Stream Source	*Whole Building Energy Simulation Model Output*	Simulation Model File Name



Data Exchange Description	**Data Exchange Object**	**Data Exchange Object Properties**
		Simulation Model File Location
		Simulation Model Output File Name
		Simulation Model Output File Location
		Unit
		Time Stamp
	Measured Data	Relationship to 1 Sensor or Meter
		Measured Data File Name or Database Entry
		Measured Data File Name or Database Location
		Unit
		Time Stamp
	Utility Provider Data	Utility Provider Name
		Utility Provider Data File Name or Database Entry
		Utility Provider Data File Name or Database Location
		Unit
		Time Stamp
Measurement Devices	*Sensors or Meters*	Co-ordinates
		Relationship to Unit
Units of Measurement	*Units*	kWh
		kW

Data Exchange Description	**Data Exchange Object**	**Data Exchange Object Properties**
		kWh/m^2
		kWh/m^3
		$kWh/m^2/Year$
		%
		Unit of Local Currency
		m^3
		kJ/kg
		PPD
		PMV
		Lux
		^oC
		m/s
		l/s
		People
		ppm
		Tons
		$kgC0_2/kWh$
		Lux/Watt
		Open/Closed
		on/off
		Seconds
		Minutes
		Hours
		Days
		Months
		Years
		kg/hour
		Pa



Data Exchange Description	**Data Exchange Object**	**Data Exchange Object Properties**
		Relationship Unit Conversion: Metric to Imperial
Formula Constant	*Constant Values*	Relationship to N Measurement Streams
		Formula Constant Values
		Relationship to Unit
Reports	*Report*	Report Date
		Report Name
		Report File Name
		Report Location
Rating System Information	*Rating System*	Rating System Name
		Rating System File Location
		Rating System Output File Name
		Rating System Output File Location
		Unit
		Date of Evaluation

Appendix G

Interactive View and Rule Set Methodology

This appendix is an interactive Version of the Model View and Rule Set Methodology as described in Chapter 6. The appendix contains an interactive Microsoft Visio file for interactive investigation of the Automated Process and individual Rule Sets. For individual without access to Microsoft Visio, I have attached a html version of the interactive Automated Process and individual Rule Sets. This website, as it is stored, works best in the Opera internet browser. An installation of which is located in Appendix G on the accompanying CD.

The interactive Automated Process images contain hyper-links to other images and subsets of the individual rule sets. The Rule Sets supported are the Energy Manager, the LEED Accreditor and the Financial Controller. Please not the main Energy Manager rule set image is not clear so it has been separated in half, 'EnergyManagerRuleSet:MechanicalA' and 'EnergyManagerRuleSet:MechanicalB'.

Appendix H

User Interface Considerations

H.1 Chapter Introduction

This appendix contains a background analysis of the following:

- Principles of User Interface Design;
- Semantics of User Interface Specification;
- Current Interface Technology Alternatives.

H.2 Principles of User Interface Design

> *"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 et al. 1996)

Effective user interfaces by their nature must be customised for the end user. Section 2.2 establishes an industry wide profile of energy management personnel. The organisational role, the tools, the techniques and the information used identified the activities of present and future Energy Managers (Chapter 2). Specification of the Ideal Building Framework identifies the interconnected holistic Performance Aspects of the environmental and energy management domain (Chapter

4). The Information Delivery Tool user interface must address these Performance Aspects individually and as part of the whole.

In addition to the established profile and the identified Performance Aspects the case studies also reveal that the Energy Managers at UCC, Pfizer and Intel each used the Microsoft Windows software environment. Intel Energy Management helped develop their own proprietary interfaces and demonstrated extensive IT skills (Geoghegan & Fenner 2007). The Energy Managers at UCC and Pfizer used off the shelf interfaces and were competent in their use. However they only possessed moderate IT and computer literacy skills compared with the Intel Energy Managers.

Three user interface specification criteria were considered for the Information Delivery tool. These specifications reflect the established profile of Energy Managers together with best practice user interface design. These include:

- Heuristic user interface evaluation criteria (Nielsen & Mack 1994);
- Eight Golden Rules of Dialogue Design (Shneiderman 1992);
- Principles and Guidelines in Software User Interface Design (Mayhew 1992).

The Nielsen & Mack (1994) methodology is most appropriate for the established user profile of an individual with moderate IT skills and familiarity with the Windows software environment. However the Interface must be flexible enough to accommodate experienced users through short-cuts (Shneiderman 1992). The following criteria describe the chosen methodology:

1. Simple and natural dialogue;
2. Speak the user's language (based on Energy Manager profile);
3. Minimise the user's memory load;
4. Consistency;
5. Feedback;
6. Clearly marked exits;
7. Short cuts;



8. Precise and constructive error messages;
9. Prevent errors;
10. Help and documentation.

The established user profile and software design criteria form the foundation for specifying the Information Delivery Tool user interface.

H.3 Semantics of User Interface Specification

Shneiderman (2002) determined that two types of software tool offer the potential to assist the Energy Manager - a visualisation tool or a data mining tool. A hybrid approach has not yet been developed for the AEC/FM industry. Extensive domain knowledge is required, in this case a complete understanding of the Ideal Building Framework, to effectively data mine therefore a visualisation approach should be utilised (Shneiderman 2002). The tool interface, using the visualisation approach, must be developed specifically for the established profile of the Energy Manager operating in the Ideal Building.

The absence of a tool that allows an Energy Manager access to holistic building performance information is discussed in Chapter 2. Such an Information Delivery Tool must be capable of fulfilling the requirements of the user as profiled in Chapter 2 and Section H.2. Agarwal et al. (1996) state that only necessary functionality is to to be included in an interface and unnecessary functionality can be inhibitive to some Energy Managers. User selections should be minimised and data processing techniques should be automated (Morrissey 2006*b*). An Information Delivery Tool incorporating only logical, necessary functionality would provide the ability to rapidly access the Scenario and Performance Metric information detailed in Chapter 3.

H.4 Current Interface Technology Alternatives

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). Energy Managers utilising information in the context of the Ideal Building Framework require access to structured display of significant amounts of data. The possible display techniques are set out here.

Research initiatives that have expanded the domain of building performance analysis have been undertaken by Haberl et al. (1996) and Prazeres & Clarke (2003). The former utilises time sequenced graphics for visualising differences between specific data at selected time intervals and conclude that certain HVAC faults can be identified using such techniques. 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 & 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. These include colour, sound, 3-D Animation, virtual reality and alpha numeric data (Prazeres & Clarke 2003). These packages have been effective for their developers but are not commonplace in industry for continuous monitoring of building operation.

The iRoom framework consists of a general, extensible common data model for the central storage of project data that can be in turn distributed among project stakeholders. iRoom is used for the interdisciplinary tasks discussed in project meetings. The hardware and software for interactive workspaces can be used to link the different application models by incorporating the mutual relationships between shared data and can therefore support the decision process through cross-application functionalities. In order to achieve this, the workspace can distribute data between the connected applications (Schreyer et al. 2002).

One such technique is Virtual Reality which has the potential to bring alive a particular domain by providing the user a means for interaction with domain objects. Its usefulness in BS 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 & Clarke 2003).

The various 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 Chapter 2, the tools were not designed for an Energy 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 BMS and simulated output simultaneously. However organising the data to be displayed would be a time consuming process and is not feasible given the established profile of Energy Managers. Other findings include:

- The disconnect between design intent and actual operation is not addressed by any of the referenced tools. Techniques such as 3-D animation, iRoom and virtual reality were dismissed for use by Energy Managers due to the perceived complexity, training time, computer power required and cost.

- Screen resolution needs careful consideration. Holistic performance evaluation cannot focus on localised performance only. The presentation concept initiated is that the Energy Manager should be able to analyse local performance in the context of global building operation (Section 3.5). Therefore a dedicated machine with dual screen functionality is an Energy Manager requirement;

- Time series graphs for differentiating between datum streams is an identified technique. This technique facilitates context sensitive benchmarking between the Ideal performance benchmark and actual operation for all Performance Metrics.



Appendix I

ERI Energy Manager & ERI LEED View

See CD



Appendix J

ERI Prototype Scenario Measurement Streams

See CD