Technical Synthesis Report

A Summary of IEA Annexes 16 & 17

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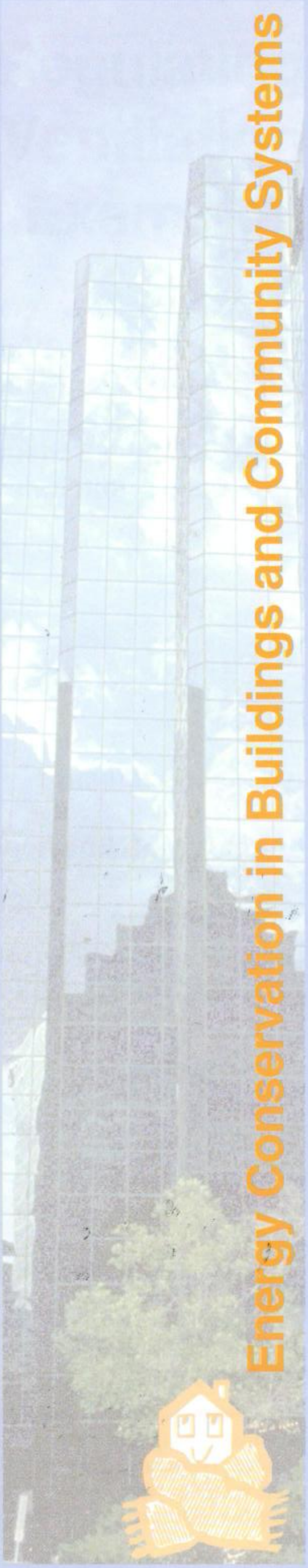
Building Energy Management Systems


Energy Conservation in Buildings and Community Systems

International Energy Agency

Controlling and Regulating Heating, Cooling and Ventilation Methods and Examples

Summary of IEA Annexes 16 and 17

Annex 16 - Building Energy Management Systems (BEMS)
- User Guidance
Annex 17 - Building Energy Management Systems (BEMS)
- Evaluation and Emulation Techniques

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Adapted from:
Styra och reglera värme, kyla och ventilation
Metoder och exempel by Lars-Göran Månsson

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Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-one IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems (ECBCS)

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following have been initiated by the Executive Committee (completed projects are identified by *):

1 Load Energy Determination of Buildings *
2 Ekistics and Advanced Community Energy Systems *
3 Energy Conservation in Residential Buildings *
4 Glasgow Commercial Building Monitoring *
5 Air Infiltration and Ventilation Centre
6 Energy Systems and Design of Communities *
7 Local Government Energy Planning *
8 Inhabitant Behaviour with Regard to Ventilation *
9 Minimum Ventilation Rates *
10 Building HVAC Systems Simulation *
11 Energy Auditing *
12 Windows and Fenestration *
13 Energy Management in Hospitals *
14 Condensation *
15 Energy Efficiency in Schools *
16 BEMS - 1: Energy Management Procedures *
17 BEMS - 2: Evaluation and Emulation Techniques *
18 Demand Controlled Ventilating Systems *
19 Low Slope Roof Systems *
20 Air Flow Patterns within Buildings *

21 Thermal Modelling *
22 Energy Efficient Communities *
23 Multizone Air Flow Modelling (COMIS) *
24 Heat Air and Moisture Transfer in Envelopes *
25 Real Time HEVAC Simulation *
26 Energy Efficient Ventilation of Large Enclosures *
27 Evaluation and Demonstration of Domestic Ventilation Systems
28 Low Energy Cooling Systems
29 Daylight in Buildings
30 Bringing Simulation to Application
31 Energy Related Environmental Impact of Buildings
32 Integral Building Envelope Performance Assessment
33 Advanced Local Energy Planning
34 Computer-aided Evaluation of HVAC System Performance
35 Design of Energy Efficient Hybrid Ventilation (HYBVENT)

Annex 16 BEMS - 1: Energy Management Procedures and Annex 17 BEMS - 2: Evaluation and Emulation Techniques

Annexes 16 (BEMS - 1: Energy Management Procedures) and Annex 17 (BEMS - 2: Evaluation and Emulation Techniques) have been established within the ECBCS Implementing Agreement.

The purpose of Annex 16 was to examine a number of existing computerised control, regulating and monitoring aspects of building energy management systems (BEMS). Their operation in various countries and climates, and also cost reductions were compared with earlier operation without this equipment. The purpose of Annex 17 was to develop the algorithms used in the control and regulating systems. Here, the options for better control and regulation were demonstrated by means of simulations using several different operating strategies. In addition, the purpose of the co-operative project was to use well-described criteria to be able to test the regulating computers in the systems in order to compare the ways in which they worked and to find out by means of real-time simulation whether they met the specifications.

Scope

This report contains a summary of ECBCS Annex 16 “BEMS-1: Energy Management Procedures and Annex 17 “BEMS-2: Evaluation and Emulation Techniques”. It is primarily aimed at building services practitioners, designers and policy makers who require background knowledge of building energy management systems (BEMS). It is designed to be accessible to the non-expert and to give an introduction to the benefits of BEMS, making reference to the full Annex reports whenever necessary.

Contents

1 Introduction

This report summarises the findings of two projects on the application of building energy management systems (BEMS), referred to as Annex 16 and Annex 17. The purpose of Annex 16 was to examine the functions of a number of existing computerised control, regulating and monitoring systems, how these worked in various countries and climates, and the cost reductions that were noted compared with earlier operation without this equipment. This work was divided into six separate areas (shown in Table 1.1).

While in Annex 16 the primary task was to examine existing systems to see how they worked, the purpose of Annex 17 was to develop the algorithms used in the control and regulating systems. Here, the options for better control and regulation were demonstrated by means of simulations using several different operating strategies. In addition, the purpose of the co-operation project was to use well-described criteria to be able to test the regulating computers in the systems in order to compare the ways in which they worked and to find out by means of real-time simulation whether they met the specifications. This work was separated into three different areas (shown in Table 1.1).

Finland, Germany, Japan, Netherlands and the United Kingdom participated in Annex 16, with Oscar Faber Consulting Engineers acting as the Operating Agent. Nine countries were involved in Annex 17: Belgium, Finland, France, Germany, Italy, Sweden, The Netherlands, the United Kingdom and the United States, with Belgium (University of Liège) as Operating Agent. The separate tasks undertaken in Annexes 16 and 17 are listed in Table 1.1.

Participating institutions are listed in Appendix 1, together with their abbreviations. The work is complete and has resulted in 9 reports containing a substantial amount of information. The titles are summarised in Table 1.2 and a brief summary of each report is given in Appendix 2.

This report summarises the findings of Annexes 16 and 17. With such a large body of work, it is impossible to do it full justice in a short summary. It is designed to be accessible to the non-expert and to give the reader an introduction to the benefits of the application of BEMS in buildings and to direct the reader to the full reports where more information is required. Examples taken from the reports are illustrative rather than comprehensive.

1.1 Definition

The IEA has adopted the following definition of a BEMS:

An electrical control and monitoring system that has the ability to communicate data between control nodes (monitoring points) and an operator terminal. The system can have attributes from all facets of building control and management functions such as HVAC, lighting, fire, security, maintenance management and energy management.

Table 1.1 Separate tasks in Annexes 16 and 17

Annex 16		**Annex 17**	
Task	**Lead country**	**Task**	**Lead country**
A. Specifications	United Kingdom	A. Control strategies for air-conditioning systems	Italy
B. Standards	United Kingdom		
C. Profitability	Finland		
D. Sensors	Japan	B. Control strategies for water radiator systems	Finland
E. Case studies, examples	Netherlands	C. Evaluation methodology for control systems (emulators)	Germany
F. User experiences	Germany		

Table 1.2 Source reports

Annex 16: BEMS 1. A User Guide	**Lead**	**Ref.**
Specifications and standards for BEMS	BSRIA, UK	[1]
Cost benefit assessment methods for BEMS	VTT, SF	[2]
A guide to sensors for BEMS	UNg, J	[3]
Case studies of BEMS installations	TNO, NL	[4]
User experiences in BEMS Applications	IDB, D	[5]
Annex 17: BEMS 2. Evaluation and Emulation Techniques		
Evaluation and Emulation of BEMS: Synthesis Report	ULg, B	[6]
Simulation exercise (Residential heating system)	IKE, D	[7]
Simulation exercise (Air Conditioning Systems)	PT, IT	[8]
Development of Evaluation methods	VTT, SF	[9]

1.2 Objectives

The objectives of computerised control, regulating and monitoring systems can be listed as follows:

1. To provide a healthy and pleasant indoor climate
2. To ensure the safety of the user and the owner
3. To ensure economical running of the building in respect of both personnel and energy

2 Building Energy Management Systems

2.1 Background

All systems in a building require some form of control; the simplest on-off switch could be described as energy management. However, the term Building Energy Management System has become restricted to advanced systems using sophisticated computer based controls.

The attribute which sets a BEMS apart from other systems is communication: information on the state of the building's systems can be received at a central operating terminal and control instructions can be transmitted from the operating terminal to remote actuators. The availability of substantial amount of information at the central point allows the application of sophisticated control and operation algorithms to optimise the operation of the building and achieves the greatest efficiency in energy use. Calculations can be automated and displayed graphically so that trends, e.g. in energy consumption, can be viewed simply.

There has been rapid development in the hardware associated with BEMS; sensors, communication highways, and above all processing power have improved greatly. However the algorithms used to control building operations have not been developed at the same rate. While the behaviour of individual subsystems is well understood, the interaction of the subsystems with each other, with the building envelope and with the unpredictable disturbances introduced by the external environment and the users is very complex.

Annex 17 considers aspects of the control algorithms used to optimise energy expenditure and the ways in which BEMS systems may be tested.

BEMS are now widely employed in all types of building. Some of their functional capabilities are listed in Table 2.1 and some of the benefits to be gained are given in Table 2.2.

2.2 Central vs. distributed systems

The first BEMS systems were introduced in the 1960s and consisted of a single central processing unit (CPU) where all executive control was carried out and all system intelligence was based. The CPU polled the sensors to collect information on the state of the building, calculated the required control action and transmitted control commands to the actuators. A central system has the disadvantage that no control action can take place in the event of a communication or CPU failure. In addition, as BEMS systems became more complex and handled functions in addition to heating and air conditioning, the time spent polling the sensors in sequence reduced the speed of operation.

Table 2.1 Some common functional capabilities of BEMS

Automatic switching on and off (e.g. on a time basis)
Optimisation of plant operation and services. Typical application includes balancing of chiller plant to required air conditioning loads and boiler plant timing and scheduling
Monitoring of plant status and environmental conditions
Provision of energy management information
Management of electrical loads
Remote monitoring and control e.g. of plants and services of buildings that are dispersed geographically

Table 2.2 Common benefits from the use of a BEMS

Increased energy efficiency by optimising plant operation and minimising unnecessary use of energy
Improved environmental conditions
Improved standards of plant commissioning and future design
Improved energy management and maintenance of the engineering services e.g. data on energy flows, consumption and overall building performance can enable an assessment of the energy efficiency improvement measures that are desired
Improved fire, security and other emergency procedures
More efficient use of staff by centralising operations

The development of the low cost microprocessor has enabled the concept of distributed intelligence to evolve. Figure 2.1 shows a schematic diagram of a distributed intelligence system; in practice, the design of systems varies widely, but the example shows the essential components, which are listed in Table 2.3.

Local intelligent microprocessor outstations are now capable of performing routine operations on a stand alone basis. This frees the central station from the need to maintain continuous communication with the sensors and actuators. The functions of an intelligent outstation may include time of day control, optimal start/stop temperature compensation, maximum demand and power monitoring, and frost protection. The role of the central control station is to supervise a group of outstations. Communication links are by a common bus. Several bus systems are in use and there are moves towards adoption of a standard communications protocol, which would allow devices from different manufacturers to communicate freely with each other.

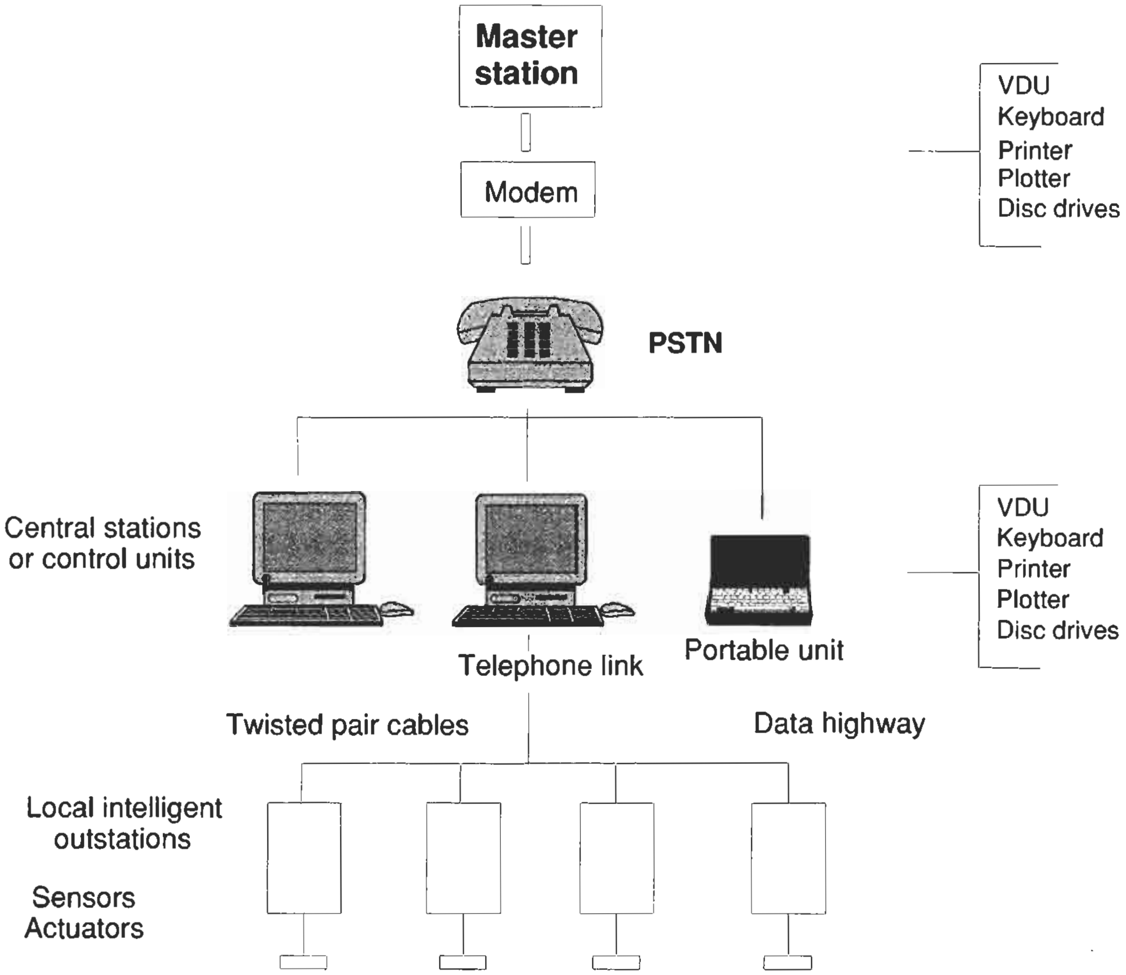


Figure 2.1 Schematic diagram of a distributed intelligence building management system

Table 2.3 Components of a BEMS

Operating station	May include a master station if there are several central stations
Modem	Interface between computer and communications
Communications links	e.g. Public switched telephone network, twisted pair, power line carrier, optical fibre
Sensors	e.g. temperature, humidity, lighting level, smoke detector, security
Actuators	e.g. valves, pumps, lighting, alarms

A bus is characterised both by its hardware, e.g. twisted pair, power line carrier, and by the communications protocol. Discussion is outside the scope of this report; for more details see [1].

With the detailed control functions delegated to outstations, the role of the central control station is now to supervise a group of outstations, Table 2.4. The central station incorporates a visual display unit, keyboard and printer and often incorporates third party software, which deals with energy management and reporting functions.

Table 2.4 Central control station tasks

Contact each outstation at pre-set times for routine reports
Receive information from any outstation to indicate the condition of the plant and display any alarm calls
Allow direct contact with any outstation under command of the operator
Store the control parameters of each outstation and allow changes to be made to the user definable settings
Transfer data to other devices e.g. an off-line processor

3 Control Strategies

3.1 System simulation methods

The task of Annex 17 was to consider the 'software' problems facing the development of BEMS. (The main subtasks of Annex 17 are listed in Table 1.1.)

Several building simulation programs were used in the course of Annexes 16 and 17 and are listed in Table 3.1. The development of systems emulation is dealt with in more detail in Section 4 below. Nine countries participated in the simulation studies. Before the BEMS strategies could be investigated, the participants examined the simulation methods to be used. Participants mainly selected simulation programs TRNSYS and HVACSIM$^+$. These require the availability of subroutines which describe the behaviour of subsystems of the HVAC system. Models were available at the end of a previous IEA project Annex 10 'System Simulation' [14], but it was necessary to develop new models of heating/cooling coil, actuator and controllers.
Reference exercises were then performed with three building systems in order to test the simulation models and to study the simulation method for BEMS control strategy evaluation. The systems used in these reference exercises are typical buildings and HVAC systems already studied in previous IEA projects:

- a residential building with a hydronic heating system

- an office building with the same hydronic heating system

- an office building with Variable Air Volume (VAV) air conditioning system

Most participants used TRNSYS in the simulation studies. Good agreements were found among the results of different participants in the common exercises. It was found that the residential heating system offered little energy saving potential and is not considered further here. Results for the office building studies are summarised in the following section.

Table 3.1 Building simulation models used by participants

Model		Originator	Reference
TRNSYS	Transient System Simulation Program	SEL	10
HVACSIM$^+$	HVAC Simulation Plus Other Systems	NIST	11
GERALT		IKE	12
PIBNET		VTT	13

3.2 Radiator systems

3.2.1 Simulation technique

The behaviour of a conventional radiator heating system installed in an office building was investigated [7]. First the participants compared results for continuous and intermittent heating with fixed start and stop times, to establish confidence in the methods used. Then the savings in heating energy consumption that could be achieved with 'perfect' optimal start were investigated as a function of boiler and radiator sizing. The third part of the investigation evaluated different algorithms that can be used in practice to calculate the optimal start for a heating system in a period of changeable weather.

The office building is a conventional multi-cellular block. Each office room is 5 x 5 m in plan, naturally lit and heated by radiators. The insulation of the building components is consistent with the German Energy Saving Code. A modern high efficiency boiler is used, with flow temperature controlled by a three way mixing valve as a function of external temperature. Room temperatures are controlled by thermostatic radiator valves. The thermal properties of the building and the behaviour of the heating and control systems are modelled in considerable detail.
The simulation period has to be sufficiently long where adaptive control systems are to be evaluated. Data of a German reference month were used; the external dry bulb temperature is around -4 °C for a few days, falls to -16 °C for two days, then moves between 6 and -4 °C for the rest of the month. Overall mean temperature is about 0.5 °C.

Firstly, the participants in the reference exercise calculated energy consumption for continuous heating and for intermittent heating with given start and stop times. Good agreement was found between the participants, with maximum deviation of 6.2% in the continuous case and 3.0% in the intermittent case. The example was therefore accepted for further simulation studies. Much of the simulation in this and other studies was based on the TRNSYS [10], GERALT [12] and PIBNET [13] simulation programs.

3.2.2 Component sizing and optimal start

Savings in heating energy consumption may be made if the heating system is turned on at the latest possible time for the occupied room temperature to reach comfort at the start of the occupation period. The amount of energy saved depends on the power of the heating system; an oversized system will heat up quickly, while a system which can just meet the steady state heat demand will require to run continuously, showing no saving over continuous operation.

The second part of the radiator heating simulation investigated the effect of:

- 4 sizes of boilers,, from 75% to 200% of nominal size
- 2 sizes of radiator, 100% and 200 % of nominal size

In this context it should be noted that the system was designed to the German standard of -12 °C external temperature; the test month had an external temperature of the order of 0.5 °C, with two nights falling as low as -16 °C.

Optimal start times were found by iteration i.e. running the simulation several times while varying the start time for the day of interest until comfort temperature was just reached at the required time. The simulation was then run for the whole month for all combinations of boiler and radiator sizes, both for continuous and optimal start heating; the same heating pattern was used for weekdays and weekends.

It was found that the combination of oversized radiators and boiler caused some room overheating, and this condition was re-run with the radiator thermostats set 1 °C lower. The results are shown in Table 3.2.

Increasing radiator and boiler size allows a later start and lower energy consumption. Energy savings are shown as percentage energy savings compared with continuous operation with nominal boiler and radiator size. Generally the influence on energy saving of boiler size is negligible and that of radiator sizing is slight.

3.2.3 Optimal start algorithms

A practical optimal start controller has to decide on the switch on time from available information on conditions inside and outside the building. The memory and data processing power of a BEMS enables learning algorithms to be used, which accumulate information on the performance of the building to enable better predictions rate of temperature rise.

Table 3.2 Energy saving as a function of boiler and radiator sizing

saving as a percentage of consumption for continuous operation with nominal sizing
LS: thermostatic valves set back by 1 °C

Boiler sizing (%)	75	100	150	200	100	200	200
Radiator sizing (%)	100	100	100	100	200	200	200 LS
Saving (%)	16.5	16.7	17.0	16.9	14.8	14.0	19.6

Three optimal start algorithms were tested in Annex 17 by different participants [7], using the same standard German weather data for February, using Gradient and Recursive Least Squares methods for the algorithms used to calculate the optimal start time.

The gradient method assumes that the rate of temperature rise of the building during heating is linear and is a function of both internal and external temperatures. The controller builds up information in its memory on temperature profiles and uses these to calculate gradients, which are then stored. It is then straightforward to calculate when to turn on the heating to reach the desired internal temperature by the start of the occupancy period. The same method may be used for optimal stop controllers. When setting up a controller it is necessary to use fixed start times for a few days while the controller builds up information on building behaviour.

3.2.3.1 Gradient method optimal start controller

The IKE optimal start control algorithm was developed at the IKE, University of Stuttgart. When tested over 1 month of weather data, it was found that the IKE controller produced errors caused by neglect of the building structure temperature. In a situation where the weather had returned to normal after a cold snap, the structure of the building was cold, requiring longer pre-heat times than provided by the optimal start algorithm.

A possible solution would be to equip the controller with an additional sensor, which would measure the structure temperature. However, this would have the disadvantage of increasing the learning time of the controller.

3.2.3.2 Gradient method with weather forecast optimal start controller

This controller was developed at the Royal Technical High School (KTH) in Stockholm. It works in a similar way to the IKE controller, but operates on a weighted average temperature profile over the last two days; this implies that the time constant of the building is not too short.

Some additional constraints to the control algorithm were found necessary to avoid instabilities. An improvement was effected, by controlling the water flow temperature as a function of the forecast weather temperature. This gave good energy saving and also reduced the amount of time that the occupied zone spent below the lower comfort limit of 19.5 °C.

3.2.3.3 Recursive Least Squares method optimal start controller

This employs the Recursive Least Squares method (RLS) and was developed at the Technical Research Centre of Finland. This also assumes a linear relationship between preheating time and temperature differences between desired temperature and both inside and outside temperature. The parameters are estimated on-line using the RLS technique with an exponential forgetting factor. This makes for simpler programming than the gradient method.

After several days of learning the error in start time reduced to a small value. However, the controller had difficulty in dealing with a cold snap and predicted too short a pre-heat period following a weekend with the heating switched off.

3.2.4 Results

The study of hydronic heating confirmed that simultaneous computer simulation of building, heating systems and BEMS can be a powerful analysis and development method, and confirmed that Optimal Start control is the most important BEMS function for hydronic heating systems. It was demonstrated that the size of the boiler had no influence and the size of the radiators had only a small influence on the energy consumption of a hydronic heating system controlled by a perfect optimal start controller. The three Optimal Start algorithms investigated showed considerable inaccuracies. The RLS method is well suited to BEMS applications because it is easily programmable and does not have large memory requirements. However, in the examples reported, the RLS controller failed to cope well with unheated weekends or cold snaps and showed little improvement in either comfort conditions or energy consumption over a fixed start procedure. The two gradient method OS controllers performed little better. It is proposed that a measurement of the structural temperature would improve performance and it was shown that modulating flow temperature according to a weather forecast improved performance.

3.3 Air conditioning

3.3.1 Reference simulation exercise

The simulation exercise [8] was based on a model of the Collins building, which is an office block situated in Glasgow, Scotland, that has already been monitored and simulated during previous IEA research projects, Annexes 4 and 10. The exercise consisted of a simulation of the Collins building over three periods of 15 days in summer, winter and mid-season.

The building includes three occupied floors. Each floor is divided into two thermal zones: an occupied space and a plenum for return air. The envelope of the occupied zones is completely glazed, while the ceiling voids are surrounded by opaque walls. The HVAC plant is a Variable Air Volume (VAV) system made of a central air handling plant, a primary system and some local units. The central plant consists of a mixing box, filter, heating coil, humidifier cooling coil supply fan and extract fan. Each floor of the building is served by separate ductwork, a reheat coil and a VAV box. The primary system consists of a boiler connected to the heating coils and a chilling system connected to the cooling coil. A schematic diagram of the whole system is shown in Figure 3.1.

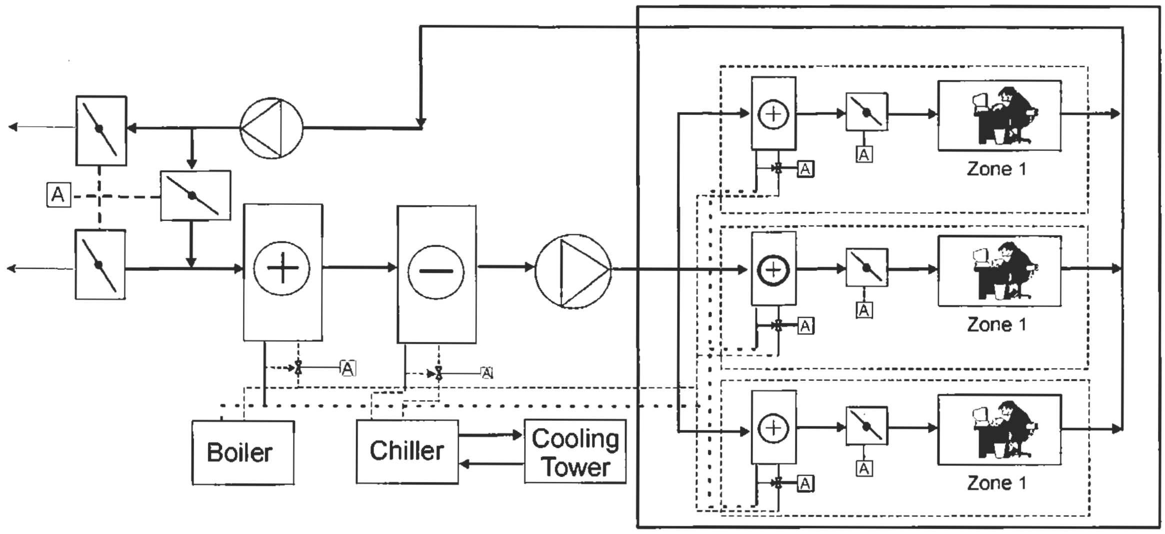


Figure 3.1 Diagram of the HVAC system of the Collins office building

The simulation modelling was carried out using TRNSYS. Annex 10 had produced simulation modules for the components of the system. In addition a supervisory controller was introduced in the system simulation, consisting of a single module whose inputs are the quantities read by the sensors (temperature, relative humidities, etc) and whose outputs are the control functions going to the actuators of the plant controlled devices. The introduction of this control module allows the maximum flexibility in implementing different control strategies.

Five participants (PT, VTT, TNO, IKE, KTH) reported daily results for the three measurement periods. Good agreement was found in the prediction of internal conditions. Most differences occurred when the plant operation was changing operating mode, resulting in unstable conditions; this occurred mostly in summer. There were convergence problems in spring and autumn operation.

The first part of the report concluded that the mathematical models used are quite capable of simulating HVAC components and are useful for the evaluation of control strategies. There were still problems of getting good agreement between different participants, and it is necessary to use the same input and output procedures and take care in the definition of control operation. Four participants undertook further simulation studies. VTT proposed a supervisory control strategy which would optimise total energy consumption while maintaining good indoor climate. Only preliminary results were reported [8], which were inconclusive and are not discussed here.

3.3.2 Case study: Static Pressure Minimisation

This section reports the Static Pressure Minimisation (SPM) algorithm developed by Politecnico di Torino (PT) [8]. It is designed to reduce the fan speed so that the static fan pressure is the minimum possible necessary to meet the requirements of the VAV boxes. The controller was developed as a PI controller with a negative decay term; the SPM controller decay term decreases static pressure at a constant rate, while the PI action increases static pressure when one of the VAV boxes is starved. It is desirable that the action of the SPM fan control be much slower than the VAV box controller and the fan blade controller. The results showed that SPM control produces no appreciable change in room temperature or in plant operating mode. Fan energy consumption is reduced significantly by 38% and overall energy cost savings of 17% are achieved for the simulation period studied. The results are summarised in Figure 3.2. Since the major savings are in fan power consumption, it is concluded that SPM control will be most effective in systems with high design flow rates and in systems employing "free cooling".

3.3.3 Control strategies from IKE

The University of Stuttgart (IKE) investigated the effect of several control strategies on energy consumption; see Table 3.3. Using the simulation programs GERALT with TRNSYS subroutines, they simulated the performance of the Collins building over winter, mid-season and summer periods. The first 9 control strategies deal with operation of the HVAC system and do not directly affect the temperature of the occupied zone. Strategies 10 to 13 operate on the VAV box, which directly controls room temperature, and so may result in changes in room temperature and comfort.

The *zero energy band*, also known as a dead band, is an interval of the controlled variable in which no response from the HVAC system is called for. A *temperature zero energy band* is used in air conditioning to prevent simultaneous operation of the heating and cooling systems.

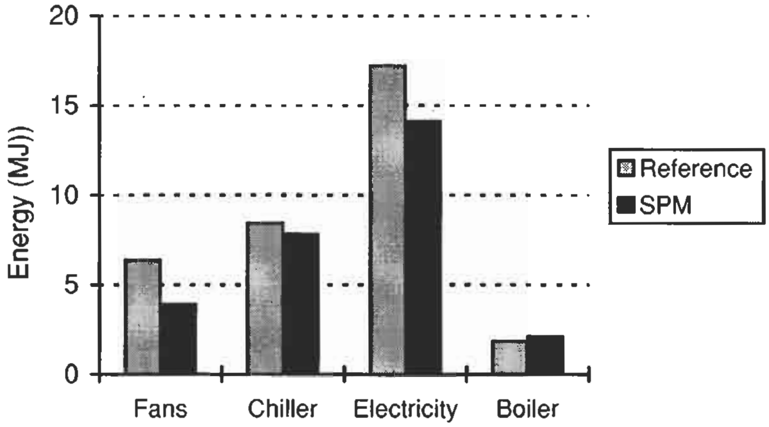


Figure 3.2 Effect of the Static Pressure Minimisation algorithm on the energy consumption of an air conditioned building [8]

Table 3.3 Control strategies evaluated by IKE

	Plant Control
1	Lower external air temperature set point below which heating mode starts
2	Lower external air temperature heating set point and increase set point above which cooling starts
3	Postpone supply air temperature reset
4	Introduce zero energy band for room humidity control
5	Enthalpy control
6	No enthalpy economiser
7	Introduce night ventilation
8	Postpone boiler temperature reset
9	Cases 2,3,4,5,7,8 above
	Room Control
10	Lower set point of the reheat coil in the VAV box
11	Zero energy band of +/-1 °C in room temperature
12	Zero energy band of +/- 2 °C in room temperature
13	Case 9, plus a room temperature zero energy band of +/- 1 °C

3.3.4 Results

The results are summarised in Figure 5.3. The largest savings come from increasing the zero energy band; in spring and summer increasing the band to +/- 2 °C results in energy savings of the order of 25%. However, this inevitably reduces thermal comfort by providing less precise temperature control. In the summer simulation period the average PPD value increased from 10 to 14% on the introduction of the zero energy band.

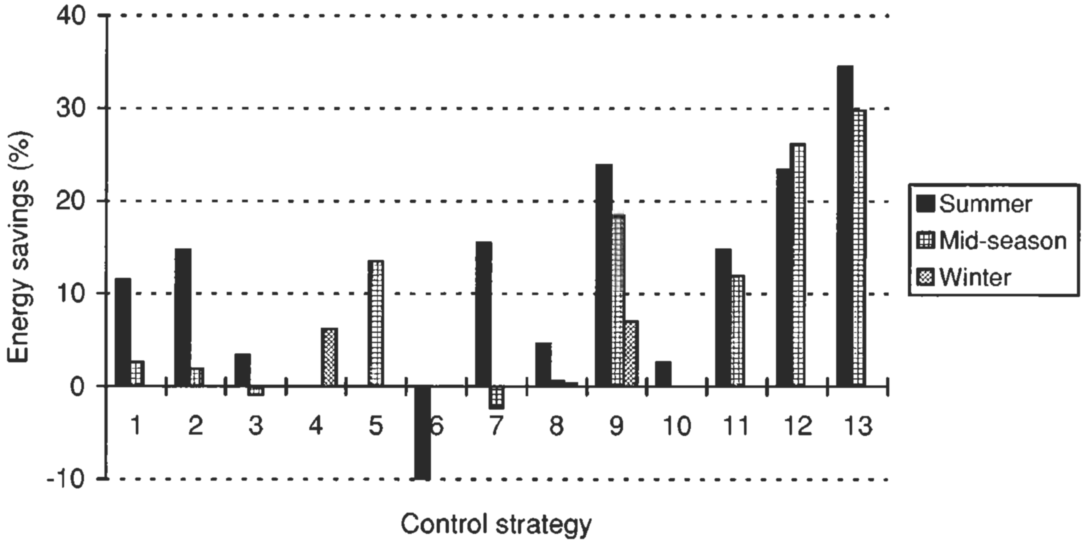


Figure 3.3 Energy saving produced by 13 control strategies investigated by IKE [8]. The strategies are listed in Table 3.3

4 Development of Emulation Methods

4.1 Building emulators

An emulator for a building energy management system consists of a simulation of a building and its HVAC system, which may be connected to a real BEMS. The real BEMS controls the simulated building as if it were real, transmitting control signals and receiving simulated information back as the simulated building responds to its actions. Since an actual BEMS controller is used, with its own time characteristics, it is necessary that the simulated building responds at the same rate as the real building. An emulation run therefore operates in real time e.g. it will take a week to emulate a week's building operation. An emulator can be used to evaluate the performance of a BEMS, for the training of BEMS operators, assisting in the development of new control algorithms and for many other purposes.

An advantage of using an emulator is that a BEMS may be tested with any type of building and HVAC system for which a simulation model is available, and tests can be run on different BEMS under identical conditions. Since a real BEMS is used, it is not necessary to know the algorithms employed by the BEMS, so that products from different manufacturers may be compared without compromising any proprietary information about the control strategies. Prior to the work carried out under Annex 17, few emulators had been built.

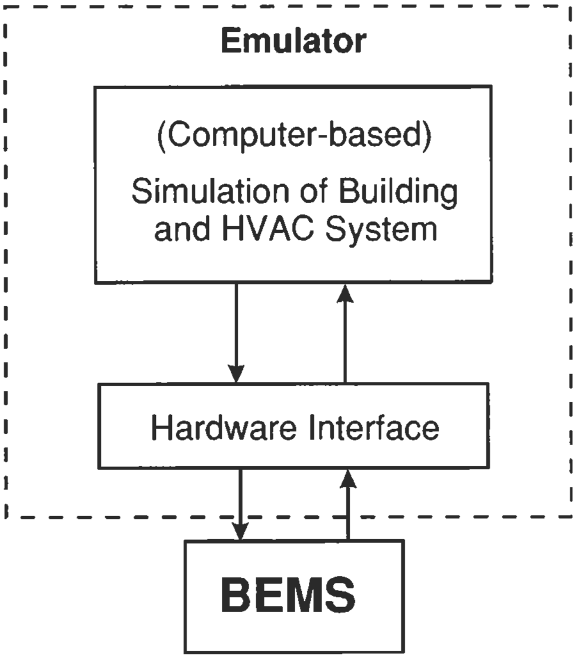


Figure 4.1 A building emulator used for control system evaluation

Figure 61 illustrates the principle of a building emulator. The building simulation model is fundamental to the emulator. As well as modelling the thermal response of the building, the dynamic behaviour of the controls and actuators must be modelled realistically. Two simulation programs were used in the Annex 17 exercises, TRNSYS [10] and HVACSIM$^+$ [11]. Additional software is required to run the simulation in real time. The interface links the real BEMS to the simulation model and converts the numerical input and output of the simulation model to and from the form required by the BEMS, which may be analogue electrical signals or digital according to the BEMS system chosen.

4.2 Annex 17 emulators

Six emulators were developed by Annex 17 participants [9]. The participants took part in exercises to compare and validate the performance of the emulators, and to use the emulators to investigate BEMS control strategies. In order to compare the operation of the emulators, a common building and HVAC system was used. This was chosen to be the Collins building in Glasgow, the same building as used in the air conditioning simulation exercise described above.

Overall performance of a system under investigation can be assessed, by taking into account energy cost, comfort and maintenance cost. Energy cost includes the consumption of electricity, oil, etc converted into currency cost. An overall comfort indicator is calculated as the average Predicted Percentage Dissatisfied (PPD),

Table 4.1 Six emulators

Participant	Computer	Simulation
ULg	386PC	TRNSYS
CSTB	Unix workstation	$HVACSIM^+$
VTT	386PC	TRNSYS
TNO	386PC	TRNSYS
UOx	Unix workstation	$HVACSIM^+$
NIST	25MHz PC	$HVACSIM^+$

calculated from Fanger's comfort equation. Where appropriate an integral of absolute error is used as an indicator of control effectiveness. The number of hourly start/stop/reversals and travelled distance of actuators are chosen as indicators of potential maintenance costs.

The participants performed three common exercises. The first one (C0) was intended to facilitate the construction and commissioning of the emulators. The common exercise C1 required both local loop and supervisory control to be evaluated using a building and plant whose behaviour is representative of an air conditioned office building. The choice of control strategy, its implementation in the BEMS and the timing of the control loops was left to individual participants. Participants in exercise C1 were encouraged to test at least two different BEMS and to vary the evaluation methodology. With the experience of C1, a new common exercise C3 was performed to validate the BEMS emulation method.

4.3 Sample results

4.3.1 Effect of temperature zero energy band

The exercises conducted in Annex 17 generated a considerable amount of information, which is summarised in [6]. Energy consumption in a heating and cooling system may be reduced by specifying a temperature interval in which neither heating nor cooling is supplied. This prevents the simultaneous operation of both systems. However, thermal discomfort may be increased by less precise temperature control.

Figure 4.2 shows the results of varying the temperature zero energy band of the VAV controller of the Collins office building. The simulations were run over 10 hours of June British weather. It can be seen that there is a significant decrease in energy cost as the zero energy band of the room temperature is increased.

Increasing the band also increases the discomfort as measured by the average PPD. However there is no comfort benefit to be obtained in reducing the zero energy band below 2ºC.

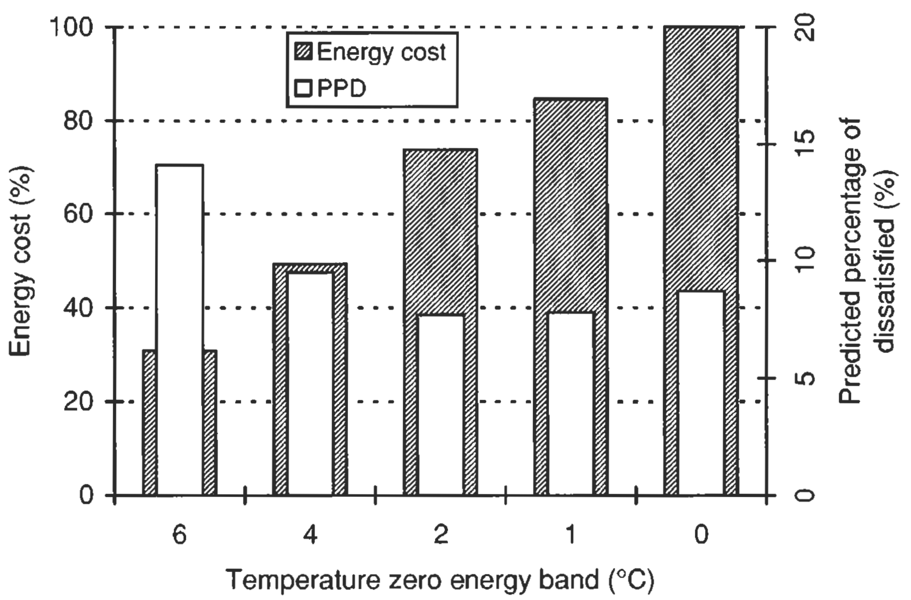


Figure 4.2 The effect of temperature zero energy band width on energy cost and average comfort [9]

4.3.2 Average error

For exercise C3, microprocessor BEMS were supplied by two different manufacturers based in the Netherlands. Three different days were used for the emulation test, a winter day in which the boiler is required to operate throughout the occupancy period, a summer day during which the chiller is required and a spring day that is cold enough for heating by boiler in the beginning of the day and also cool enough of the cooling load to be met entirely by the use of outside air. The same building model was used as before.

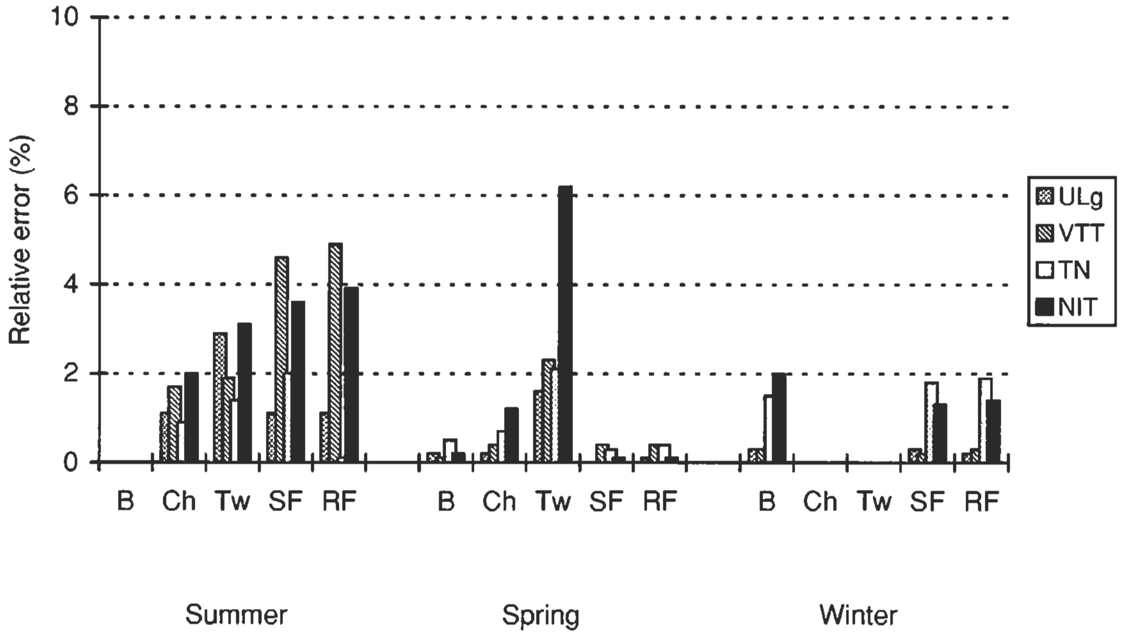
Detailed temperature profiles and energy use were calculated and compared. As an example of the results, Figure 4.3 compares the errors of the calculated energy consumptions. The relative error is defined as the absolute difference between the energy consumption calculated by one emulator and the average energy consumption for all four emulators in the test, expressed a percentage of the greatest average error over the three seasons.

The average error of all the components of the four emulators with BEMS2 is 3%. Note that there is no "true" figure with which to compare the estimates; the emulators are being compared with each other.

4.4 Conclusions of emulation study

The work in Exercise C1 confirmed that the basic idea of evaluating the performance of real BEMS using emulation works well, but that test conditions need to be tightly specified. The comparisons showed that the tests are not dependent on the design of emulator and the choice of simulation program; the agreement between the results of different participants was acceptable. Careful calibration of sensor and actuator signals is required to achieve accurate results. In addition, when using short period tests the initial conditions have a notable influence on the results. In brief, emulators can be used to:

- Inspect or examine the software and hardware of the control and regulating systems
- Assess the structure, control strategies and algorithms of the control and regulating systems
- Fine-tune the pre-set values
- Train and teach operating personnel



B Boiler Ch Chiller Tw Cooling tower SF Supply fan RF Return fan

Figure 4.3 Comparison between the results of four participants when comparing the emulation of controller BEMS2 [9]

5 Sensors

Sensors are a vital component of any BEMS system. One of the Annex 16 tasks was to draw up a guide to the selection of sensors; this task was carried out by a Japanese working group and is reported in [3]. The report stresses that sensor selection can not be done in isolation; the choice must take into account both the system which is to be controlled and the nature of the control system and its algorithms.

The sensor must of course produce an output that is compatible with the input of the measurement circuitry. The sensor must also have suitable response characteristics, providing a suitable speed of response for both the measured variable and the control algorithm. For instance a sensor must have sufficiently fast speed of response to ensure that the necessary control action is taken in time; however a very sensitive sensor may provide nuisance action on short-term transient inputs.

Care must be taken over the relation of the sensor to the physical quantity being measured; air temperature may vary considerably over an occupied room, so that placement of the sensor is critical to satisfactory operation. The report summarises the stages in sensor selection as follows:

- Select each sensor with all aspects of its intended purpose in mind.
- Assess whether or not a complete space can be satisfactorily represented by measurement made at a single point.
- Consider carefully whether there are disturbing influences present which may affect the accurate operation of the sensor, such as temperature, humidity, radiation, vibration, contamination, electromagnetic fields, etc.
- Special attention should be paid to the long-term reliability of integrating sensors, since errors are accumulated over time.
- Pay special attention to the maintenance aspects, which vary considerably among types of sensor.

With the falling cost of electronics, there is a growing tendency to incorporate signal processing within the sensor itself, to produce the so-called intelligent sensor. Intelligent sensors offer some or all of the following characteristics:

- signal processing within the sensor, including automatic calibration and compensation,
- detection and exclusion of abnormal values,
- built in control algorithms,
- memory,
- communication capability, offering direct linking to a communication bus,
- combination of several measured variables to produce an index.

The report goes on to consider a very wide range of sensor types, from snowfall detection to urinal flushing, from earthquake sensors to flue gas detection. Several case studies are given to demonstrate the process of sensor selection. The importance of considering the control software when choosing the most appropriate sensor is stressed throughout the text. Most of the sensors considered are used throughout the participating countries. However, there are variations between different national regulations, particularly with respect to fire detection and prevention.

6 Cost Benefit Analysis

6.1 Objectives

A comprehensive BEMS system represents a substantial investment, which is expected to bring a variety of benefits. In order to make a rational design over the level of investment to choose, it is necessary to have some method of comparison between alternative systems. Cost benefit methods of analysis have been developed by economists which aim to express all costs and benefits associated with a plan of action in common units, i.e. money, and to make rational comparisons between plans which may have different size and time scales. One important principle is that the benefits and costs must be expressed from a single point of view e.g. better indoor air quality may be beneficial to the office worker in terms of health and comfort and it may produce a benefit for the office tenant in terms of increased productivity. However, neither is a direct benefit for the building owner, who may be able to achieve the benefit in increased rent. Cost benefit analysis is most straightforward where the building owner, operator and employer are the same. Where they are not, it must be borne in mind that the organisation receiving the benefit of a reduction in energy consumption may not be the organisation that installed the BEMS.

The Annex 16 task on Cost Benefit Assessment Methods for BEMS [2] set out to produce a coherent analysis procedure which could be used by the participating countries to calculate savings from BEMS and to make investment decisions. After discussions with the participants, the report concluded no single model would become accepted; the more common methods of analysis are given in the report and summarised below. More important than the method chosen is the ability to provide good quality input data, particularly where it is necessary to compare different types of costs and savings e.g. investment cost vs. productivity gain.

6.2 Cost and benefits

The report recommends that a detailed listing is prepared of the cost incurred and the benefits expected from the BEMS. A detailed list assists estimation and comparison between alternative systems. Table 6.1 summarises the suggested headings, which may be expanded into considerably more detail.

Estimation of energy saving requires a reference norm against which the savings are to be compared. A control system cannot in itself save energy, in the way that improved thermal insulation reduces the energy requirement of a building. A good control system reduces waste rather than reduces energy requirements. In a modern office building, staffing costs dominate over energy costs. The benefits of improved staff utilisation may therefore outweigh the savings in energy consumption. The report quotes estimates which state that the benefits of an intelligent building in terms of energy savings, increased productivity and reduction in building management costs are roughly equal; put another way, this means that the overall benefits of a good BEMS may be three times the direct saving in energy consumption. Another rule of thumb quoted is that an overall productivity improvement of 2.5% would be enough to pay for the entire BEMS system.

Table 61 Listing of costs and benefits

First cost	Specification & design Hardware Software Installation, commissioning Training
On-going costs	Maintenance Communication costs Staffing
Benefits	Savings in energy costs Savings in staffing costs Better maintenance and fault detection Improved productivity

6.3 Assessment methods

The report considers several assessment methods, which are all to be found in standard economic texts, e.g. [15]. It is emphasised again that good quality data is important, and that the costs and benefits should be assessed from the same standpoint.

6.3.1 Net cash flow

Cash flow analysis is the basis for all other cost benefit analyses. For a number of periods, typically yearly, the costs and benefits of the investment opportunity are written down. The total period may extend up to the expected life of the investment. Thus the cash flow table shows both the total costs and benefits and when they are expected to be achieved.

6.3.2 Payback method

The payback period is commonly defined as the length of time to recover the initial investment from the benefits produced by that investment; no account is taken of interest rates. Using the cash flow table described above, the net cash flow is accumulated. The year in which the total benefits equal the total cost is the simple payback period. i.e. it is the time after which the investment cost is repaid. There are several variants on the payback period and it is important to state which one is used when making comparisons.

For instance, the payback period calculated by dividing the initial cost by the annual benefits does not take into account the initial period e.g. construction phase, during which no benefits are received. In general the payback period fails to consider the time value of money i.e. the value of money to be received in the future is less than that of money received now, nor does it consider what happens after the payback period, e.g. the magnitude and timing of the cash flows.

The payback method tends to favour shorter-lived investments. Acceptable values of payback period vary with the type of organisation. Typically, payback periods of 3 years or less are required by industry and up to 10 years by Government projects.

6.3.3 Discount techniques

There are several discount techniques, all of which use a discount rate in the calculations, reflecting the time value of money. The Present Worth method is typical; also known as Net Present Value. All future amounts in the cash flow table are discounted back to the start of the project. The discount rate may be thought of as the return available on money from other investments; 10% is typically used. With this method of analysis, it is possible that an investment which shows a positive net cash flow after a few years may show a negative present worth; the implication is that it would be more profitable to invest the money elsewhere. Related methods include Future Worth and Internal Rate of Return.

6.4 Results

Economic assessment methods of cost benefit analysis are well established. The IEA report [2] summarises the methods and also give detailed examples of analysis for buildings submitted by participants. It is emphasised that the main difficulty is in assessing and quantifying the benefits to be achieved from the BEMS. Table 6.1 is reproduced from Appendix B of the report and shows estimates of the payback periods associated with the major control functions of a BEMS. It must be emphasised that these are rough estimates only and that the savings from different BEMS control functions are not additive.

7 Case Studies

7.1 Summary of case studies

Part of the brief of Annex 16 was to study examples of actual BEMS installations in participating countries. The work was reported in [4] and is briefly summarised here. The reports were intended to inform the reader on the possible applications of energy management and to illustrate the use of BEMS in a range of building types. The range of buildings studied was wide, covering a range of size and complexity of installation. Most of the buildings studied were offices, but there were also examples of large systems which linked together a number of disparate buildings under common administration. Table 7.1 summarises the studies. When considering the case studies, it must be remembered that the report was issued in 1991, and that most of the installation studies were commissioned in the mid-1980s. The available technology of BEMS has developed greatly since then. However, the basic principles of a distributed BEMS system were then well established and many of the lessons are still relevant.

Table 7.1 Rough estimates of payback periods by control function

Function	Payback (years)	
	Conventional	BEMS
Scheduling	*	>3
Optimal start/stop	<2	<2
Room temperature reset	<3	<3
Single room control	>2	>3
Zone control	>2	>2
Demand limiting, fuel	<2	<2
Load shedding, electrical	>3	<1
Duty cycling	<3	<2
Temperature economiser	<2	<2
Enthalpy economiser	<2	<2
Supply air reset	*	<3
Water temperature reset	NA	>4
Zero energy band control	<3	<2
Hygrostat control	<3	<2
Boiler optimisation	>3	>3
Chiller optimisation	NA	<3
Lighting control	>4	>3
Automatic blind handling	>5	>3
Compressed air generation control	<1	<1
Heat redistribution with heat pump	NA	>5
Warm water storage and heat reclaim	>6	>5

The examples vary greatly in type and complexity. For example, the heating systems in the UK schools project were relatively simple. An outstation in each school provided optimal start/stop control, coupled with time and type of day control. The outstations were controlled and monitored from a central station via the conventional public switched telephone network. Energy consumption was monitored over a pre-installation season and two seasons following installation. The scheme was considered successful, with a simple payback period of 2.9 years and improved management. In contrast the three Japanese offices described in [4] represent state of the art intelligent buildings of the mid-1980s. The KI building in Tokyo included, among other things, optimising control of an ice storage system, monitoring of internal comfort conditions including IAQ, automatic control of solar control blinds and lighting levels and peak lopping of electrical power consumption.

Since the three Japanese buildings were new, there was no previous experience on which to base payback systems. However, all reported low levels of energy consumption and satisfactory operation of the BEMS.

Table 7.1 Systems investigated

Country	**Business**	**No of bldgs**	**Area (m^2)**	**Date of buildings**	**% saving energy, (electricity)**	**Pay back (yrs)**	**Ref**
Finland	Office	1	13 000	1986		2.8	[4]
	Apartments	1	30 000	1986		3.8	[2]
	Apartments & offices	60 5	200 000				[4]
Japan	Business centre	1	120 000			1.9	[2]
	Offices	1	52 000			5.2	[2]
	Offices, lab	1	4 000	1982		10	[2]
	Office	1	75 000				[4]
	Office	1	30 000				[4]
	Office	1	9 000				[4]
Netherlands	Hospital	1	60 000		20	1.5	[4]
UK	Bank	50	400-7 800	1800-1985	27 (8)	7.8	[4]
	Schools	50	3 000-10 000	1900-1985	16	3	[4]
Germany	Offices	4	17 000		40 (16)	5	[4]
	Various	22	500-14 000	1950-	10 - 20	1	[4]

Ref [2] deals primarily with the economic aspects, while ref [4] with system description

7.2 Example: Dual Energy Management System Schwandorf

One case study is described here in greater detail as an example. It has been chosen because it illustrates the ability of BEMS to integrate the energy management requirements of a number of disparate building types dispersed over a large area.

Schwandorf is a rural district in Bavaria, Germany. In 1985 it was decided to set up the Dual Energy Management System Schwandorf (DEMSS) project, which would connect 22 public buildings to a network with the objective of reducing energy and operating costs. The system is called “Dual” because energy management strategies are applied at different levels in the system:

- local control functions at plant level with adaptive control,
- control via terminals at the larger buildings e.g. hospitals,
- control and analysis at the central intelligent facility.

Figure 9.1 gives the schematic layout of the system. Information is exchanged bi-directionally to and from the various sites and the operating centre:

- data and fault messages from the sites
- operating commands, set point adjustment, maintenance instructions, etc to the sites.

The design of the extended system, which encompassed a wide range of equipment and building types, was not without difficulties. Special attention had to be paid to reliability of operation in the event of a communication break down, since the technical staff qualified to deal with control problems are located in the operations centre. First results have been very encouraging, with schools showing a reduction in energy consumption of the range 10 to 20%.

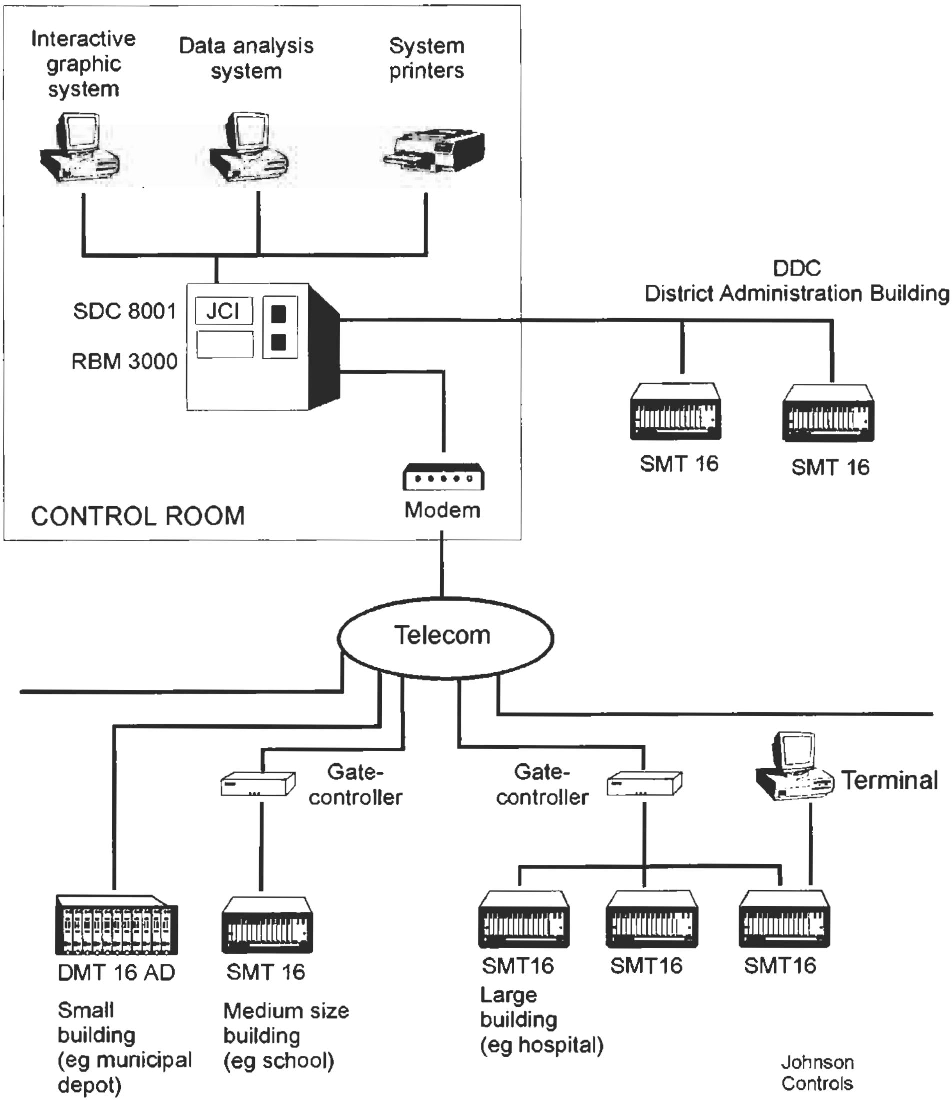


Figure 7.1 Diagram of the BEMS facility in Schwandorf

In addition, the improved load factors of plant operation make for greater energy efficiency and reduced emissions, together with extended lifetime of the equipment. This is helped by improved maintenance and more rapid reporting of fault conditions. During normal operation, the 22 buildings will be operated by a single part time energy manager, showing a considerable reduction in personnel costs.

8 User Experience

8.1 The survey

As part of Annex 16, an international audit exercise was conducted to survey the experience of users of BEMS systems. The results have been reported in [5]. Manufacturers, consultants and users in Finland, Japan, the United Kingdom and Germany filled in a comprehensive standardised questionnaire, detailing their views on system of which they had experience. 33 system audits were performed, representing 49 buildings. In addition 8 interviews with manufacturers and 8 interviews with consultants were made.

Table 8.1 summarises the range of BEMS types included in the survey. The buildings were predominantly offices, representing 23 out of the 49 buildings surveyed. The next category was hospitals, with seven buildings. Other building types represented included shops, factories and sports halls. Systems from 20 different manufacturers were included. The largest number from any one manufacturer was four systems.

Table 8.1 Classification of BEMS systems in the user survey

Category	Description	Number
A	Central minicomputer, dumb outstations	8
B	Multiply connected minicomputers, dumb outstations	3
C	Central minicomputer, intelligent outstations	10
D	Multiply connected minicomputers, intelligent outstations	3
E	Centralised PC based system	5
F	Decentralised PC-based system with DDC outstations	0
G	Stand-alone DDC system	1
Z	Combination of above	2
X	Miscellaneous	1

The sample is not large enough to be statistically significant and is not truly representative, since it is biased by the willingness of the respondents to contribute information. There was a surprising lack of information about energy consumption. The respondents were also asked to rank the function of a BEMS in order of importance: see Table 8.2. All the functions mentioned were considered to be important, but there were differences. Reduction in staffing costs was considered by users to be much more important than by consultants. Conversely, consultants considered the provision of good thermal comfort to be second only to reduction in energy costs, while the users placed it well down the list.

It was interesting to observe that the users had not always checked the extent to which they had derived financial benefits from their investment in BEMS. Since most of the systems were installed in new buildings, it was not generally possible to make before and after comparisons of energy savings. Only four complete before and after surveys were available, which produced the high figure of 27% savings.

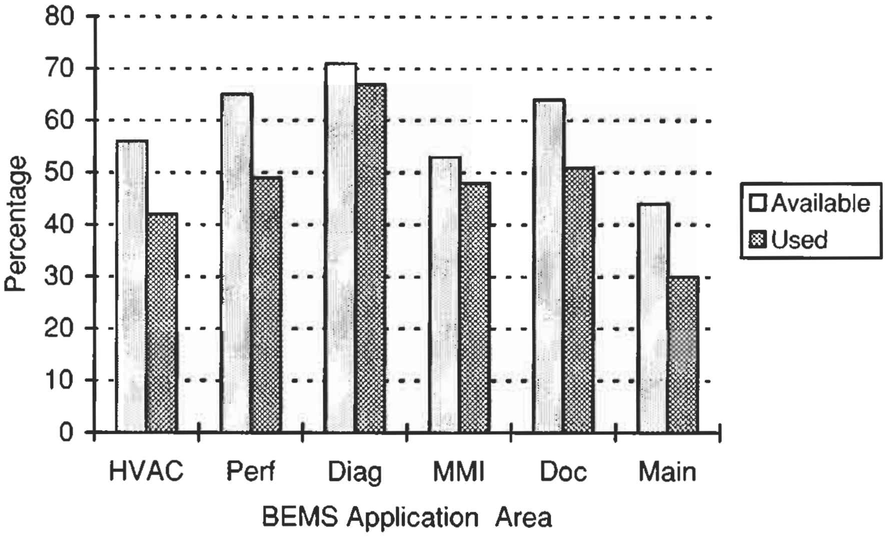
The report considers savings of 15 to 30% to be more realistic for the general case. Cost information was obtained. Care should be taken when interpreting cost data, since the figures are derived from a small sample taken over several different countries; no adjustments have been made for inflation.

Aggregating all the respondent buildings together, the mean density of information points was one point per 12 m^2 of floor area, with a gross average installed BEMS cost of 370 ECU/point. A typical ratio of BEMS cost to the total building and HVAC cost was 1.5%. On average, the annual running costs for operation and maintenance of the BEMS systems were 3.1% of the original BEMS investment, whether the system is operated from within the building or is linked to an operating centre. The 33 systems were analysed in respect of their installed functions and the functions actually used in practice. Figure 8.1 shows that almost a quarter of the functions installed were not used, either because the system had been fitted with functions that were not required, or because the functions were too difficult to use.

Table 8.2 Ranking of BEMS objectives by users and consultants

Function	Users	Consultants
Functionality of HVAC system	1	3
Energy saving	2	1
Reduction in staffing costs	3	7
Reduction in maintenance costs	4	4
Reduction in downtime	5	4
Thermal comfort	6	2
Good air quality	7	6

However, it took between three and four years for staff to learn all about the system so that all functions could be properly utilised. Not surprisingly there was a strong correlation between the BEMS problems encountered and the degree of overall satisfaction Most of the users (70%) reported a degree of satisfaction of 66% or more, while 30% were more or less content with the system. The most disappointed user reported only 12% satisfaction. The survey showed that conventional types of BEMS caused the least problems; see Figure 8.2. BEMS type A are considered to be representative of the older conventional type and Type C to represent modern practice at the time of the survey.



HVAC	HVAC control	Perf	Energy performance	Diag	Diagnostics
MMI	Interface, usability	Doc	Documentation	Main	Maintenance

Figure 8.1 Reported use of BEMS functions in user survey [5]

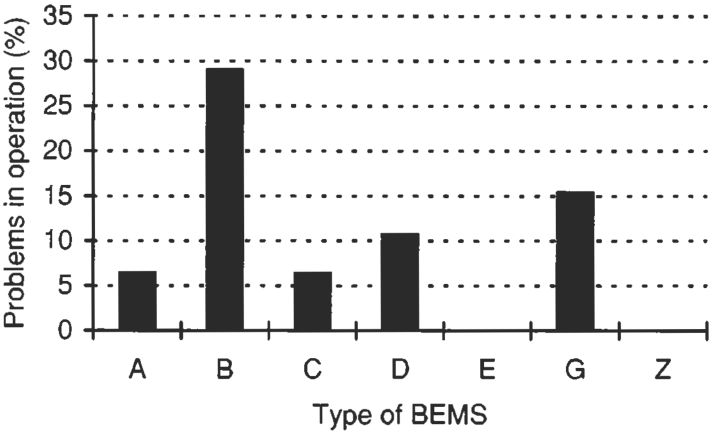


Figure 8.2 Problem frequency related to type of BEMS [5]. The types of BEMS in the survey are listed in Table 8.1

Systems with distributed intelligence at the supervisory level (Types B and D) tend to cause more problems, though the number in the survey is limited. There is a clear tendency for the number of operating problems to reduce when staff are better qualified or have received more training. From this, it can be concluded that a system cannot be expected to run itself. The number of problems is reduced when extensive and detailed documentation is provided and when staff are given thorough training.

8.2 Conclusions of survey

More than 50% of the BEMS installers or users noticed problems in one or more of the phases of design, commissioning or operation.

As an average, 70% of the users declared themselves satisfied with their systems. Common problem areas were the more sophisticated control or operation strategies, the object specific software adaptation, user programming, as well as poor documentation and training offered by the manufacturers.

Only in four cases were energy savings reported to have resulted from the installation of a BEMS.

The decision to install a BEMS is mainly based on consideration of how to operate a large complex system; energy savings and other motives are important, but secondary.

The highest degree of integration of non-Energy management functions as well as the highest density of instrumentation was reported from Japan.

To make the best use of a BEMS, a considerable investment in time and training courses of operating personnel is required.

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Appendix 1 Participating Institutions

List of institutions and abbreviations		
	Institution	Location
BSRIA	Building Services Research and Information Association	Bracknell, UK
CSTB	Centre Scientifique et Technique du Bâtiment	France
IDB	Ingenieurbüro Dr Brendel	Frankfurt, Germany
IKE	University of Stuttgart	Germany
KTH	Royal Institute of Technology	Stockholm, Sweden
NIST	National Institute of Standards and Technology	Washington, USA
OF	Oscar Faber	St Albans, UK
PT	Politecnico di Torino	Italy
SEL	Solar Energy Laboratory, University of Wisconsin	USA
TNO	TNO Building and Construction Research	Delft, The Netherlands
ULg	University of Liège	Belgium
UNg	University of Nagoya	Japan
UOx	University of Oxford	UK
VTT	Technical Research Centre of Finland	Espoo, Finland

Country	Name and *organisation*	National representative	Expert
Annex 16			
Finland	R Kohonen, *VTT*	x	
	J Hyvärinen, *VTT*, M Hermunen, *Duocon Oy*		xx
Japan	N Nakahara, *Univ. of Nagoya, Dept. of Architecture*	x	
	Y Tanaka, *Takenaka Co*; E Iwama, *Tokyo Gas*; H Tomisawa,		xxx
	Y-Johnson Control; H Kurata, *Sumitomo Co*; M Kitano, *Omron Tateishi El.*		xx
	Co; S Hayakawa, *Y-Honeywell Co*; T Aratani, *Hochiki Co*; K Matsumoto, T		xxx
	Fujimura, W Inokuma, *Inst. Building Energy Conservation*		xx
Netherlands	Henk Nicolaas, *TNO*	x	
United Kingdom	E M McKay, *Oscar Faber*	Operating Agent	
	R Grey, M K Mathews, A Teekaram, *BSRIA*; D Joseph, *Merlin Gerin Ltd*		xxxx
Germany	Thomas Bendel, *Ing.büro Dr Bendel*	x	
	W Stephan, M Madjidi, H Bach, *Univ. of Stuttgart*		xxx
	R Braschel, H Ast, *IFB Planungsgruppe*; P Fischer, *Honeywell GmbH*		xxx
Canada, observer	J D Lindsay, *Canadian Std Ass*		x
USA, observer	S T Bushby, *NIST*		x

Country	Name and *organisation*	National representative	Expert
Annex 17			
Belgium	Jean Lebrun, *Univ. of Liège*	Operating Agent	
	G Liebecq, P Nusgens, S Wang, *Univ. of Liège*		xxx
Finland	Reijo Kohonen, *VTT*	x	
	J Hyvärinen, S Kärki, K Katajisto, P Laitila, *VTT*		xxxx
France	Jean-Christophe Visier, *CSTB*	x	
	D Caccavelli, E Hutter, H Vaezi-Nejad, *CSTB*; C Henry, M Jandon, *Gaz de France*		xxxxx
Italy	A Mazza, *Politecnico di Torino*	x	
	V Corrado, *Politecnico di Torino*		x
Netherlands	H Nicolaas, *TNO*	x	
	H Peitsman, J B C v d Kruk, H Brouwer, *TNO*		xxx
United Kingdom	P Haves, *Oxford Univ.*	x	
	A L Dexter, *Oxford Univ.*		x
Sweden	L Göran Olsson, *KTH Installationsteknik*	x	
	P Blomberg, *KTH Installationsteknik*		x
Germany	W Stephan, *Univ. of Stuttgart*	x	
	M Madjidi, *Univ. of Stuttgart*		x
USA	G Kelly, *NIST*	x	
	J Seem, C Nesler, J Braun, *Johnson Control*		xxx

Appendix 2 Publication Summary

Annex 16 and 17 Summary Report

Månsson L.-G., *Styra och reglera värme, kyla och ventilation Metoder och exempel,* Swedish Council for Building Research, Stockholm, Sweden, ISBN: 91-540-5719-1, 1995 (in Swedish).

Annex 16. Building Energy Management Systems: A User Guide

Five reports were published under Annex 16, and are summarised briefly below. They can be purchased from:
ECBCS Bookshop, c/o AIVC, Unit 3a, Sovereign Court, University of Warwick Science Park, Sir William Lyons Rd, Coventry, CV4 7EZ, United Kingdom,
Tel: +44 (0)1203 692050, Fax: +44 (0)1203 416306, Email: bookshop@ecbcs.org

Specifications and Standards [1]

Specifications and Standards for BEMS by A.J.H Teekeram, and R.W. Grey.

Part I: Specifications. Part I provides guidance which will be useful to users and consultants in writing a BEMS specifications. Practices differ among countries and the report summarises specifications documents in use in the five participating countries: UK, Finland, Japan, Germany and the Netherlands. The report goes on to cover the important early stages of a project before specifying starts. Guidance in compiling a BEMS specification is given, with example clauses. The report also gives the full contents lists of specification documents in use in the participating countries.

Part II. Standards for BEMS. The second part of the report starts with a review of the current (1991) status of standardisation of BEMS in each of the participating countries. The state of development of the following standards is summarised: FND, PROFIBUS, BACnet, BATIBUS ; fuller descriptions are given in Appendices. The next chapter lists Standards, Guidelines and Codes that may be applicable to a BEMS project. The report concludes with a list of useful addresses and the IEA Glossary of BEMS terms.

Cost Benefit Assessment Methods [2]

Cost Benefit Assessment Methods for BEMS by J. Hyvärinen.

The benefits of a BEMS are realisable in different forms e.g. saved energy, reduced manpower, more favourable tariffs. The aim of cost benefit analysis is to express all costs and benefits in common financial terms, to allow the best investment decision to be made. It is concluded that no common model could be developed from practices in the participating countries. Instead, the report discusses the principles of analysis and presents the most commonly used models. The report emphasises that the reliability of the results depends more on the quality of information used in the assessment than on the method chosen. The report sets out the economic principles involved and describes the simple payback method, Net Present Value methods and the Vector Diagram method. The simple payback period is the most commonly used method, but is most suitable for schemes with a rapid return on investment. Where the period is over 3 years, more detailed methods should be used. The report gives guidance on listing all relevant costs and benefits throughout the lifetime of the project and gives detailed case studies from the participating countries.

Sensors [3]

A Guide to Sensors for BEMS by N. Nakahara.

The report gives a comprehensive listing of all types of sensor that find application in buildings; the application is not restricted to HVAC, but extends to all fields of building services, including fire and security. Throughout the report, the importance of the control software in influencing sensor selection is stressed; a sensor should not be selected independently of the control system it serves. The main body of the report consists of five chapters dealing with different categories if building services. Each gives guidance to the selection of control systems and sensors. Emphasising the procedures to be followed. A final chapter details nine case studies which illustrate sensor selection for a variety of situations.

A separately issued Appendix gives details of the international survey of sensor applications carried out as part of the study, together with references and bibliographies on sensor application.

Case Studies [4]

Case Studies of BEMS Installations by H. Nicolaas.

The report describes 10 case studies drawn from the UK, Finland, Japan, Germany and the Netherlands. A common reporting format was used and the systems described cover a wide range of schemes, including relatively simple heating only school buildings, a widely dispersed group of local authority buildings, and advanced single office buildings. The schemes were generally successful, though the need for training is emphasised. Most of the schemes described date from the mid 1980s.

User Experience [5]

User Experiences in BEMS Applications by Th. Brendel and A. Schneider.

The report describes the methods and results of an international audit programme of buildings equipped with BEMS. 33 site audits were performed in 1990, representing 49 buildings in four countries. In addition, interviews were carried out with manufacturers and consultants. The findings are discussed in some detail, with the following conclusions:

The main reasons quoted for installing BEMS is the need to operate large complex systems; energy saving and other motives were important, but secondary. Payback periods of over 10 years were accepted. As an average, 70% of the users declared themselves satisfied with their systems. More than 50% of the installations had problems at some stage. Common problems were the more sophisticated control and optimisation strategies, software provision, poor documentation and training. The need for experience and training of operating personnel is stressed.

Annex 17 BEMS Evaluation and Emulation Techniques

Four reports were published under Annex 17, and are summarised briefly below. They can be purchased from:

ECBCS Bookshop, c/o AIVC, Unit 3a, Sovereign Court, University of Warwick Science Park, Sir William Lyons Rd, Coventry, CV4 7EZ, United Kingdom,
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Synthesis report [6]

Synthesis report. Evaluation and Emulation of BEMS by J. Lebrun and S. Wang
This document gives a summary of the work described below from references [7,8,9]. It gives a complete set of references to the interim reports issued under Annex 17. The report briefly describes the simulation methods and concludes that they are a powerful method of development of BEMS control strategies. There is little discussion of the strategies themselves.

The report then summarises the six emulators constructed under Annex 17. An emulator is a computer simulation of a building and its HVAC system, together with an interface which allows it to be connected to an actual BEMS system and behave as if it were a real building. The different emulators produced comparable results and it is concluded that an emulator provides a very attractive testing approach for a real BEMS under simulated 'real' working conditions. Emulators can be used for evaluation of control strategies, controller pre-tuning and for the training of operators.

Residential Heating Systems [7]

Simulation Exercises A2 (Residential Heating System) by M. Madjidi.

Computer simulation of a building, systems and BEMS is shown to be a powerful analysis and development tool. Optimal Start (OS) is the most important function for BEMS in the control of hydronic heating systems. This report uses computer simulation to investigate OS algorithms in a residential and an office building equipped with hydronic heating systems. It is shown that the size of boiler has no effect and the size of radiator only a small effect on the energy consumption of a hydronic heating system controlled by an optimal start controller.

Different practical OS algorithms were evaluated: the recursive least squares method and two versions of the gradient method. All showed inaccuracies, due to the linear approximation of the preheat time. The gradient method fails to compensate fully for the thermal inertia of the building. A possible improvement is to add a sensor which measures the structure temperature; this should improve prediction in periods of changeable weather.

Air conditioning systems [8]

Final report: Collins building simulation exercises (Air conditioning systems) by V. Corrado, A. Mazza, S. Karjalainen, K. Katajisto, P. Laitila, W. Stephen and L. G. Olsson.

This report contains the thermal simulation of a commercial building fitted with a VAV air conditioning system. The first part of the report compares the simulation results of the common exercise carried out by the participants. This demonstrated that existing mathematical models are quite capable of simulating building and control systems. In order to get good agreement between different users, it is necessary to use the same input/output procedures and the control system parameters must be carefully defined. A standard procedure is also required to combine energy and comfort considerations when evaluating control strategies.

The second part of the report presents particular studies on control strategies. The Static Pressure Minimisation strategy controls fan speed to produce the minimum pressure necessary to meet the requirements of the VAV boxes. This can produce significant reductions in fan energy consumption. Another study investigated the effect of 13 variations on the control strategy, producing energy savings of up to 30%. The main point is that the method of investigation has been proved. It is emphasised that the achieved savings cannot be generalised to other buildings and are only valid for the case investigated.

Emulation methods [9]

Development of Emulation Methods by S Kärki.

An emulator is an artificial system which acts externally like a real system. An emulator for a BEMS consists of a simulated building and its HVAC system connected via an interface to a real BEMS. The simulated building responds to the control outputs of the BEMS and the computer model feeds back the appropriate sensor signals. Emulators are suitable for use in testing, product development, training, tuning control equipment and imitating fault conditions.

The report presents a collaborative research effort under Annex 17. Six emulators were constructed in different countries, using different hardware and software. Their performance was compared in a series of tests. In general agreement was good, but there is a need to ensure systematic initialisation of the systems at the start of a test run and for well defined calibration procedures.

Overall, the experience of performing the exercise showed that the emulation method is a very convenient method for BEMS performance evaluation. The agreement of the test results shows the emulation method is also a reliable testing method for BEMS.

The International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems Programme (ECBCS)

The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Co-operation and Development (OECD) in 1974, with the purpose of strengthening co-operation in the vital area of energy policy. As one element of this programme, member countries take part in various energy research, development and demonstration activities. The Energy Conservation in Buildings and Community Systems Programme has sponsored various research annexes associated with energy prediction, monitoring and energy efficiency measures in both new and existing buildings. The results have provided much valuable information about the state of the art of building analysis and have led to further IEA sponsored research.

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