International Energy Agency

Integral Building Envelope Performance Assessment

Technical Synthesis Report
IEA ECBCS Annex 32

Energy Conservation in Buildings and Community Systems

Integral Building Envelope Performance Assessment

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Annex 32 Synthesis Report based on the final reports of the project.
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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-four IEA participating countries and 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

The IEA sponsors research and development in a number of areas related to energy. The mission of one of those areas, the ECBCS - Energy Conservation for Building and Community Systems Programme, is to facilitate and accelerate the introduction of energy conservation, and environmentally sustainable technologies into healthy buildings and community systems, through innovation and research in decision-making, building assemblies and systems, and commercialisation. The objectives of collaborative work within the ECBCS R&D program are directly derived from the on-going energy and environmental challenges facing IEA countries in the area of construction, energy market and research. ECBCS addresses major challenges and takes advantage of opportunities in the following areas:

- exploitation of innovation and information technology;
- impact of energy measures on indoor health and usability;
- integration of building energy measures and tools to changes in lifestyles, work environment alternatives, and business environment.

The Executive Committee

Overall control of the program 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 projects have been initiated by the executive committee on Energy Conservation in Buildings and Community Systems (completed projects are identified by (*)):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)

Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HEVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx)
Annex 38: Solar Sustainable Housing
Annex 39: High Performance Insulation Systems
Annex 40: Building Commissioning to Improve Energy Performance
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (COGEN-SIM)
Annex 43: Testing and Validation of Building Energy Simulation Tools

(*) - Completed Annexes

This summary report concentrates on Annex 32: Integral Building Envelope Performance Assessment.

Annex 32: Integral Building Envelope Performance Assessment

A good envelope design should be the result of a systematic approach, checking all relevant elements. A new approach to consider the building and the envelope quality is the "performance concept". The performance of an envelope includes all aesthetic and physical properties to be fulfilled by that envelope, integrated into the function of the building as a whole.

The objective of Annex 32 was to develop a methodology for performance assessment that will support the integral design and the evaluation process of building envelopes, with the aim of realising significant energy saving along with environmental and indoor comfort benefits.

Although the envelope in itself is a crucial element for the overall performance of the building, the interaction with other building components, and the climatic control systems are of equal importance. Therefore, the emphasis of the Annex was on the overall performance of the building seen from the perspective of the envelope. While the focus is on energy efficiency, a high quality was aimed at with respect to aspects such as durability, comfort, acoustics, moisture, etc.

The work of the Annex was divided into two principal Subtasks:

Subtask A: Development of a comprehensive assessment methodology, including performance criteria, leading to a rational strategy for optimising building envelopes, based on an integral performance approach.

Subtask B: Testing and evaluating the developed methodology by applying it on selected case studies. The case studies are ranked in three thematic groups: retrofitting, advanced envelopes and performance testing, concentrating on both evaluation and improvement of design tools, assessment methodology, performance criteria and practical experience.

The countries participating in Annex 32 were Belgium, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, the Netherlands, USA and the UK. The Annex 32 Operating Agent was the University of Leuven, Laboratory of Building Physics, Belgium.

Scope

This report contains a summary of the work of Annex 32, the formal duration of which was from 1996 to 1999. The report is mainly based upon the principal Annex 32 project reports listed under References.

CONTENTS

1. Introduction

The exterior envelope of a building has a major effect on the heating and cooling loads required to maintain a satisfactory interior environment and, in consequence, on the energy consumption of the building. In addition to its influence on energy consumption, the building envelope also plays other roles. For instance, the amount of glazed area affects the level of satisfaction of occupants through the availability of daylight and view. The overall aesthetic impact of a building is largely determined by its façade. In setting out to develop a systematic approach for the assessment of the exterior envelope, Annex 32 recognised that it would be necessary to consider all of the functions of the envelope and not solely those that directly concern energy efficiency.

Further, the assessment of the envelope cannot be considered separately from other aspects of the building, such as its use and the installed building services, nor can it be dissociated from the wider context of the building stock as a whole. Therefore, Annex 32 recognised that an integrated approach would be necessary and two principal objectives were set:

The development of a comprehensive performance assessment methodology leading to rational strategies for the evaluation and optimisation of envelopes with respect to their physical, environmental and energy-related qualities, based on a fitness for purpose approach.

The application of the methodology to advanced envelopes, traditional envelope solutions and retrofit with an emphasis on design, evaluation, optimisation, control, laboratory testing and field demonstration.

The first of these objectives, developing the methodology, is summarised in Sections 2, 3 and 4 while Sections 5 and 6 deal with the application of the methodology to existing and advanced envelope solutions respectively.

2. Holistic Perspective

2.1 Introduction

A necessary first stage in the development of an integral assessment methodology is to bring together the requirements of all of the stakeholders concerned with a building, ranging from society at large to the occupants, and, together with economic considerations, to link these requirements to the design and construction process. Figure 2.1 illustrates this matching process which is not solely concerned with building technology but also the context within which that technology will be used. It provides a sound basis for optimising the building in relation to its intended use within available financial resources.

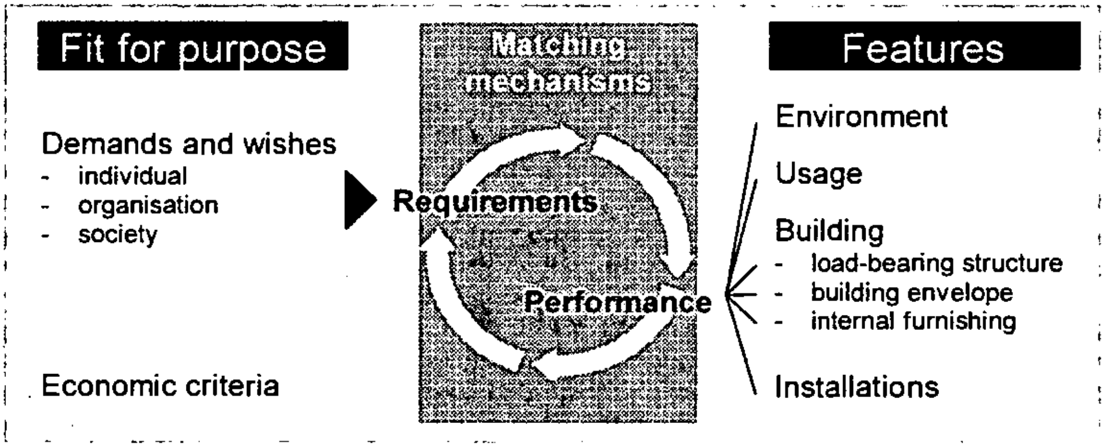


Figure 2.1 Matching requirements to performance

2.2 Building Stakeholders

Very often the design and construction of buildings is undertaken solely from the point of view of the supplier. The requirements of the end-user, the effect of the building on its immediate environment and its impact on broader areas of consideration such as the environment and energy use often receive limited consideration. The guiding principle of Annex 32 was that the building should be 'fit for purpose'. This places the emphasis on customer requirements rather than benefits to the supplier. Three hierarchical categories of customer may be identified

(a) Society

Buildings, through their location, design and function influence both their immediate surroundings and broader societal aspects such as population movement, cultural development and the use of resources.

(b) Organisation

The building and its facilities should enhance the primary function of an organisation that occupies it. Considerations will include the performance targets for the organisation and the image that the organisation may wish to project.

(c) Individual

Individual requirements will depend upon activities being undertaken but will include a safe, healthy and comfortable environment and an appropriate social climate.

The requirements of these customers need to be integrated together and then 'translated' into appropriate building solutions. It follows that good communication between interested parties is essential at all stages of the building process and Annex

32 paid particular attention to methods and tools aimed at promoting a high level of mutual understanding and opportunity to influence the process.

2.3 Economic Criteria

In parallel with the requirements set out above it is necessary to consider the financial and economic implications of a building. These go beyond just the first cost of construction or renovation and include the following:

(a) Capital cost

This includes all of the factors that contribute to the capital cost of the building to the developer or owner.

(b) Operating costs

These include costs such as those for cleaning, maintenance, utilities and energy.

(c) Business costs

Direct building-related costs tend to be only a small part of business costs, in comparison to other aspects such as salaries. However, the building environment may introduce hidden costs (or benefits) due to its effect on the productivity of an organisation.

(d) Societal costs

A building has an impact on its social and physical environment. The use of non-renewable resources in the construction or use of a building may result in non-reversible changes to the environment and to eco-systems. This may not always be possible to cost in financial terms but can represent a loss to society.

2.4 The Transaction Model

In order to describe the complex, interacting processes which are required to match supply and demand at all stages in the design and construction of a building, Annex 32 adopted the concept of the 'transaction model' which can be applied at the level of both the building stock and individual buildings. The model aims to identify and clarify the often very different interests and activities of the various stakeholders and to integrate these in such a way as to optimise the final solution. The clear identification of the various interests also enhances collaboration and creativity.

Figure 2.2 shows schematically the way that the transaction model approach applies at building level.

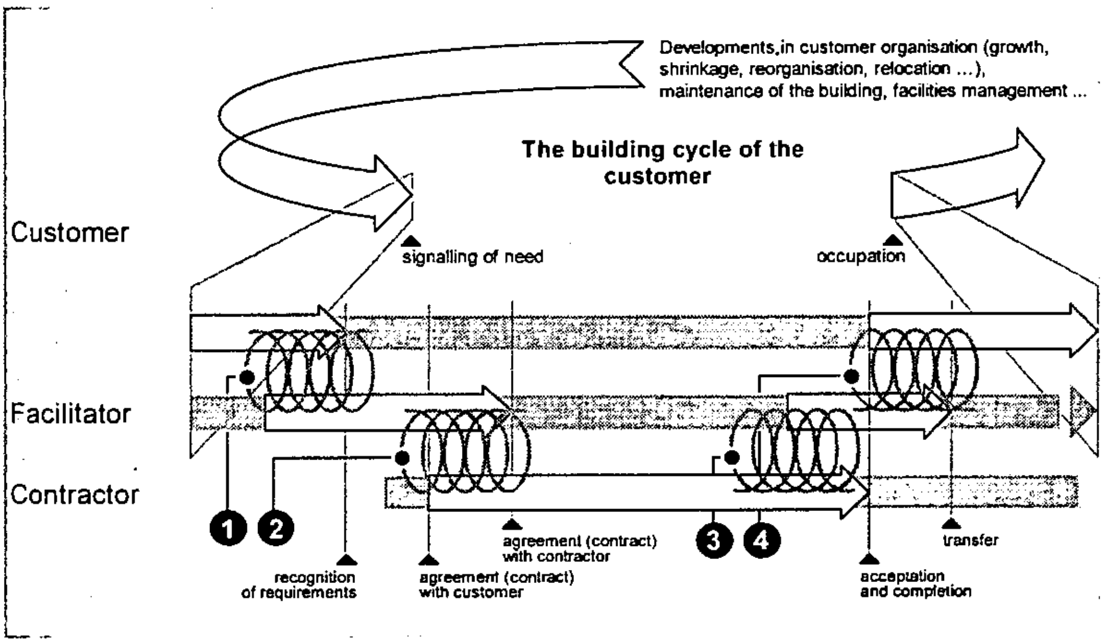


Figure 2.2 Essential transactions in the design and construction of buildings

The key transactions, numbered 1 to 4 in Figure 2.2 may be summarised as follows:

1. Initiation: Development of the functional requirements, taking into account relevant codes, standards and customer needs.

2. Translation: The translation of the functional requirements into a fully-developed, integral clients brief, with an indication of possible solutions such as a new building, retrofitting an existing building etc.

3. Assessment: Matching the financial budget and the brief to available buildings or the completed new building and assessment of performance of proposed solutions against the client's brief, including risk analysis and consideration of life-cycle factors such as maintenance, facilities management and sustainability.

4. Evaluation and use: This includes commissioning, transfer of building to the customer, user instructions, identification and remediation of problems.

The work of Annex 32 was concerned principally with transactions 2 and 3, while acknowledging their relationship to transactions 1 and 4. At building level, transaction 2 and 3 involve (i) the setting of requirements and (ii) the development of assessment methodologies and design tools.

2.5 Project Management

The design and construction of a building is often regarded as an idealised linear, sequential process, with a clear set of decisions and actions resulting in a target – the completed building. The aim of good project management is to steer this process and to make best use of the resources available. In reality, the process is not capable of such clear definition, with the target developing as the process proceeds. The transaction model is well suited to overcoming some of the problems associated with a more traditional approach. These include;

- Phases that are too detailed and sequential for practical application. In practice some activities encompass several phases.

- Phases that do not include a clear definition of some essential transactions, focussing too much on target attainment than target development.

It follows, that an appropriate knowledge be introduced into the process at the correct time. In relation to transactions 2 and 3 at building level, this involves setting requirements, developing assessment methodologies and identifying tools for design, construction and maintenance scheduling.

Overview of the main REN-QS aspects

FUNCTIONAL QUALITY

				score QSR
1 LOCATION	2 accessibility	1 car		
		2 public transport		
	3 facilities and amenities			
	5 parking	1 parking own premises		
2 BUILDING	1 flexibility	2 horizontal-constructive		
		3 adjustability		
		4 unit size/sub-division		
		6 fitness regarding adaptability of working areas		
	2 main access/entrance of building			
	4 integral accessibility			
	5 floor load			
	6 communications	1 cable infrastructure	1 wall cable ducts	
			2 connecting cable ducts	
			3 cable ducts on horizontal catwalks	
			4 central, vertical cable ducts	
	9 amenities	1 sanitary		
		2 other		
3 WORKPLACE	1 internal environment	1 thermal comfort	1 in summer	
			2 in winter	
		2 lighting	1 daylight and view	
			2 light intensity and blinds	
		3 air quality		
		4 acoustics	1 external noise entering	
			2 internal sound-proofing	
		5 operational comfort	1 installations and blinds	
			2 windows to be opened	
		6 blinds		

SPATIAL-VISUAL QUALITY

		score
1 LOCATION	2 standing surrounding area	
2 BUILDING	2 identity	
	3 finish of exterior	
3 WORKPLACE	1 finish of interior	

Figure 3.1 Functional classification questionnaire (from [1])

3. The Integral Client's Brief

3.1 Introduction

At the building level the first step is to establish the functional requirements. This involves a dialogue with the client to establish such factors as the purpose of the organisation occupying the building, its business processes and any likely future developments. A systematic approach is required to identify the levels of importance of particular aspects. Figure 3.1 illustrates one such approach. This is an extract from the methodology developed in the Netherlands [1]. It provides a means by which the client can communicate his requirements in the form of a rating score for a wide range of building attributes. The same approach can be used in relation to a potential building design. The results of both can then be compared in a matching process with the intention of achieving a consensus.

While for small projects it may not be necessary to go beyond this simple approach, for most projects which involve new construction or substantial changes to existing buildings a much more detailed brief will be required. This involves the use of functional descriptions.

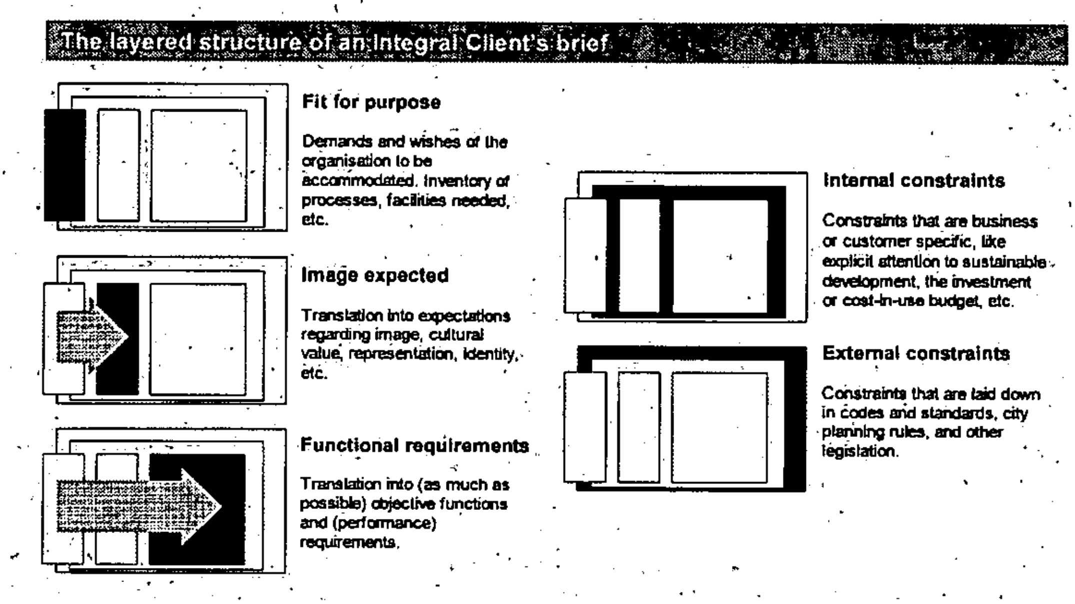


Figure 3.2 The layered structure of the client's brief

Figure 3.2 shows, schematically, the relationship of the various components that contribute to developing the integrated client's brief. The starting point is a clear understanding of the needs of the organisation to be accommodated, linked to the required image. This is then translated, as far as possible, into objective performance requirements. The process is limited by internal constraints, such as budgetary restrictions, and external constraints, such as codes, standards and planning requirements.

3.2 Functional Descriptions

Using a structure developed by the Netherlands Building Agency a detailed set of functional descriptions was developed within Annex 32. A summary of the principal headings is included in Appendix 2. A more detailed explanatory version is included within reference [2]. These functional descriptions form the basis for drawing up the client's brief. They provide a structure to facilitate communication between the various stakeholders throughout the design and construction process, as well as forming the basis for development of performance requirements.

3.3 The Matrix

The client's brief matrix sets out the links between the functional requirements and two key aspects of the design and construction process;

- process phasing and
- knowledge domains.

These are discussed below. The table is necessarily extensive and is given in detail in reference [2]. An extract for illustrative purposes is shown in Figure 3.3.

The functional requirements are given on the left hand side of the table. On the right hand side are two columns dealing with process phasing and knowledge domains.

Process phasing. This follows traditional project management approaches and is separated into a number of stages:

- Initiation
- Definition/feasibility study
- Design/preliminary design
- Design/final design
- Construction documents
- Construction
- Use/service and maintenance

The importance of these stages in relation to any component of the functional requirements is shown by an indication of the nature of the decision-making required, using a simple colour code marking:

- Preparation for decision
- Decision ('go' or 'no go')
- Verification of decision

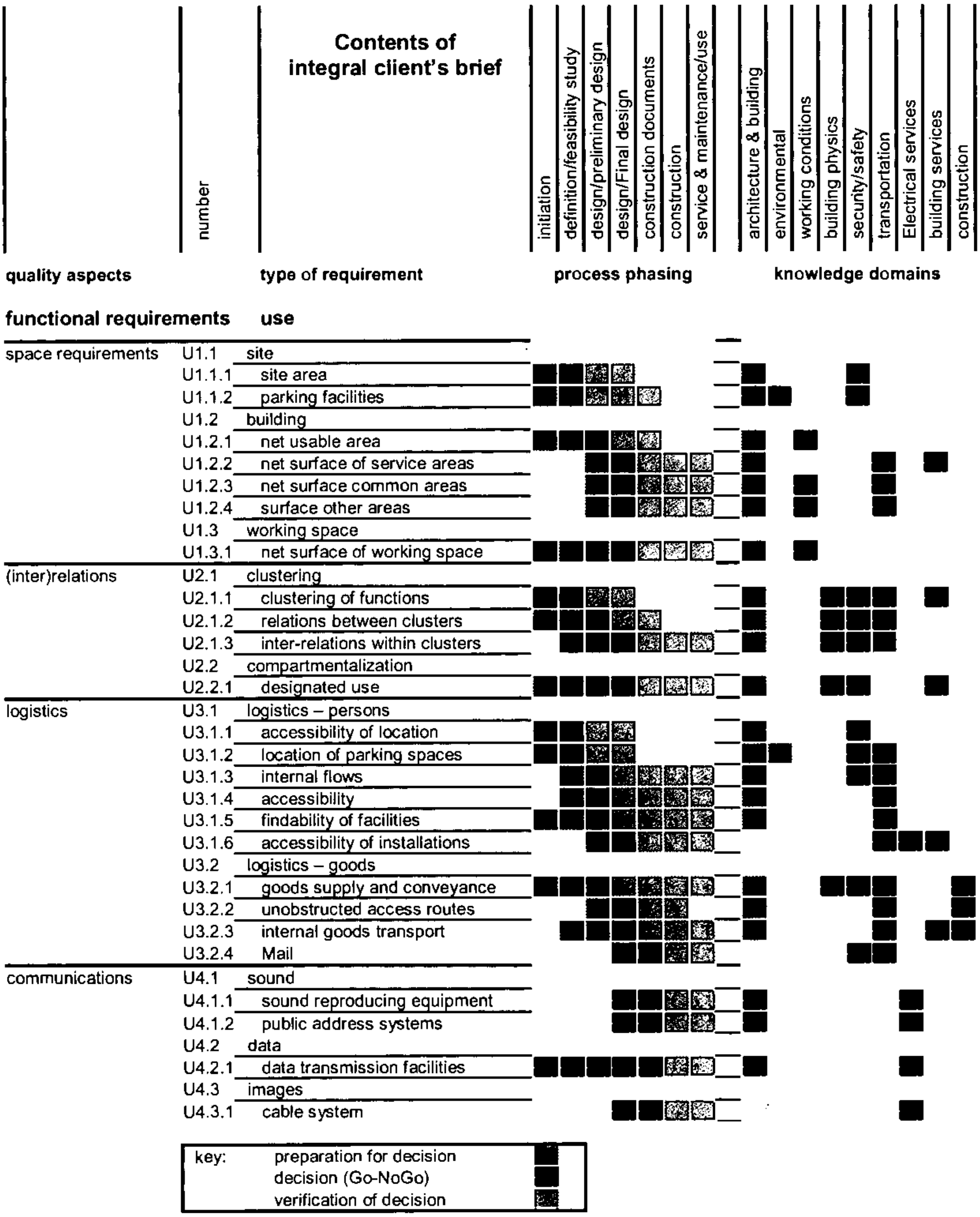


Figure 3.3 An extract showing the layout of the client's brief matrix

Knowledge domains. These include the main areas of expertise required and may vary from project to project.

- Architecture
- Environment
- Working conditions
- Building physics
- Security/safety
- Transportation
- Electrical services
- Building services
- Construction

Each component of the functional requirements may involve links to one or more of these knowledge domains.

Although the table is principally concerned with functional requirements, it can also include other aspects such as (i) the image that the building is intended to convey, (ii) internal constraints and (iii) external constraints and show the way that components of these can also be linked to process phasing and knowledge domains.

3.4 Facilitating Information Exchange – the Multi-Criteria Decision Aid

As noted earlier, underpinning the development of the client's brief is the need to facilitate communication between the various parties or 'actors' involved in the design and construction process. Figure 3.4, dealing with the preliminary design stage of a building, illustrates the potential complexity of the possible interactions. The Multi-Criteria Decision Aid (MCDA) is a computer-based tool that was developed within Annex 32 to help each actor express his requirements, either in the form of constraints or as objectives, particularly during the early stages of design.

It is useful to distinguish between the 'client' and the 'project author'. The client may include the building developer or the organisation that will occupy the building. The project author, the facilitator of the design and construction process, will often be the architect but may include other contributors to the design team Taking, as a starting point, an initial rough feasibility study for a project, the MCDA presents the client with a questionnaire on a computer screen.

This questionnaire is set out in non-technical terms and is intended to assist the client in defining his requirements. Figure 3.5 shows a set of questions dealing with building geometry. In answer to many questions, it is possible to give either a single answer or a range. The project author is presented with a similar questionnaire but at a more technical level, as illustrated in Figure 3.6. The MCDA software analyses the response and presents an output matching the results of the two questionnaires,

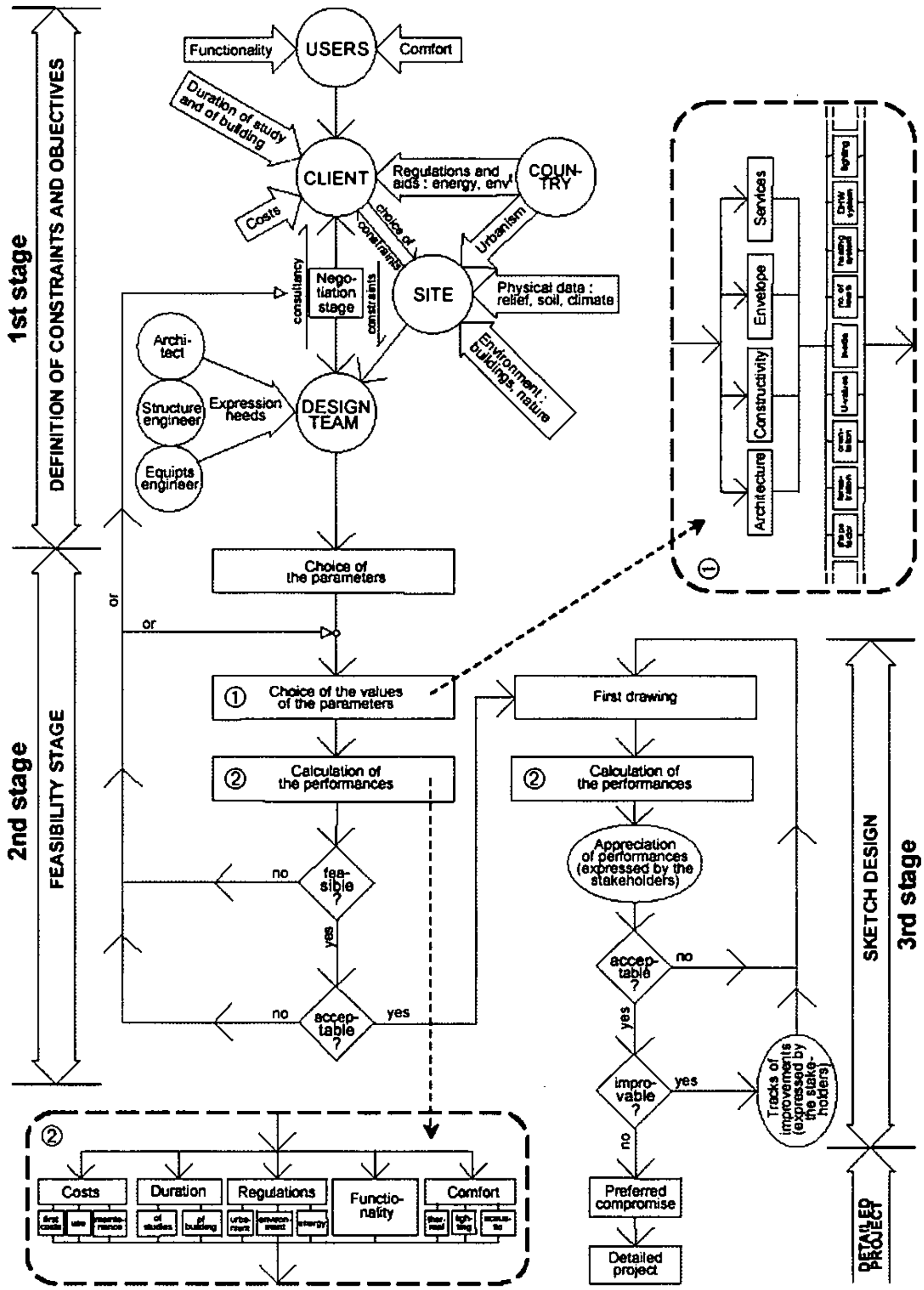


Figure 3.4 *Interactions during the preliminary stages of the design process*

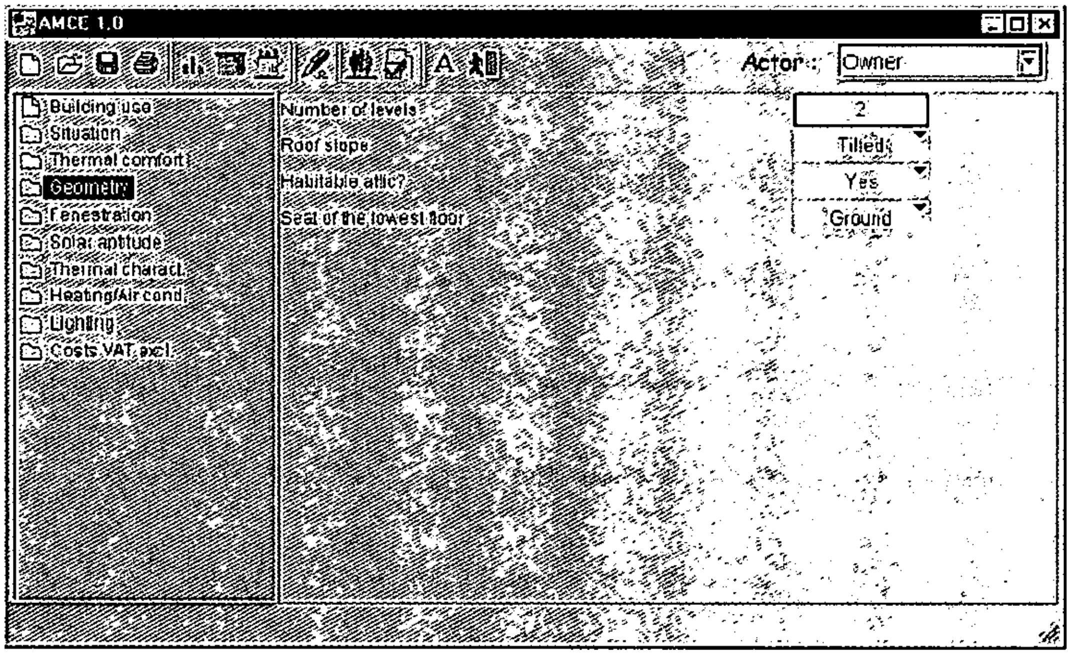


Figure 3.5 MCDA – Typical screen from the client questionnaire

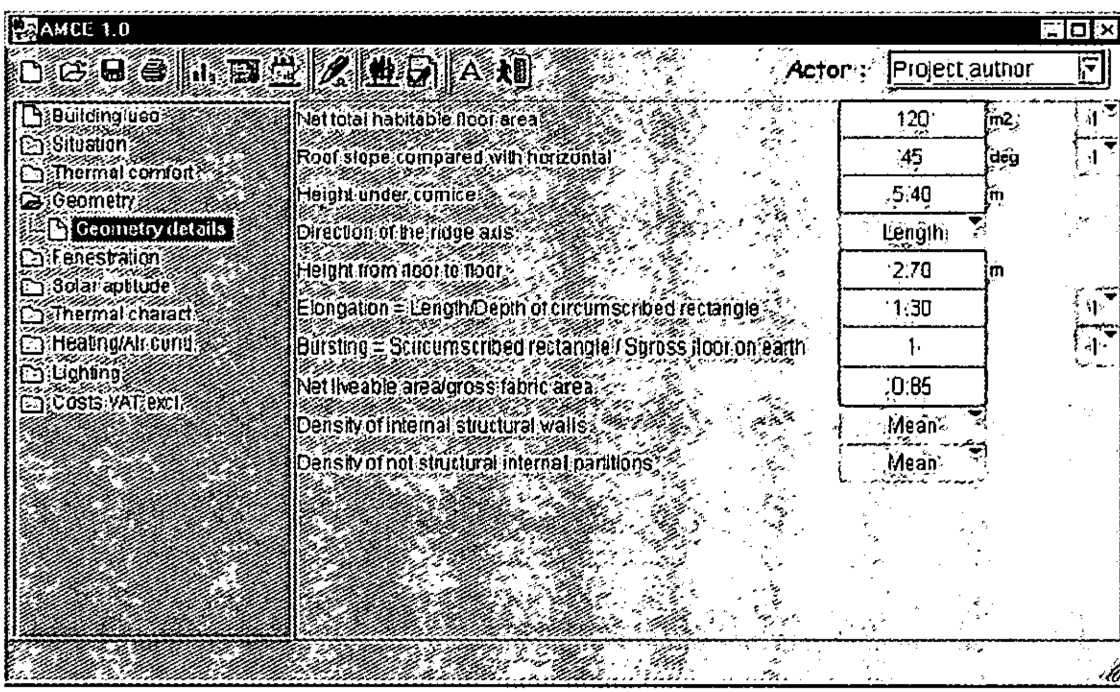


Figure 3.6 MCDA – Typical screen from the project author questionnaire

indicating where comparisons are satisfactory or unsatisfactory. An additional facility indicates the sensitivity of various components of the design to altering a chosen design parameter, for instance floor area. The outcome may be a design that satisfies both actors. Alternatively, there may be conflicting requirements that are irreconcilable resulting in the need to reconsider more fundamental aspects of the trial design.

4. Performance Assessment

4.1 Performance Formulation

The next stage is to translate the integral client's brief into performance requirements. This, of course, relates to all aspects of the design and construction process but, for the purposes of Annex 32, is restricted to the building and building systems and material levels, as illustrated schematically in Figure 4.1.

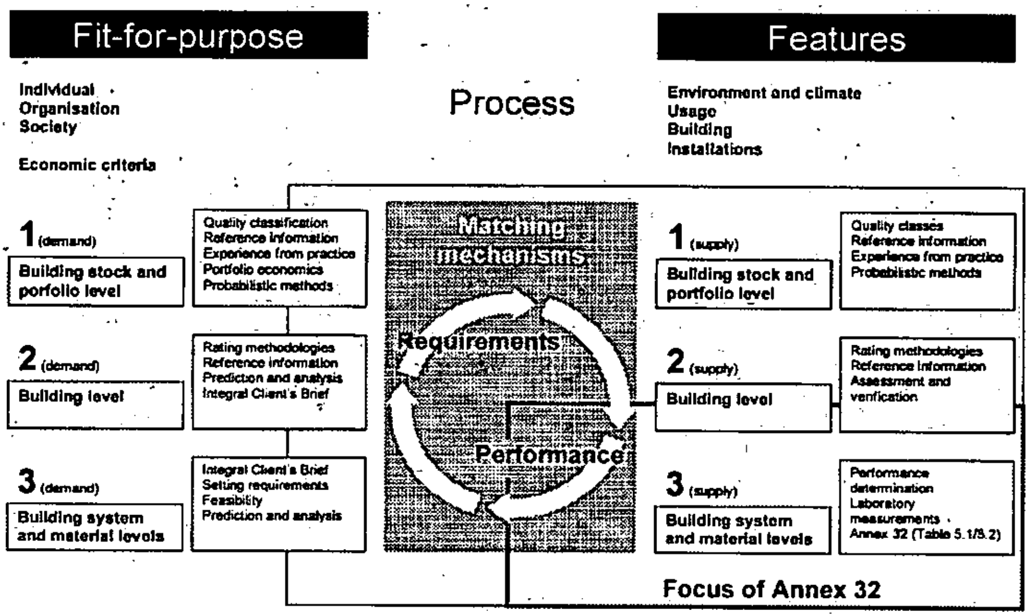


Figure 4.1 Matching requirements to performance – focus of Annex 32

For the purpose of Annex 32, performance was defined as "all physical (and functional) qualities of a building that can be (i) expressed in numerical, or at least exact, manner; (ii) are predictable at the design stage and (iii) are controllable during and after construction." Each aspect of performance must be associated with one or more 'reference values' that are either set by society (say, in the form of codes or regulations) or defined in the client's brief.

In order to limit the scope of the work of Annex 32, consideration was limited to performances that could be linked to the 'building physics' knowledge domain, introduced in 3.3. The performances required at whole building level are summarised in Table 4.1 and, at building envelope level, in Table 4.2. The performances are arranged under particular topic areas. Appendices 3 and 4 of Reference 2 show how each performance is related to the quality aspects set out in the integral client's brief.

Topic		Aspects of performance
Heat and mass	1	Minimising total energy consumption per unit of floor area, per unit of heated volume or per unit of envelope area
	2	Providing thermal comfort during the warm season (air temperature, radiant temperature, air velocity, relative humidity)
	3	Providing thermal comfort during cold season (air temperature, radiant temperature, air velocity, relative humidity, draughts, floor temperature, radiation asymmetry, vertical temperature gradient)
	4	Controlling the moisture balance for mould, mildew and house dust mite prevention
	5	Guaranteeing indoor air quality (dust, fibres, VOC, radon, CO_2 control, fresh air intake position and filtration efficiency, air pressure control and distribution efficiency)
Acoustics	6	Correct noise control and acoustic comfort
	7	Purpose-adapted room acoustics (reverberation time, clarity, speech transmission, etc.)
	8	Optimal acoustic insulation
Light	9	Good visual comfort (illuminance, glare, contrast)
	10	Optimal use of daylight (daylight factors)
Fire	11	Correct compartmentalisation
	12	Means of escape
	13	Prevention of fire spread
Service life	14	In relation to functional requirements
	15	In relation to economic requirements
	16	In relation to technical requirements
Costs	17	Lowest total cost
Sustainability	18	Assessment of the whole building life cycle

Table 4.1 Whole building performance – building physics related aspects

4.2 Performance Requirements

4.2.1 Introduction

In order to carry out a meaningful performance assessment at the design stage, it is necessary that the performance formulation include requirements, in the form of the reference values noted above. Typically these reference values define the minimum quality that should be guaranteed. The specification of reference values is a complex, consensus-based process which must take into account all of the factors which are affected by a particular aspect of performance. For example, setting a U-value requires consideration of comfort, health, energy, environment and costs – all of which interact. A common alternative to specific reference values is a scale of requirements with a minimum and maximum, depending upon circumstances. The minimum will usually relate to a value set for regulatory purposes.

4.2.2 Basis of Comparison of Different Designs – Quality Scores

Where a range of performance levels are specified, the opportunity exists to make a comparison between different design solutions and identify an optimal solution. One approach to this is to allocate a score of 0 to 5 in respect of each aspect of performance, where 0 results in rejection; 1 is the lowest and 5 the highest quality level. These scores are then added and divided by the total number of performance aspects to give an overall score. This can be used to compare various design solutions. Not all aspects of performance may be given equal weight, in which case appropriate, agreed weighting factors can be introduced.

Topic		Aspects of performance
Heat and mass	1	Air tightness
		. Air permeance, n50 and equivalent leakage area (infiltration,exfiltration)
		. Buoyancy induced air rotation around the insultation in cavities
		. Buoyancy indced flow in air permeable insulation in opaque envelope elements
	2	Thermal insulation
		. Whole wall U-value of an opaque envelope element
		. Whole window U-value
		. Whole envelope U-value
		. Dynamic U-value for active envelopes
	3	Transient response
		. Harmonic thermal resistance and admittance of the opaque parts
		. Solar transmittance
		. Temperature damping of an enclosure
		. Fenestration to whole wall area ratio
		. Resulting thermal resistance
	4	Moisture response
		. Initial moisture and dryability
		. Rain penetration
		. Rising damp
		. Pressure flow
		. Hygroscopicity
		. Surface condensation
		. Interstitial condensation
	5	Thermal bridging
		. Temperature ratio
Acoustics	6	Whole envelope insulation against external noise
	7	Lateral sound transmission
	8	Sound absoption
Light	9	Light transmittance for the transparent elements
	10	Fenestration to whole wall elevation area ratio
Fire	11	Fire resistance
	12	Reaction to fire of internal finishes and components
	13	Flame spread along the envelope
Service life	14	Physical attack (stress and strain due to moisture and temperature gradients, frost attack, salt crystallization and solution, salt hydration, biological degradation etc.)
	15	Chemical attack (lime to gypsum reaction, carbonization, corrosion etc.)
	16	Biological attack (mould, algae, moss, plants, bacteria, insects etc.)
Costs	17	Net present value and optimization investments, operational cost, maintenance costs
Sustainability	18	Sustainability profile

Table 4.2 Envelope performance – building physics related aspects

4.3 Performance Assessment During Design

Performance assessment may, therefore, consist of two elements:

- Satisfaction of required reference values
- Optimisation between alternative solutions

Only some aspects, such as costs, thermal insulation and sustainability, can be easily included under optimisation. Others, such as air tightness, acoustics, lighting and fire safety, are generally prescribed by regulators on grounds of health, safety or comfort.

Key to methodology (column 3):

C = calculation tool
D = design tool
S = standard
R = regulation/legislation

Country and number	Name of methodology	Type of methodology	Initiation	Definition/feasibility study	Design/preliminary design	Design/final design	Construction documents	Construction	Service & maintenance/use	Description of methodology/instrument
B1	Verbruik 2	C			■					Program to predict the heating load, insulation level of a building
B2	Diagrams	D			■					Aid for judging the daylight factor at any point in space
B3	Report	D			▨	■	▨			Design aid for exterior wall solutions for residential buildings
B4	HYGRAN 24	C				▨			▨	Program to calculate the HAM response for a 1-D wall system
B5	WAND	C			▨	▨				Program to evaluate the hygro-thermal performance of a wall design
B6	TRISCO-VOLTRA	C				■				Program to evaluate the 3-D heat transfer through building details
B7	KOBR86 VECTI	C				■				Program to evaluate the 2-D heat transfer through building details
B8	CAPSOL	C				■				Program to evaluate energy demand under non-steady state conditions
B9	HARMONIC	C			■					Methodology to predict summer comfort
D1	BR95	R		▨	▨	■	▨	▨	▨	Building Regulation – Danish housing and building agency
D2	BV95	C		▨	▨	■				Report and software for predicting heating load
D3	Win-Sim	C		▨	■	▨				Software for predicting heating load and thermal comfort
D4	Match						■			Prediction of moisture
E1	prEN 832	S				▨				Thermal performance of buildings (heating energy)
E2	prEN ISO 13791/2	S				▨				Thermal performance of buildings (summer comfort)
E3	prEn 12354	S				▨				Sound insulation of buildings
G1	DIM 2.8	C			▨	■				Simulation of coupled heat & mass transfer in porous building materials
G2	DIN 4102	S			▨	■				Behaviour of building materials and components in fire
G3	DIN 4108	S			▨	■	▨			Thermal insulation of buildings
G4	DIN 4109	S					■			Sound insulation of buildings
G5	DIN 4701	S				▨				Rules for calculating the heat requirement of buildings
G6	DIN 18195	S					▨			Waterproofing of buildings
G7	DIN 5034	S			▨	■				Daylighting of interiors
G8	VDI	R			▨	▨	▨	▨	▨	General information on calculation and design
G9	WSVO 95	R					■			Regulation on energy saving thermal insulation of buildings
G10	TGL 35424/06	D				▨	▨			Floor temperature
N1	COMIS	C			▨	■				Simulation of ventilation (and prediction of indoor air quality)
N2	BFEP	C		▨	▨	■			▨	Building physics finite element package
N3	VA 114	C			▨	■	▨		▨	Building simulation
N4	SIBE	C		▨	▨	▨			▨	Solar irradiation in the built environment
N5	Trees	C		▨	▨	▨			▨	Ray-tracing in a CAD environment (interior lighting)
S1	IDA	C			▨	▨				Simulation of building and energy systems
UK1	ESP-2	C		▨	▨	■				Building energy simulation
US1	TRNSYS	C		▨	▨	▨			▨	Transient building simulation program

Table 4.3 Inventory of tools and methodologies for envelope performance assessment

As part of Annex 32, a detailed review was undertaken to identify the key elements of performance and to set out methods for predicting these during the design stage. Reference [2] describes the results of this review in detail and covers the main elements set out in Table 4.2.

As an adjunct to this review, an inventory of specific tools and methodologies developed in Annex 32 member states was produced. This is summarised in Table 4.3. It is not intended to be comprehensive but to provide an indication of the range of methodologies that are available at different stages of the design and construction process.

4.4 Performance Control After Construction

A thorough assessment of performance requires that checks be carried out at the commissioning phase, although this is often currently neglected for most aspects. A review of available measuring methods was carried out and these are summarised in Table 4.4, together with an indication of the time required to undertake the necessary tests.

Aspects of performance		Method	Duration
Air permeance	1	Blower door	Hours
	2	Tracer gas measurement	Hours
Clear wall U-value	3	Hot box test on site	Weeks
	4	Heat flow meter and temperature measurements on site	Weeks
	5	λ- needle	Hours
Fenestration to whole wall fenestration ratio	6	Geometrical control	Day
Solar transmittance	7	Indirect measurement by long-term logging of inside temperatures	Weeks
Moisture response	8	Rain test on site	Hours
	9	Infra-red scanning	Hours
	10	Tracer gas measurement with a constant concentration inside and logging of tracer gas build-up in the construction element under scrutiny	
	11	Spot measurement of moisture ratios with an X-ray probe	Hours
	12	Spot measurement of moisture ratios with a resistance probe	Hours
	13	Spot measurement of moisture ratios with a carbide bottle	Hours
	14	On site measurement of surface temperatures at critical locations on the envelope, together with inside/outside temperature and humidity	Hours
Temperature ratio	15	See moisture response	
Acoustic insulation	16	Measurement of the noise levels inside and outside over a representative length of time; measurement of interior reverberation time	Hours to days

Table 4.4 Methods for measuring building envelope performance

5. Assessment of Traditional Building Envelope Designs

5.1 Introduction

There is a need to upgrade the performance of traditional building envelopes both by using improved components and by making better use of traditional materials. There is also a need to improve the envelopes of existing buildings using retrofit measures. The integral building envelope performance assessment methodology outlined in the preceding sections was applied to a number of examples of modified traditional envelopes. Firstly, the functional requirements were identified for each of the aspects of performance listed in Table 4.2. The various envelope types were then assessed against these requirements, using appropriate methodologies, ranging from conformity with appropriate standards to calculation methods. The detailed assessment of each envelope design is set out in reference [3].

5.2 Upgraded Traditional Building Envelope Designs

5.2.1 Dryable Insulation System for Low Slope Roofs

<u>Description</u>

Roofs are typically constructed as warm deck roofs with the insulation material placed on the top of the deck. The deck is typically constructed from concrete or steel, while in most cases the insulation is mineral wool, polystyrene or polyisocyanurate. Figure 5.1 shows a typical such roof arrangement. A vapour barrier is installed between the deck and the insulation and an outer, weather-proofing roof membrane is installed on the outer side of the insulation. The lifetime of the roof ranges from 15 to 35 years, with an average of 25 years, when subject only to climatic conditions and normal wear.

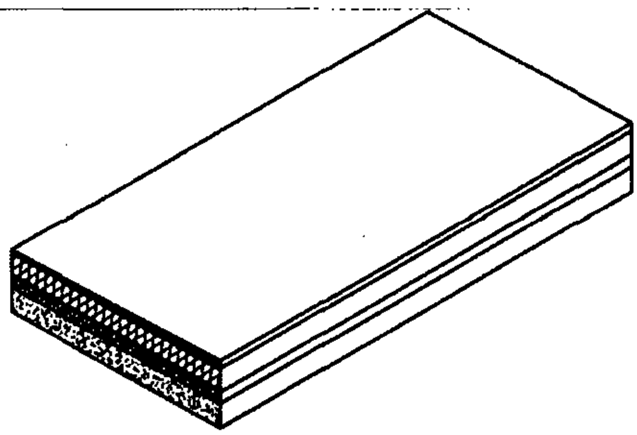


Figure 5.1 Flat roof insulation system using a concrete deck and rigid insulation boards, separated by a vapour barrier

However, often such roofs may become damaged with the result that leakage paths occur, allowing water into the insulation layer. At present, remedial action involves either replacement of the insulation layer and outer membrane or the installation of a second insulation layer and membrane on top of the first. Both methods are expensive. A new method has been proposed, this involves the use of longitudinal grooves in the edge of the insulation layer abutting the vapour barrier and the positioning of moisture detectors in the insulation layer. If water is detected, then any leakage path is identified and sealed and moisture within the layer is removed by drawing air through the grooves with temporarily installed fans.

Integral performance assessment

The performance of the dryable roofing system was compared with the requirements for roofing systems, following the systematic methodology presented earlier. It was found to satisfy all of the requirements. However, comparison of costs, allowing for the higher capital cost but lower potential operation and repair costs showed a 12% reduction in NPV in comparison with a standard system.

5.2.2 Wall System with a High Insulation Level

Description

There is a proposal to increase the insulation requirements for walls in the next revision of the Danish Building Regulations with the aim of reducing heating energy consumption by 33%. A number of wall systems have been designed to achieve this. These are shown as vertical sections in Figure 5.2.

insulation levels

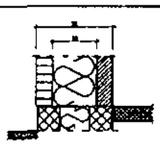
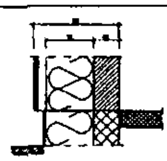
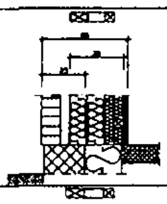
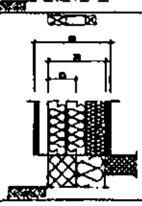
Wall number	Vertical section	Description
1		Traditional outer wall. Consist of inner load-bearing cellular concrete leaf and outer brick veneer
2		Inner load-bearing cellular concrete leaf and outer finish of wooden boards or tiles
3		Wooden frame construction as load-bearing part. Gypsum as inner facing plate, outer brick veneer. The two columns are connected by horisontal beams
4		Wooden frame construction as load-bearing part. Gypsum as inner facing plate, outer finish of wooden board or tiles. The two columns are connected by horisontal beams

Figure 5.2 Vertical sections and descriptions of four outer wall components with high insulation levels

Integral performance assessment

The performance of each of the four systems was compared with the requirements for wall systems, including the modified insulation requirement, following the systematic methodology presented earlier. It was found that all four satisfied the requirements. In consequence emphasis was placed on optimising the systems in respect of costs. Four possible scenarios were used:

Scenario 1: Energy price 0.067 Euro/kWh; 2.5% real interest rate
Scenario 2: Energy price 0.134 Euro/kWh; 2.5% real interest rate
Scenario 3: Energy price 0.067 Euro/kWh; 5.0% real interest rate
Scenario 4: Energy price 0.134 Euro/kWh; 5.0% real interest rate

Under scenarios 1, 3 and 4 the optimum thickness was the minimum, under the proposed revised Building Regulations, of 200mm. For scenario 3 the optimal thickness was between 250mm and 300mm depending upon the design. Overall, Design 2 was the least cost option.

5.3 Retrofitting Building Envelopes

5.3.1 Introduction

During the course of Annex 32 a number of systems for upgrading the insulation of the walls of existing buildings were analysed. These included systems in which additional insulation was added to the external walls or to the internal walls. The former can affect, for better or worse, the aesthetic properties of the building. The latter are hidden from external view, but may have disadvantages in respect of interstitial condensation or cold-bridging at wall-floor junctions.

5.3.2 External Insulation Systems

Description

Following a survey of the twelve methods most commonly used in Denmark, three broad types of retrofit insulation were identified and designated as follows:

- Type A - systems with cladding and a ventilated air gap.
- Type K - systems without an air gap.
- Type L - systems with brick facing.

These are illustrated schematically in Figure 5.3. All twelve systems were analysed and three representative systems are reported in detail [4].

Integral Performance Assessment

The performance requirements for the walls were identified, using a number of sources, including Reference 2, a European Organisation for Technical Approval document concerned with external insulation systems [5] and the Danish Building Regulations[6]. Applying the methodology discussed earlier, the performance of each of the types of system was assessed. All three systems were found to satisfy the requirements. A cost benefit analysis, using the four economic scenarios used previously in 5.2.2, showed that the total construction and operating cost over 30 years is lowest with an added insulation thickness of 200mm for all scenarios. In general, System K had the lowest total cost and System L the highest.

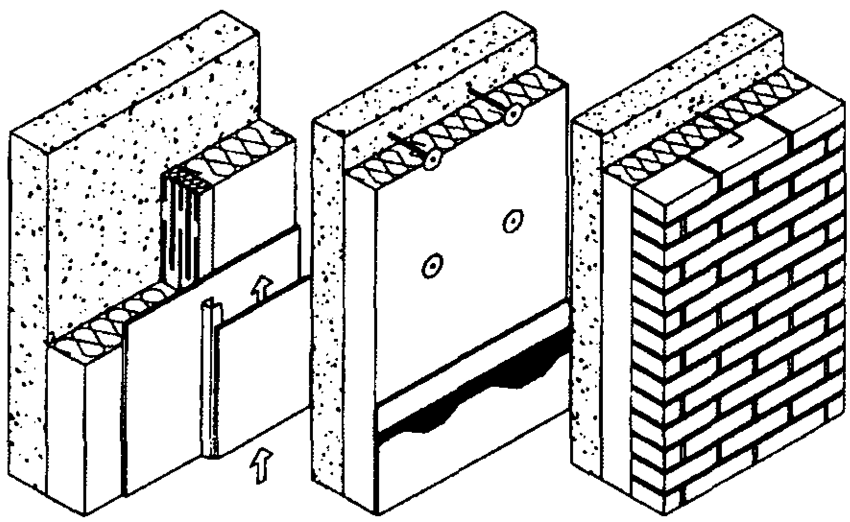


Figure 5.3 External insulation systems – Type A, Type K and Type L

5.3.3 Internal Insulation – Using Capillary Active Materials

Description

In some circumstances, the application of external insulation is not possible. Traditional internal insulation consists of an insulation layer and a vapour barrier. However, often vapour barriers can be accidentally penetrated or may be difficult to seal at junctions of the wall with other building components. This allows interstitial condensation. In order to ameliorate the effects of this, should it occur, a system has been proposed which replaces the conventional insulant (say, mineral wool) with a capillary active material, such as calcium silicate. If condensation occurs, water is transferred back to the inner surface from where it can evaporate into the room.

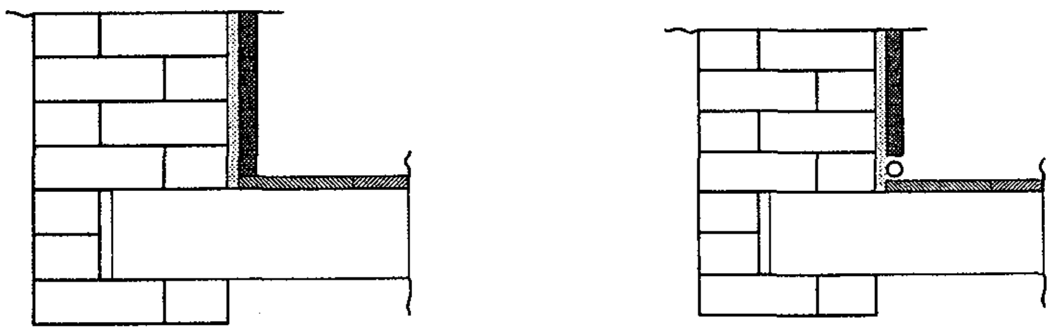
Integral performance assessment

The same requirements apply as for the externally applied insulation systems. The performance of the internal insulation system was assessed using the previously described methodology. In particular modelling was used to assess the hygroscopic performance of the novel system and to compare it with traditional systems. This showed that while the potential moisture content of the insulation layer of the traditional system varied between 2% and 30% by volume, depending upon time of year, the range for the capillary active system was only 2% to 6%. The risk of fungal growth and deterioration was, therefore, substantially higher with the traditional system, resulting in higher maintenance and energy costs.

5.3.4 Internal Insulation – Localised Heating

Description

As noted earlier, one problem with retrofitted internal insulation is ensuring a vapour tight junction between the wall and floor. This can be a particular problem where the floor is supported by timber joists, the ends of which are embedded into the wall, as shown in Figure 5.4a. The joist end acts as a cold bridge, potentially leading to high moisture levels and consequent timber rot. A solution that has been proposed is to install a heating pipe at the junction of the wall and floor as shown in Figure 5.4b.



(a) Standard (b) With heating pipe

Figure 5.4 Junction between masonry wall with internal insulation and timber floor

Integral performance assessment

The performance of the proposed system was assessed against the requirements set out previously for walls. Most aspects were already covered by the earlier study of internal insulation and the principal emphasis was placed upon moisture response. Again a numerical model [7] was used to investigate the hygroscopic performance of the system. This showed that, with the heating pipe, the relative humidity at the joist head was between 10% and 14% lower than without. Also, the risk of rot was considerably reduced.

6. Assessment of Advanced Envelopes

6.1 Introduction

An advanced envelope applies technology in an innovative way to optimise one or more aspects of the performance of the building as a whole. These may include:

- Conventional weather protection.
- Thermal insulation.
- Daylighting.
- Solar control.

- Ventilation.
- Energy generation.

Such novel technology needs to be integrated both into the building and the building process, taking into account the differing viewpoints of the main stakeholders.

Two particular examples of advanced envelope were studied within Annex 32:

(i) Building integrated photovoltaics (BIPVs).
(ii) Active envelopes.

The essential characteristics of these are described briefly below.

6.2 Building Integrated Photovoltaics (BIPVs)

6.2.1 Description

Photovoltaic cells transform 5% (amorphous silicon) to about 20% (mono-crystalline silicon) of the incident solar radiation into electrical energy. Figure 6.1 shows a typical photovoltaic module for installation in a roof. Photovoltaic technology is seen as one of the attractive, renewable energy technologies for electricity production in the future. Recently, designers have turned their attention to the integration of photovoltaic elements in buildings. This can be achieved either by installing photovoltaic components on the roof, as in figure 6.1, or in front of façade elements or by developing integrated building components.

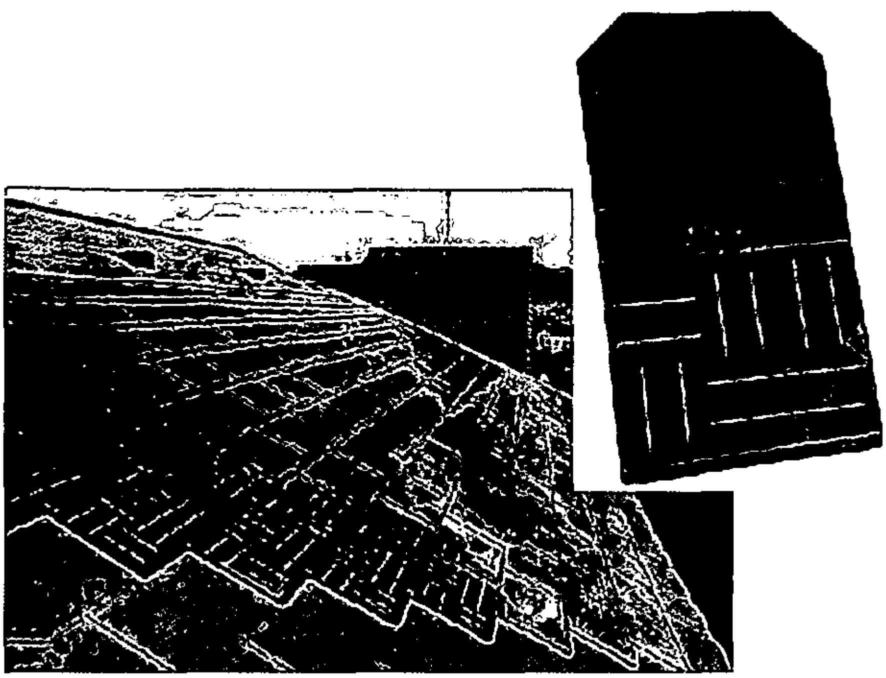


Figure 6.1 Photovoltaic cells installed as roof tiles

The main barriers to the uptake of BIPV technology are

- lack of guidance on integration issues,

- lack of certified building products with integrated PV elements,
- lack of performance data or accepted calculation method for the evaluation of hybrid PV components, and
- perceived high investment cost.

6.2.2 Design Considerations

BIPV employs well-proven power generation technology with a high degree of reliability which allows electrical power to be generated at the point of use, eliminating disadvantages and costs associated with power transmission and reducing peak load. Building surface area is used effectively and, with careful design, the aesthetics of the building can be enhanced. There are cost benefits in using BIPV to replace conventional materials in integrated designs, including:

- Solar shading devices
- Rainscreen cladding
- Façade elements
- Roof tiles

These advantages have to be balanced against some potential disadvantages. BIPV may not be appropriate (or, perhaps, perceived to be appropriate) for some climates. It may be difficult to incorporate where a building may be over-shadowed, either in the present or future, by other buildings. Vertical facades do not provide the optimal orientation for photovoltaic elements. More importantly, there is a lack of experience and knowledge in designing and constructing BIPV systems and costs are high – typically 1000 – 1400 Euro/m^2, although these costs are expected to reduce as use becomes more widespread.

6.3 Active Envelopes

6.3.1 Description

Active envelopes consist of two panes, separated by an air gap, which may contain a shading device. Air passes through the cavity, driven by either natural or mechanical means. Active envelopes can be defined by three principal characteristics:

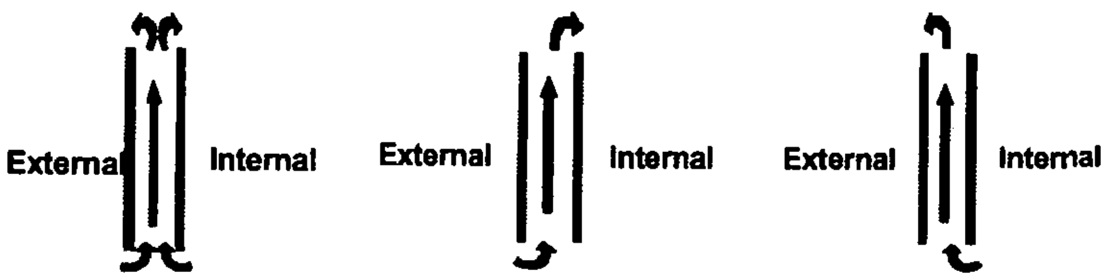
(a) <u>The nature of the airflow</u>

Three possibilities exist and these are shown schematically in Figure 6.2.

(i)	Air curtain:	no air exchange between inside and outside.
(ii)	Air supply:	fresh air from outside flows through the cavity to the outside.
(iii)	Air exhaust:	air from inside the building flows to outside.

(b) <u>The way the airflow is generated</u>

Air movement through the cavity may be driven mechanically, typically as part of the building HVAC system or by natural means, resulting from wind or stack effect.



(i) Air curtain *(ii) Air supply* *(iii) Air exhaust*

Figure 6.2 Possible air flow arrangements in an active envelope

(c) Horizontal partition of the façade.

The airflow envelope may be interrupted at each floor level or it may extend over several storeys. In the former case, the term 'active window' is used and in the latter, 'active façade'.

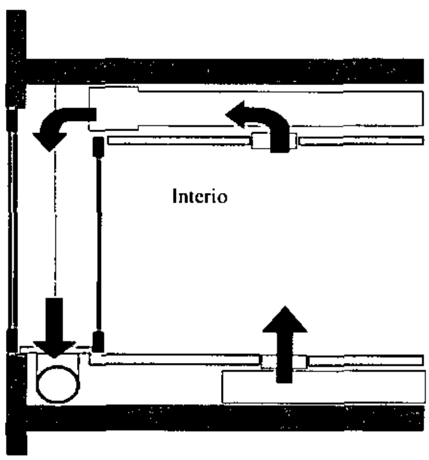


Figure 6.3 Schematic diagram of an 'active window' system

Figure 6.3 shows a typical example of an 'active window', forming part of the HVAC system. Air is extracted from the occupied space and returns to the HVAC system, thus forming an air curtain type installation.

6.3.2 Design Considerations

As well as providing a 'high-tech' image for a building, active envelopes contribute to energy efficiency. They have good acoustical performance. They can be used in conjunction with naturally driven ventilation systems and should enhance the thermal comfort of occupants. In relation to energy efficiency, two modes of operation may be distinguished:

Active envelopes as air-to air heat exchangers: Transmission losses through the inner pane are recovered. This is more appropriate where internal heat gains are low.

Active envelopes as solar collectors: In the heating season, solar energy may be used to preheat air entering the HVAC system, reducing energy demand. In summer, solar energy is collected and removed before entering the occupied zone

In an attempt to identify the advantages and drawbacks of active envelopes, as well as other advanced envelopes, a design matrix was drawn up, based upon the integral client's brief discussed earlier. A list of performance requirements was constructed with the aim of:

- Evaluating the possible impact of an advanced envelope type on the overall building performance, in comparison with traditional solutions.
- Identifying which knowledge domains are required to identify the relevant performance indicators.
- Identifying where existing design tools, standards, codes etc. are unsatisfactory or need improvement.

Main Design Requirements		BIPV		Active envelopes	
		Impact	Tools	Impact	Tools
use	suitability	2	2	2	1
	adaptability	2	2	2	2
occupant comfort	hygrothermal	2	2	3	3
	air quality	2	2	3	3
	visual	2	2	3	2
	acoustical	2	2	3	2
	hygiene	2	2	2	2
	water/air-tightness	2	2	2	2
safety	fire	3	2	3	3
	operational	3	2	3	1
identity		3	3	2	2
cost		3	2	3	2
environmental	energy	3	2	3	2
	raw & building materials	3	2	2	2
	air	3	2	2	2
	water	3	2	2	2
	land	3	2	2	2

key:	impacts	1: about the same	2: slightly different	3: different
	tools	1: satisfactory	2: partially satisfactory	3: unsatisfactory

Table 6.1 Summary design matrix

The impact of the system on each of the requirements was assessed using a scale ranging from (1) having the same impact as a conventional envelope to (3) having a more significant impact (either positive or negative). In parallel, the availability of suitable design tools, or standards was assessed on a similar scale, ranging from (1) – satisfactory to (3) inadequate. The results are summarised briefly in Table 6.1.

Generally, advanced envelopes have a greater impact on performance requirements than conventional envelopes and fall into categories (2) or (3). It is also clear that the availability of appropriate assessment tools is limited for advanced envelopes. More detailed analyses of both BIPV and Active Envelopes are included as appendices to reference [8] and illustrate the use of a much expanded design matrix.

6.4 Performance Assessment

6.4.1 Introduction

Detailed assessments of performance and risk of BIPV and Active Envelopes were carried out using the methodology summarised earlier in Section 4. The full analysis is set out in reference [8] and only selected, key points are summarised here.

6.4.2 BIPV

Thermal performance

While existing reference values and tools can be applied to some aspects of BIPV, including air-tightness, acoustics and lighting, thermal performance is less easy to deal with. In order to maintain the PV cells at a satisfactory temperature to maintain efficiency it is necessary for them to be cooled, usually by the air passing through ventilated space behind the cells. This can be arranged by natural means if the cells are mounted in the form of rain-screen cladding. However, PV cells may be integrated into the façade so that the heat transferred to the air can be used, for instance, to supplement heating in winter and to drive natural ventilation in summer. In relation to the building performance, heat transfer is complex, involving the components of incident solar radiation that are transferred to the air in the ventilated gap and by direct transfer to the internal space of the building by conduction, convection and radiation (which may include direct radiation where the PV cells are mounted to allow some transparent areas). Heat transfer may also occur from internal space to outside and to the air in the ventilated gap. As part of the work for Annex 32, a dynamic analysis tool [9] was used to examine the possibility of estimating thermal performance indicators and experimental studies were undertaken using a reference component. The latter indicated that while significant quantities of heat can be obtained by operating PV cells in a hybrid mode, it is less easy to make use of this low-grade heat in practice.

Integrated performance view

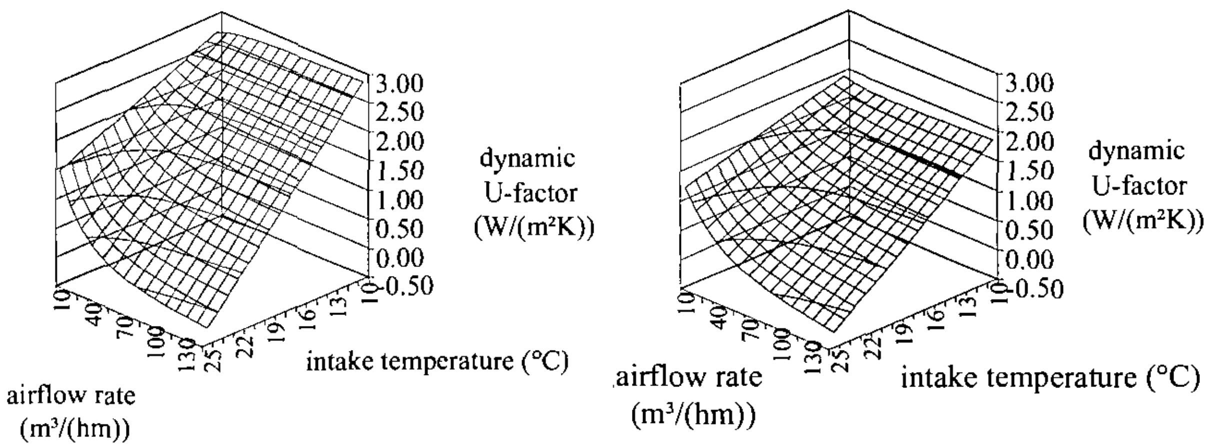
Modelling was used to extend the results to full-scale buildings and to identify the potential for the use of locally generated heat and power. Simulation allowed the following to be determined:

- The overall performance of hybrid PV technology
- The degree to which PV hybrid facades affect other aspects of building performance
- The potential for further improvement of PV component performance
- Replicability by assessing the effect of varying design and climate parameters

The general conclusion is that hybrid ventilation systems can deliver significant energy savings but are most effective in climates where pre-heating of ventilation air is important. The general approach used, evaluation at component level and extrapolation to determine performance of real designs at whole building level, is the best approach to maximising energy performance of BIPV.

6.4.3 Active Envelopes

The performance of active envelopes was assessed against the relevant functional aspects, summarised in Table 4.2. Again, as with the BIPV, thermal performance was the principal area of concern, although aspects such as acoustics, lighting and fire safety were also considered, together with cost and sustainability. The full analysis is set out in reference 8 and is illustrated here by considering one aspect of thermal performance – the effect of flow rate and intake temperature of air flowing through the active envelope on the U-value of the component. This was determined using a numerical simulation program based upon a cell-centred control volume method, described in detail in reference 10.



(a) Shading device up. *(b) Shading device down.*

Figure 6.4 The dynamic U-value of the envelope shown in Figure 6.3 as a function of air flow rate and intake air temperature.

Figure 6.4 shows the variation of the dynamic U-value both with and without a shading device present in the cavity between the inner and outer faces of the envelope. Combined with calculations of the solar gain for range of air flow rate and angle of incidence of the solar radiation, the dynamic U-value can be used to estimate the heat transfer across the envelope for particular operating conditions. However, the complexity of integrating the assessment of the envelope into that of the building as a whole is illustrated by the results of a calculation made for the system shown in Figure 6.3 during the heating season. This indicated that the energy demand by the HVAC system rose despite a reduction in U-value with increased air flow rate.

6.5 Advanced Envelope Case Studies

6.5.1 Introduction

In addition to the general studies of BIPV and Active Envelopes, the IBEPA approach was applied retrospectively to two existing buildings incorporating advanced envelopes. These projects are briefly summarised here but are fully described in reference[8].

6.5.2 The BRE Environmental Building, Watford, UK

Description

This building, shown in Figure 6.5 was intended to demonstrate the energy efficient office of the future. The building incorporated an active envelope, in the form of motorised external louvres and photovoltaic cells integrated into the façade. The

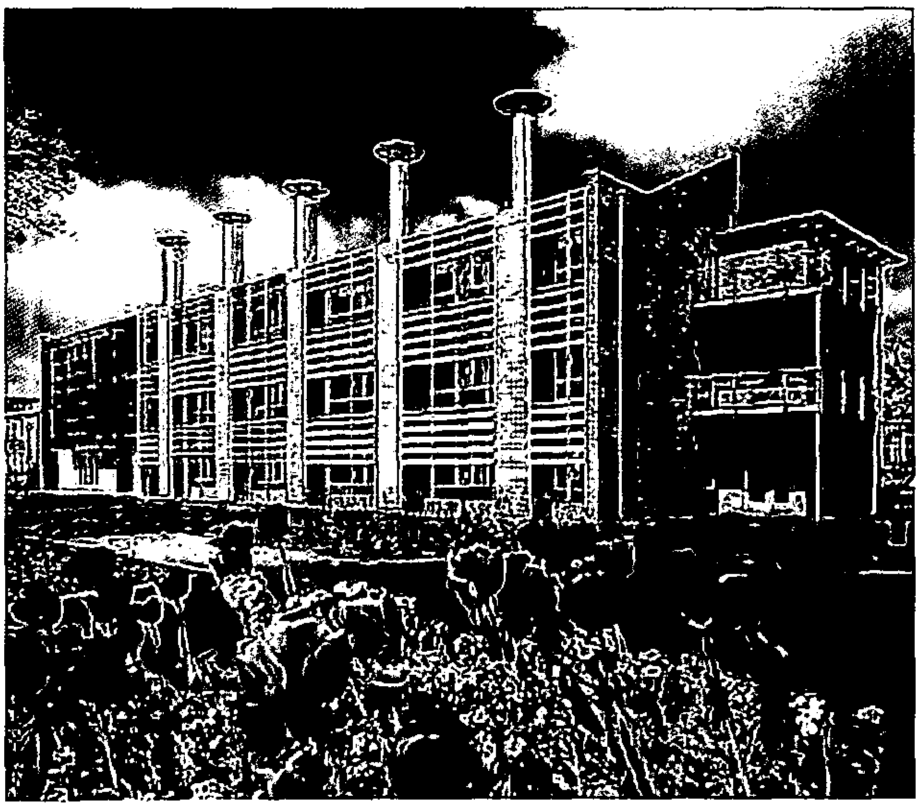


Figure 6.5 The BRE Energy Efficient Office of the Future – South façade

other essential features of the three-storey building are (a) windows designed to optimise the balance between solar gain, heat loss and natural lighting (b) the use of controlled natural ventilation, enhanced by the use of vertical stacks and a relatively thermally heavyweight internal structure. The motorised louvres were designed to respond to internal conditions by rotating to either allow or inhibit solar gain.

BRE Environmental Building, Garston, UK

Anticipation on decision
Go-NoGo
Verification of Go-NoGo

quality aspects		type of requirement	process phasing (Initiativ / Definition/Feasibility study / Design/Preliminary / Design/Final Design / Construction documents / Construction / Service & Maintenance/Use)		knowledge domains (architecture and building / environmental / working conditions / building physics / security/safety / transportations / electrotechnics / building services / construction)
functions/requirements: use					
suitability/workability	**U5.1**	**construction**			
	U5.1.1	floor-loading			
	U5.1.2	external walls			
	U5.1.3	inner walls			
	U5.1.4	finish of floors, walls and ceilings			
adaptability/flexibility	**U6.1**	**the premises**			
	U6.1.1	possibilities of extension in situ			
	U6.1.2	possibilty of extending the building			
	U6.1.3	possibilty of subdivision			
	U6.2	**contruction**			
	U6.2.1	internal flexibilty			
functions/requirements: conditions					
thermal hygric comfort	**C2.1**	**temperature**			
	C2.1.1	differing temperatures in areas		GIR30'	
	C2.1.2	comfort, office (working) areas		GIR30	
	C2.1.3	comfort, other (working) areas		GIR30	
	C2.1.4	temperature gradient		GIR30	
	C2.1.5	floor temperature		GIR30	
	C2.2	**radiation**			
	C2.2..1	radiation asymmetry			
	C2.3	**air speed**			
	C2.3.1	air speed			
	C2.4	**humidity**			
	C2.4.1	humidity indoor air	no humidity control		no humidity control
	C2.5	**condensation**			
	C2.5.1	surface condensation	?		
	C2.5.2	internal condensation	?		
	C2.6	**climate control, general**			
	C2.6.1	specific conditions		GIR 30	
air quality	**C3.1**	**air quality**			
	C3.1.1	ventilation		GIR 30	
	C3.1.2	air pollution		GIR 30	
water / air tightness	**C4.1**	**watertightness**			
	C4.1.1	damp-proofing, outside			
	C4.1.2	damp-proofing, inside			
	C4.2	**air tightness**			
	C4.2.1	air tightness, building envelope		GIR 30	
	C4.2.2	air tightness, envelope fillings		GIR 30	
visual comfort	**C5.1**	**light**			
	C5.1.1	daylight and view		GIR 30,BREEAM#	
	C5.1.2	artificial + standard lighting, quality & quantity		GIR 30, BREEAM	
	C5.1.3	light reflections			
	C5.2	**blinds**			
	C5.2.1	blinds			
acoustical comfort	**C6.1**	**sound-proofing of the buildng envelope**			
	C6.1.1	sound-proofing of the buildng envelope			
	C6.2	**air and structure born noise pollution**			
	C6.2.1	sound proofing between buildings			
	C6.2.2	sound proofing between areas/spaces			
	C6.4	**spacial acoustics**			
	C6.4.1	spacial acoustics			
	C6.5	**vibrations**			
	C6.5.1	vibrations			
hygiene	**C7.2**	**dirty buildings**			
	C7.2.1	floors, walls and ceilings			
	C7.2.2	combatting allergens			
internal conditions: costs					
investment	**Co1.1**	**investment**			
	Co1.1.1	investment			?

Table 6.2 Application of the client's brief matrix to the BRE Environmental Building

Application of IBEPA methodology

The methodology developed within Annex 32 was applied retrospectively to the BRE building. Table 6.2 identifies the performance requirements for the building as a whole. Had this been applied at the early design stage, then the client and the design team would have been better placed to integrate considerations of the building envelope with the building as a whole. In particular, the photovoltaic cells could have been incorporated in the ventilation stacks to provide additional heat gain to the air and, possibly, to contribute to the power requirements of the extract fans. Roof mounting of the PV cells could also have been investigated.

6.5.3 The TEPCO Research and Development Centre, Tokyo

Description

This building incorporates an advanced window system, designed to satisfy the requirements for daylighting, thermal comfort, psychological satisfaction and visual comfort, while reducing the energy consumed for lighting and air conditioning. The window system consists of a double window with automatically controlled, slatted blinds in the cavity. The blinds can be positioned to optimise either daylight or horizontal visibility, or may be drawn upwards if shading is not required. Solar heat absorbed by the blinds is removed by air drawn upwards through the window cavity, thereby reducing the cooling load. Daylighting illuminance is measured and used to control the level of artificial lighting, again reducing the cooling load. The general arrangement of the system is shown in Figures 6.6.

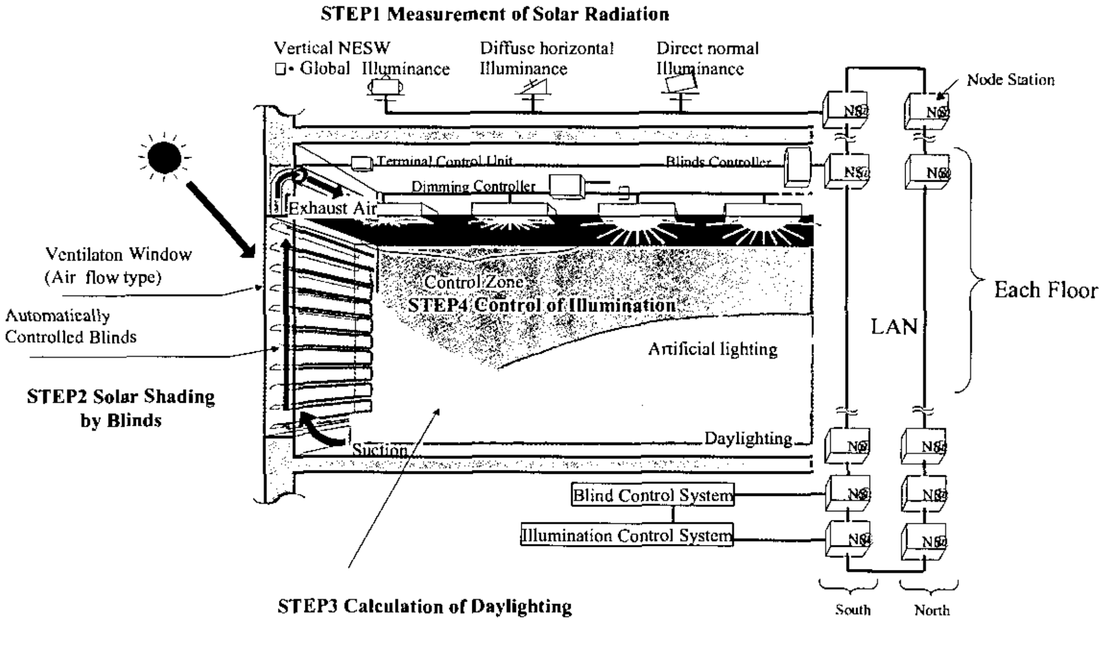


Figure 6.6 Schematic arrangement of the active window and illumination control system – TEPCO Research and Development Centre, Tokyo.

Application of IBEPA methodology

A full trial design matrix for the advanced window system was prepared, based upon the client's brief and this is set out in an appendix to reference [8]. This showed that although most aspects of performance could be specified and reference values identified, there were areas of weakness. In particular, it is important to consider occupant satisfaction, particularly psychological and visual comfort, at an early stage in the design and to consider including the ability of occupants to over-ride the automatic system.

7. Conclusions

A major outcome of the work of Annex 32 has been the development of a structured methodology to deal with the complex transactions which take place in the design and construction and use of buildings. The methodology facilitates communication between the wide range of stakeholders and, when applied, should lead to both greater efficiency in the construction process and to better optimisation of the use of resources, including energy.

The performance assessment procedure has been applied specifically to the design of building envelopes and has been shown to provide valuable insights in relation to both traditional envelope design and advanced envelopes.

Having demonstrated the value of an integrated approach, the aim should be to apply the methodology more widely. To do this, it will be necessary to provide information to the wide range of stakeholders concerned with buildings. Suggested ways of doing this include:

(a) Information dissemination using target group specific guides; visual presentations and summaries of key Annex 32 reports on CD-ROM and, possibly, a dedicated internet website.

(b) Implementation of the methodology in carefully targeted pilot projects.

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Appendix 1 Participating Organisations

Country	Organisation
Belgium	**K.U.Leuven, Laboratorium Bouwfysica.**
	Prof. Hugo Hens, Fatin Ali Mohamed, Dirk Saelens.
	University of Gent, Vakgroep Stedenbouw en Architectur
	Arnold Janssens
Canada	**NRC, Institute for Research in Construction, Building Performance Laboratory**
	Kumar Kumaram, Michael Lancassc
Denmark	**TUD, Lyngby, Denmark**
	Prof. Sven Svendsen, Claus Rudbeck.
Finland	**VTT**
	Tuumo Ojanen, Mikael Salonvaara
	Technical University of Tampere
	Hannu Mäkelä, Teroi Ristonen, Timo Kalema
France	**EdF (in cooperation with Ulg, Belgium)**
	Jean Marie Hauglustaine, Thiery Duforestel
Germany	**Technische Universität Dresden, Institut fur Bauklimatik**
	Horst Stopp
Greece	**Technical University of Athens, Chemical Engineering Department**
	E. Triantis
Italy	**CNR-IEREN, Palermo**
	Antonio Ciaccone
Japan	**Science University of Tokyo, Department of Architecture**
	Takashi Inoue

The Netherlands	**Aacee Bouwen en Milieu** Kees van der Linden **Rijksgebouwendienst** Leo Hendriks **Technische Universiteit Eindhoven, Vakgroep FAGO** Martin de Wit **Blesgraaf Raadgevende Ingenieurs** Daniël van Rijn **Novem BV** Piet Heynen
UK	**BRE** Paul Baker, Matt Grace
USA	**Oak Ridge National Laboratory** Jeff Christian, Achilles Karagiosis,

Appendix 2 Integral Client's Brief – Functional Descriptions

FUNCTIONAL REQUIREMENTS – USE

Space requirements	U1.1	Site
	U1.1.1	Site area
	U1.1.2	Parking facilities
	U1.2	Building
	U1.2.1	Net usable area
	U1.2.2	(Net) surface of service areas
	U1.2.3	(Net) surface common areas
	U1.2.4	Surface other areas
	U1.3	Working space
	U1.3.1	(Net) surface of working space
(Inter)relations	U2.1	Clustering
	U2.1.1	Clustering of functions
	U2.1.2	Relationships between clusters
	U2.1.3	Interrelations within clusters
	U2.2	Compartmentalisation
	U2.2.1	Compartmentalisation of different uses
Logistics	U3.1	Logistics, persons
	U3.1.1	Accessibility of location
	U3.1.2	Location of parking spaces
	U3.1.3	Internal flows
	U3.1.4	Accessibility
	U3.1.5	Findability of facilities
	U3.1.6	Accessibility of installations/facilities
	U3.2	Logistics, goods
	U3.2.1	Goods supply and conveyances
	U3.2.2	Unobstructed access routes
	U3.2.3	Internal goods transport
	U3.2.4	Mail
Communications	U4.1	Sound
	U4.1.1	Sound reproducing equipment
	U4.1.2	Public address system(s)
	U4.2	Data
	U4.2.1	Data transmission facilities
	U4.3	Images
	U4.3.1	Cable system
	U4.4	Telephone
	U4.4.1	Telephone
	U4.5	Monitoring
	U4.5.1	Door bell
	U4.5.2	Personnel locating system(s)
Suitability/Workability	U5.1	Construction
	U5.1.1	Floor-loading
	U5.1.2	External walls
	U5.1.3	Inner walls
	U5.1.4	Finish of floors, walls and ceilings
	U5.2	Installations/Systems in the building
	U5.2.1	Building management facilities
	U5.2.2	Technical areas, shafts etc.
	U5.2.3	Individual operation
	U5.3	Building services (electrical)
	U5.3.1	Main electrical structur

	U5.3.2	Cable ducting
	U5.3.3	Switchability of artificial lighting
	U5.3.4	Connection to electricity grid
	U5.4	<u>Building services (heating)</u>
	U5.4.1	Heating system
	U5.5	<u>Set-up</u>
	U5.5.1	Set-up of archives
	U5.5.2	Set-up of restaurant
	U5.5.3	Set-up of kitchen
	U5.5.4	Set-up of other areas
Adaptability/Flexibility	U6.1	<u>The premises</u>
	U6.1.1	Possibilities for extension in situ
	U6.1.2	Possibility of extending the building
	U6.1.3	Possibility of sub-division
	U6.2	<u>Construction</u>
	U6.2.1	Internal flexibility
	U6.3	<u>Building services/systems</u>
	U6.3.1	Building flexibility
	U6.4	<u>Building services/systems (electrical)</u>
	U6.4.1	Internal flexibility

FUNCTIONAL REQUIREMENTS – CONDITIONS

Comfort urban planning - physics	C1.1	<u>Comfort urban planning physics</u>
	C1.1.1	Wind pollution
	C1.1.2	Irritating solar reflection
Thermal comfort	C2.1	<u>Temperature</u>
	C2.1.1	Differing temperatures in areas
	C2.1.2	Comfort, office (working) areas
	C2.1.3	Comfort, other (working) areas
	C2.1.4	Temperature gradient
	C2.1.5	Floor temperature
	C2.2	<u>Radiation</u>
	C2.2.1	Radiation asymmetry
	C2.3	<u>Air flow</u>
	C2.3.1	Air flow
	C2.4	<u>Humidity</u>
	C2.4.1	Humidity of indoor air
	C2.5	<u>Condensation</u>
	C2.5.1	Surface condensation
	C2.5.2	Interstitial condensation
	C2.6	<u>Climate control</u>
	C2.6.1	In general
	C2.6.2	Specific functions
Air quality	C3.1	<u>Air quality</u>
	C3.1.1	Ventilation
	C3.1.2	Air pollution
Water/Air tightness	C4.1	<u>Water-tightness</u>
	C4.1.1	Damp-proofing, outside
	C4.1.2	Damp-proofing, inside
	C4.2	<u>Air tightness</u>
	C4.2.1	Air tightness, building envelope
	C4.2.2	Air tightness, envelope contents

Visual comfort	C5.1	Light	
	C5.1.1		Daylight and view
	C5.1.2		Artificial lighting, quality and quantity
	C5.1.3		Light reflection
	C5.2	Shading	
	C5.2.1		Shading devices
Acoustic comfort	C6.1	Exterior noise reduction	
	C6.1.1		Sound insulation of building envelope
	C6.2	Air and structure-borne noise transmission	
	C6.2.1		Sound insulation between buildings
	C6.2.2		Sound insulation between areas/spaces
	C6.3	Noise in working areas	
	C6.3.1		Noise produced by machines
	C6.3.2		Noise produced by services
	C6.3.3		Noise produced by appliances
	C6.4	Room acoustics	
	C6.4.1		Room acoustics
	C6.5	Vibrations	
	C6.5.1		Vibrations
Hygiene	C7.1	Personal care	
	C7.1.1		Hot water facilities
	C7.1.2		Showers
	C7.1.3		Sanitary and other facilities
	C7.1.4		Food preparation
	C7.2	Cleaning of the building	
	C7.2.1		Floors, walls and ceilings
	C7.2.2		Combatting allergens

FUNCTIONAL REQUIREMENTS – SECURITY/SAFETY

Security/safety - disasters	S1.1	Facilities	
	S1.1.1		General
	S1.1.2		Emergency (escape route) lighting
	S1.1.3		Alarm system(s)
	S1.1.4		Lightning conductor
	S1.1.5		Rescue/fire-fighting equipment
Occupant safety	S2.1	Facilities	
	S2.1.1		General
	S2.1.2		Sign-posting
	S2.1.3		First aid
	S2.1.4		Glazed partitions
	S2.1.5		Electrical earthing
Social safety/security	S3.1	Site/surroundings	
	S3.1.1		Roads and entrances
	S3.2	The building	
	S3.2.1		Entrance to the building
	S3.3	Common areas	
	S3.3.1		Entrance to spaces/areas
Operational reliability	S4.1	Building services/systems, general	
	S4.1.1		Building management systems
	S4.2	Building services (electrical)	

	S4.2.1		Emergency power supply
	S4.2.2		Emergency lighting
	S4.2.3		Voltage surge protection
	S4.2.4		Monitoring systems
	S4.3	Building services (mechanical)	
	S4.3.1		Heating and cooling plant
	S4.3.2		Internal transportation (lifts etc.)
Anti-burglar security	S5.1	Construction	
	S5.1.1		Partitioning
	S5.1.2		Key and lock system
	S5.2	Building services (electrical)	
	S5.2.1		Lighting
	S5.2.2		Alarm systems
Safety – harmful influences	S6.1	General	
	S6.1.1		Areas for computer hardware
	S6.1.2		Other harmful influences

IMAGE EXPECTED – CULTURAL VALUE

Visual arts	IE1.1.1	Art

IMAGE EXPECTED – IDENTITY

Recognisability	IE2.1.1	House style
	IE2.1.2	Flags
	IE2.1.3	Dirt/contamination

IMAGE EXPECTED – PERCEPTION

Arrangement	IE3.1.1	Urban association/physical planning
	IE3.1.2	Spacial development of the building
Atmosphere	IE3.2.1	Illuminaton of/in the building
Diversity	IE3.3.1	View

INTERNAL CONSTRAINTS – COSTS

Investment	Co1.1	Investment	
	Co1.1.1		Investment
Operational costs	Co2.1	Durability/quality of materials	
	Co2.1.1		Materials/components
	Co2.1.2		Fixing/fastening devices
	Co2.2	Maintenance	
	Co2.2.1		Level of upkeep
	Co2.2.2		Supplementary maintenance needs

INTERNAL CONSTRAINTS – ENVIRONMENTAL

Energy	E1.1	Energy	
	E1.1.1		Mobility/transportation
	E1.1.2		Total energy performance
Raw and building materials	E2.1	Choice of materials	
	E2.1.1		Choice of materials (raw and building)
	E2.2	Waste	
	E2.2.1		Building waste/rubble
Soil	E3.1	Soil pollution	
	E3.1.1		Soil protection policy
Water	E4.1	Water consumption	
	E4.1.1		Water-saving fittings
	E4.1.2		Use of rainwater
Air	E5.1	Air pollution	
	E5.1.1		NO_x emission
	E5.1.2		CO_2 emission
	E5.1.3		SO_2 emission
	E5.1.4		particulate emission
Noise	E6.1	Noise transmission	
	E6.1.1		Noise from construction site
	E6.1.2		Noise from building

INTERNAL CONSTRAINTS – WORKING CONDITIONS

Security/safety	W1.1		
Health	W2.1	Heavy work	
	W2.1.1		Laying screeds
Well-being	W3.1		

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.