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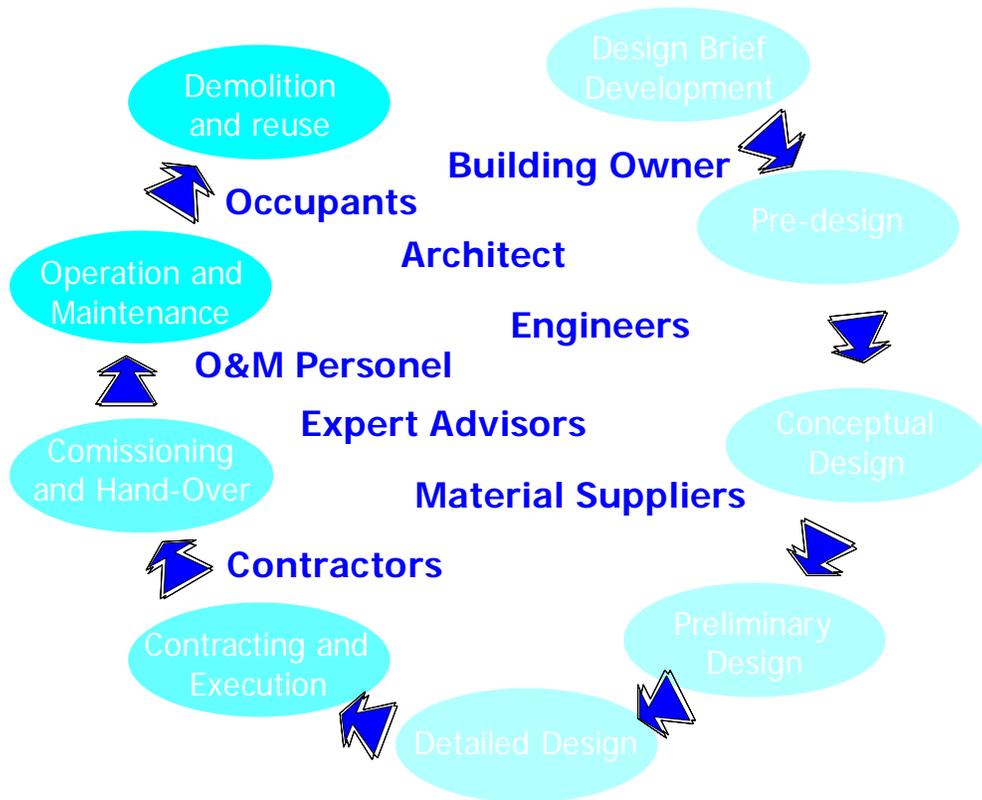
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Integrated Building Design

Per Heiselberg



Aalborg University
Department of Civil Engineering
Indoor Environmental Engineering

DCE Lecture Notes No. 017

Integrated Building Design

by

Per Heiselberg

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1. Integrated Building Design

1.1. Introduction

In the first half of the 20th century, HVAC systems and artificial lighting were developed to meet indoor comfort needs. Before the introduction of mechanical systems, climate – not building style or appearance – was the major determinant of building form. Comfort was achieved through passive means and architectural features built into the design. However, with the advent of new technologies, architects were no longer constrained by the need to ensure that buildings had ample daylighting, remained airy and cool in the summer and warm in the winter. Since HVAC systems and artificial lighting could satisfy comfort needs, architects could pursue unrestricted designs without making comfort part of the architectural design.

1.1.1. Sequential versus integrated design process

Sequential design Process

These innovations started a design revolution. With the freedom to pursue the architectural design as a pure art form, the architect created a design and then passed it on to the constructional and HVAC designers to “fit” the equipment needed to achieve comfort. The design process that at one time integrated all design disciplines evolved into a sequential process carried out in separate disciplines. The usual interaction between HVAC designers and architects no longer occurred, which severely handicapped each discipline’s ability to contribute to the overall design. The result was buildings that were not designed to coexist with the surrounding climate. It resulted in development of poor concept design choices, thereby providing sub-optimal performance and buildings that were energy intensive, costly to operate and had a significant effect on the environment.

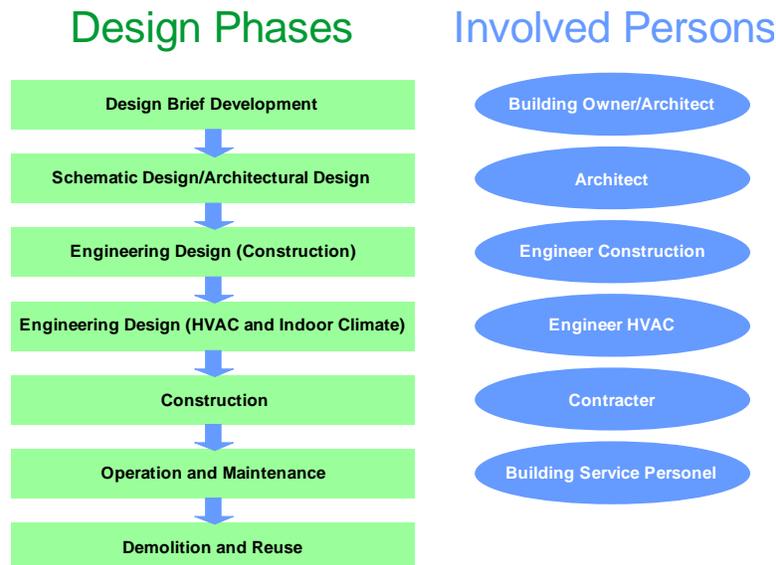


Figure 1. Sequential design process.

Before the advent of modern design practices, buildings were protected from the inclement weather or designed to take advantage of fair weather through orientation and strategic placement of entrances and windows. Similarly, the use of natural

lighting was planned into the building design. Architects utilised a number of design features such as atriums, light shelves, or narrow building designs to bring natural lighting into building interiors. Other techniques were also used to keep buildings comfortable in the summer, ranging from finishing the building exterior in light colours to introducing natural ventilation via thermal stacks. In contrast modern construction seldom considered orientation, building shape, daylighting features or passive cooling techniques. Clearly, there was a need for architects and HVAC designers to consider the implications of building design on the resulting energy use. This ultimately required the development of a process that emphasised the use of passive (i.e., weather integration) and active (i.e., mechanical systems) techniques to meet all comfort needs.

Integrated Design Process

Today, the construction industry is in the early stages of a revolution to reinvent the design process that was used before the advent of HVAC equipment. Design teams including both architects and engineers are formed and the building design is developed in an iterative process from the conceptual design ideas to the final detailed design. Building energy use and HVAC equipment size are reduced without the use of sophisticated technologies, but only through an effective integration of the architectural and HVAC designs. The integrated design approach achieves this improved energy utilisation due to the relationship that exists between the building, its architecture and the HVAC equipment. Besides this, the integrated design approach also achieves an improvement in the environmental performance of the building, as well as fewer construction problems and lower costs.



Figure 2. Integrated design process.

1.1.2. Motivation and benefits of integrated design

The most important advantage of the integrated design approach is illustrated in figure 3. The figure indicates how the effectiveness of decisions declines during the various stages of the life of a building. The effectiveness is defined as the relation between the

impact of the decision on the final building performance and the cost of the action needed to implement the decision. The decisions made early have the greatest impact on the performance and the efficiency of a building for its entire 50- or 100-year life, while the cost is often minimal.

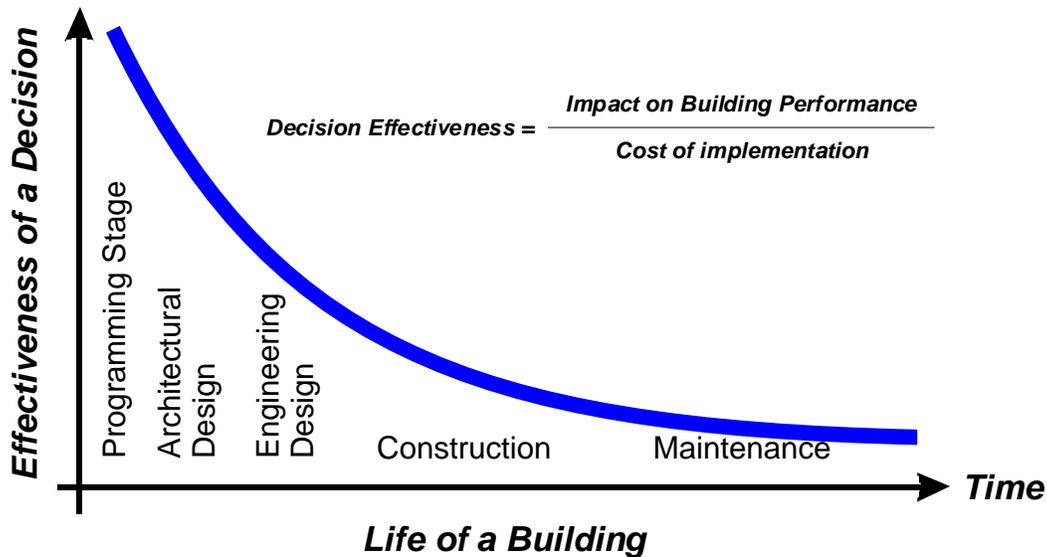


Figure 3. Effectiveness of decisions made in different stages of a buildings lifetime.

In a sequential design process it is much harder for an engineer at the later stages of design to have the same impact as the architect has at the conceptual design stage and the risk that poor design concepts are developed is therefore higher.

There are a number of serious consequences if the proper decisions are not made at the conceptual design stage. The building will almost certainly cost more to build and operate (e.g. it often takes huge air conditioning equipment and much energy to compensate for poor orientation, window placement etc.). The cost is not only in terms of money, but also in the depletion of non-renewable resources, in the degradation of the environment and often also in poorer building performance in terms of comfort. Inefficient buildings contribute significantly to pollution and the greenhouse effect, which is likely to negatively alter life on earth.

An integrated design process ensures that the knowledge and experience gained by an analytical consideration of design is formalized, structured and incorporated into the design practice.

In the integrated design process the expertise of the engineers is available from the very beginning, at the preliminary design stage, and the optimisation of the architectural and HVAC designs can start at the same time as the first conceptual design ideas are developed. The result is that participants contribute their ideas and their technical knowledge very early and collectively. The concepts of energy and building equipment will not be designed complementary to the architectural design but as an integral part of the building very early.

1.1.3. Implementation barriers

A number of barriers appear when the borderline between architecture and engineering is crossed and the design process contains a lot of challenges to the persons or groups who participate in the process.

Architects belong to the humanistic arts tradition while the engineer belongs to a technical natural science tradition. This often creates problems for architects and engineers working as a team, as the communication between the two groups relies on a common language and in this case the languages are at the outset very different.

The integrated design process is a holistic method that intertwines knowledge elements from engineering with the design process of architecture to form a new comprehensive strategy to optimize building performance. This implies evaluation and weighting of very different building performance characteristics that are often non-comparable and requires willingness from all participants to reach acceptable compromises.

The goal of integrated design is an improved and optimized building performance for the benefit of the building owner and the occupants. Changes in design process and methods will require investment in education and will always be more expensive for the designers in the beginning. Therefore it cannot be expected that architects and engineering consultants will be the main drivers for these changes unless the building owners and clients recognize the benefits and are willing to contribute to the investments needed to implement the changes.

1.2. Sustainable Building Design Principles

Developments in building energy efficiency over the last decade have focused on efficiency improvements of specific building elements like the building envelope, including its walls, roofs and fenestration components and building equipment such as heating, ventilation, air handling, cooling equipment and lighting. Significant improvements have been achieved and, whilst most building elements still offer opportunities for efficiency improvements, the greatest future potential lies with technologies that actively respond to changing conditions and also promote the integration of building design, building construction and building services.

In this perspective *Integrated Building Concepts* can be defined as solutions where the building and its responsive building elements together with building services and renewable energy systems are integrated into one system in order to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality. *Responsive Building Elements* are defined as building construction elements which are actively used for the transfer of heat, light and air. This means that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling and ventilation and also with renewable energy systems and energy storage. With the integration of responsive building elements, building services and renewable energy systems, the requirement for building design completely changes from the design of individual systems to the integrated design of “whole building concepts, augmented by “intelligent” systems and equipment. Application of integrated design methods therefore goes hand in hand with the development of the next generation of sustainable buildings.

1.2.1. Integrated Building Concept

A whole building concept or integrated building concept includes all aspects of building construction (architecture, facades, structure, function, fire, acoustics, materials, energy use, indoor environmental quality, etc...). It can be defined to consist of three parts (Heiselberg et al. 2006):

- the architectural building concept,
- the structural building concept and
- the energy and environmental building concept

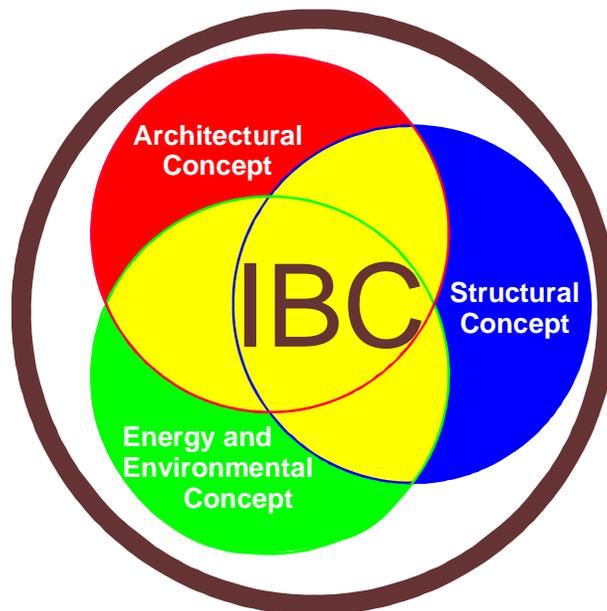


Figure 4. Illustration of the Integrated Building Concept. (Heiselberg et al. 2006).

This corresponds to the three different main professions involved and each concept is developed in parallel by the three professions using their own set of methods and tools - but in an integrated design process leading to an integrated solution – the Integrated Building Concept.

1.2.2. Classification Energy and Environmental Building Concepts

The purpose of a classification of is to define/specify what is meant by the concept and to get an idea of what direction to take in the conceptual and preliminary design phase.

A general classification should not be too complicated and not with too many categories. An “Energy and Environmental Building Concept” can be classified according to the following categories and parameters; see table 1:

Table 1. Categories and parameters for classification of Energy and Environmental Building Concepts. (Heiselberg et al. 2006).

Category	Parameter
Climate	Cold, moderate, warm, hot-dry, hot humid, ...
Context	Urban, suburban, rural
Building use	Office, school, residential, ...
Building type	High-rise, low-rise, row-houses, single houses, multifamily buildings, ...
Demand reduction strategies	Thermal insulation, air tightness, buffering, reduction of heat and contaminant loads, building form, zoning, demand control, efficient air distribution, solar shading, ..
Control strategy	Natural mechanism, adaptive/rigid, user control/automatic
Renewable energy technologies	Passive and active solar heating, wind, natural cooling, geothermal heat/cool, biomass, daylighting, natural ventilation,..
Efficient energy conversion	CHP, HE gas boiler, heat pump, ...
Energy Supply Network	District heating, Electricity, Gas, ...

In the development of existing energy and environmental building concepts the main focus has typically been on some of the available technical solutions. Examples are:

- The “Passive House” concept which mainly focuses on super insulated and air tight envelopes combined with high efficiency heat recovery of ventilation air
- The “Solar House” concept which mainly focuses on utilization of renewable energy technologies such as passive and active solar heating and solar cells
- The “Smart House” concept which mainly focuses on advanced solutions for demand control and efficient use of fossil fuel technologies
- The “Adaptive Building” concept in which building elements actively respond to changing climate conditions and indoor environmental conditions as required by the occupants

These concepts are clearly the result of a sub-optimisation by an expert in either building physics, renewable energy or control engineering.

1.2.3. The Climatic Design Principle

Climatic design principles are essential to achieve an optimum energy and environmental building concept. Climatic design is the art and science of using the beneficial elements of nature – sun, wind, earth and air temperature, plants and moisture – to create comfortable, energy-efficient and environmentally wise buildings. The desirable procedure is to work with, not against, the forces of nature

and to make use of their potentialities to create better living conditions. The principles of climatic design derive from the requirement for creating human comfort in buildings using the elements of the natural climate. Perfect balance between natural resources and comfort requirements can rarely be achieved, except under exceptional environmental circumstances, and the climatic design will vary throughout the year depending upon whether the prevailing climatic condition is “underheated” compared to what is required for comfort (i.e., as in winter) or “overheated” (i.e., as in summer).

Figure 5 summarizes the set of climatic design principles that follow logically from these climatic extremes and will apply to nearly all climates.

In order to create the conditions for comfort during winter (underheated) conditions, the designer obviously aims to “resist heat loss” and to “promote heat gain”. Resisting heat loss can be achieved by using insulation and other techniques to retain heat inside the occupied space (minimize conductive heat flow), by constructing an airtight building envelope to reduce heat loss by air infiltration (and exfiltration) and by application of wind breaks to shield the building from dominating winter winds to reduce winter wind-chill and cooling effects. Promoting heat gain can be achieved by application of passive solar technologies combined with buffer zones and high building thermal mass to reduce the daily temperature variations.

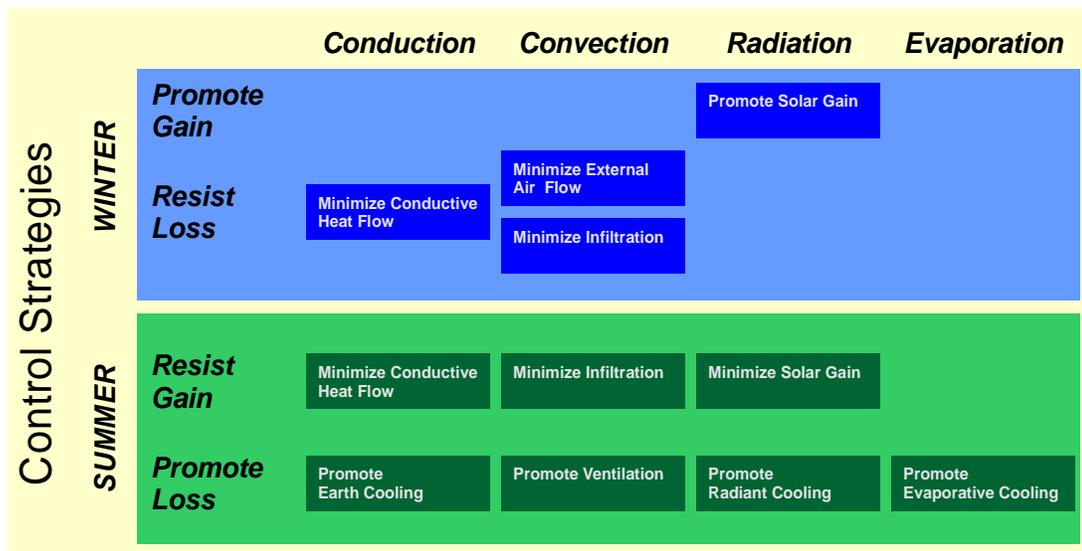


Figure 5. Summary of the principles and strategies of climatic design /Watson and Labs/.

To provide comfort during summer (overheated) conditions, the design goals are reversed and the aim is to “resist heat gain” and to “promote heat loss”. In summer resisting heat gain also include application of insulation and airtight envelopes to avoid heat exchange with the outside environment. However, it is often more important to apply passive cooling techniques as reduction of internal heat loads, application of thermal mass to dampen temperature variations and application of solar shading to reduce the solar heat gain but at the same time ensure a satisfactory daylight level. Promoting heat loss is achieved by utilizing natural cooling technologies as earth cooling either by conductive heat loss through the building construction or by pre-cooling of outside air, by using vegetation and other water evaporation techniques to cool outside (and inside) air, by exposing the building

construction to the “night sky” to cool it by “sky” radiation and by utilizing natural ventilation during night time with cool outside air (night cooling).

The principles can appear to be contradictory, that is, to “promote solar gain” in winter and to “resist solar gain” in summer or “to minimize infiltration” and “promote ventilation” in summer. In the case of solar radiation, the sun co-operates by its seasonal change of position with respect to the building – the design of a properly oriented and shaded “solar window” resolves the conflict optimally by maximising winter sun and summer shade. In the case of infiltration and ventilation the focus is on the possibility for control, where infiltration will be dominating in daytime (warm outdoor conditions) while ventilation can be controlled and mainly used during night time (cool outdoor conditions). In other instances, the principles do conflict and a compromise must be reached, as in the case of application of solar shading and at the same time achieving acceptable daylight levels.

From this overall set of principles, the designer selects those most appropriate to the actual building case and site according to a climatic analysis.

1.2.4. Design strategy for Energy and Environmental Building Concepts

In order to reach an integrated design solution and develop an Energy and Environmental Building Concept it is necessary to define and apply a certain design strategy.

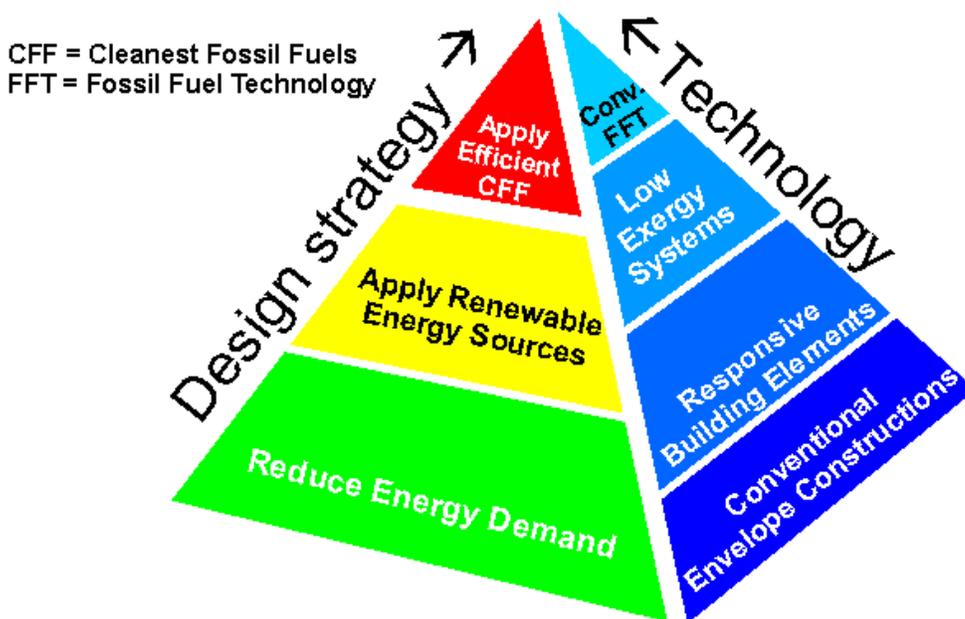


Figure 6. Illustration of Energy and Environmental Design Strategy and corresponding Technologies applied. (Heiselberg et al. 2006).

The design strategy illustrated in figure 6 is based on the method of the “Kyoto Pyramid”. The *Kyoto Pyramid* is a strategy that has been developed for the design of low energy buildings in Norway, (Dokka and Rødsjø, 2005). It is based on the Trias Energetica method described by Lysen (1996). The left side of the pyramid shows the design strategies, and the right side of the pyramid shows the technical solutions that

may be applied in each of the steps. In the integrated design strategy, you start at the bottom of the pyramid, applying the strategies and technologies as follows:

- *Reduce Demand*

Optimize building form and zoning, apply super insulated and air tight conventional envelope constructions,

Ensure low pressure drops in ventilation air paths, apply efficient appliances to reduce heat load, etc.

Apply Responsive Building Elements if appropriate, including advanced façades with optimum window orientation, exploitation of daylight, proper use of thermal mass, redistribution of heat within the building, dynamic insulation, etc.

- *Utilize renewable energy sources*

Provide optimal use of passive solar heating, daylighting, natural ventilation, night cooling, earth coupling. Apply solar collectors, solar cells, geothermal energy, ground water storage, biomass, etc.

Optimise the use of renewable energy by application of low exergy systems.

- *Efficient use of fossil fuels*

If any auxiliary energy is needed, use the least polluting fossil fuels in an efficient way, e.g. heat pumps, high-efficient gas fired boilers, gas fired CHP-units, etc.

Apply efficient heat recovery of ventilation air during heating season, apply energy efficient electric lighting. Provide intelligent control of system including demand control of heating, ventilation, lighting and equipment

The main benefit of the method is that it stresses the importance of reducing the energy load before adding systems for energy supply. This promotes robust solutions with the lowest possible environmental loadings.

Application of the strategy in the conceptual and preliminary design of the heating, cooling, lighting and ventilation of buildings can be accomplished in the following way. The first step is to establish the function of the building envelope as the primary climatic modifier, supported by the services to trim conditions. It is the aim of the design of the building itself to minimise heat loss in winter, to minimise heat gain in summer, and to use light and fresh air efficiently. Decisions at this step determine the size of the heating, cooling and lighting loads and good fabric design is essential for minimising the need for services. Poor decisions at this point can easily double or triple the size of the mechanical equipment eventually needed. Where appropriate, designs should avoid simply excluding the environment, but should respond to factors like weather and occupancy and make good use of natural light, ventilation, solar gains and shading, when these are beneficial.

At an early stage, it should be possible to modify the design to reduce the capacity, size and complexity of the building services, which can reduce the capital cost of the services without having to remove features from the design. The second step involves optimisation of internal gains, passive heating, passive cooling, daylighting techniques and natural ventilation, which actually heat the building in the winter, cool

it in the summer and light and ventilate it all year. Proper decisions at this point can greatly reduce the loads as they are created during the first step leading to the wanted reduction in size and complexity of the building services. In general, a “simple” approach is the best way of promoting good installation, operation and maintenance. Simple services promote good understanding of how the building and plant is intended to work. This generally improves building management and hence energy efficiency.

Step three consists of designing the building services to handle the loads that remain from the combined effect of steps one and two and of ensuring that the services operate in harmony without detrimental interaction or conflict. Many energy problems can be traced to a conflict between building services and many conflicts between services are control issues. An energy efficient design strategy should avoid this and the underlying reasons for conflict should be identified and eliminated to prevent carrying a flawed design forward. It is not a good policy to hope that the control system will resolve the conflicts.

Figure 7 shows the design considerations that are typical at each of these stages.

	Heating	Cooling	Lighting	Ventilation
Step 1	Conservation	Heat avoidance	Daylight	Natural ventilation
Basic Design	1. Surface to volume ratio 2. Insulation 3. Infiltration	1. Shading 2. Exterior colours 3. Insulation	1. Windows 2. Glazing 3. Interior finishes	1. Building form 2. Windows and openings 3. Stacks
Step 2	Passive solar	Passive cooling	Daylighting	Natural ventilation
Climatic design	1. Direct gain 2. Thermal storage wall 3. Sunspace	1. Evaporative cooling 2. Convective cooling 3. Radiant cooling	1. Skylights 2. Light shelves 3. Light wells	1. Single sided ventilation 2. Cross or stack ventilation 3. Air distribution 4. Control strategy
Step 3	Heating system	Cooling system	Electric light	Mechanical ventilation
Design of Mechanical Systems	1. Radiators 2. Radiant panels 3. Warm air system	1. Refrigeration machine 2. Cooled ceiling 3. Cold air system	1. Lamps 2. Fixtures 3. Location of fixtures	1. Mechanical supply 2. Mechanical exhaust 3. Mixing or displacement principle

Figure 7. Typical design considerations at each design stage /revised from Norbert Lechner/.

The heating cooling, lighting and ventilation design of buildings always involve all three steps whether consciously considered or not. As mentioned before, minimal demands have in the recent past been placed on the building itself to affect the indoor environment. It was assumed that it was primarily the engineers at the third step who were responsible for the environmental control of the building. Thus architects, who were often indifferent to the heating and cooling needs of buildings, sometimes designed buildings with large glazed areas for very hot or very cold climates, and the engineers would then be forced to design giant heating and cooling plants to maintain thermal comfort. On the other hand, when it is consciously recognized, as in an integrated design process, that each of these steps is an integral part of the heating, cooling, lighting and ventilation design, better buildings result.

The buildings are better for several reasons. They are often less expensive because of reduced mechanical equipment and energy needs. Frequently they are also more comfortable because the mechanical equipment does not have to fight such giant loads. Buildings and services are often responsive to the needs of the occupant and therefore generally more successful in achieving comfort, acceptability and efficiency. Occupants usually prefer some means of altering their own environment while management will require good overall control of systems.

The importance of a comprehensive approach to energy utilisation is illustrated by a parametric study conducted for the design of a new office building in Copenhagen., where the influence of the glazing area relative to the total facade area on primary energy consumption was modeled. Any increase in glass area facing east or west resulted in increased heating or cooling demands. The obvious conclusion based on this condition alone would be to minimise the glass area. Conversely, increasing the glass area to 45% of the facade area strongly decreases the electricity demand for lighting. When primary energy demand for heating, cooling and lighting are considered together, then increasing the glass area to 40% of the facade area results in increased total energy savings; see figure 8. The savings in electricity from daylighting have a dominant influence because of the assumption that thermal energy is produced with an efficiency of 67% versus an efficiency of 27% for energy in the form of electricity. It should be emphasized that the conclusions will always be case specific as they depend on the specific climate, the type of energy production and distribution, the type of glazing, etc.

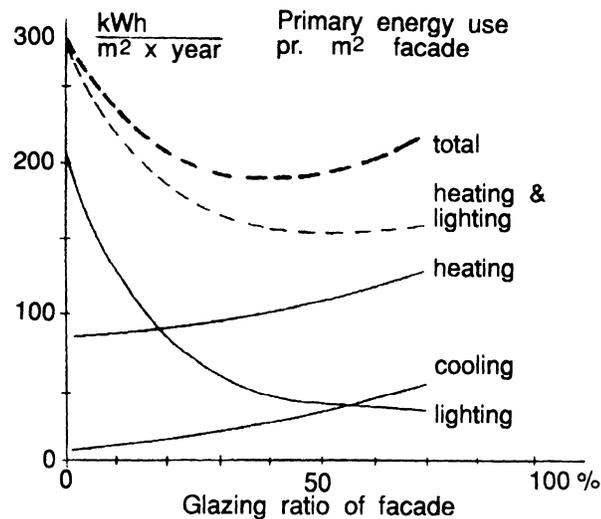


Figure 8. Primary energy use per m^2 double glazed windows facing east or west in Copenhagen. /Kristensen and Esbensen/

However, it should not be forgotten that a successful development of an energy and environmental building concept also depends on the understanding of the interactions between the occupants, the building fabric and the buildings services as illustrated in figure 9. This includes a building design that are adapted to the climatic conditions and the building use requiring a minimum effort of building services and user controls to achieve acceptable indoor environmental conditions. It includes the design of

building services that fit to the needs of the building and the users and that can be controlled according to the changes in these needs due to changes in outdoor climate and building use. It also includes appropriate strategies for user control of both building services and building components that are understandable and accessible for the users and which results in quick and visible changes of the indoor environment.

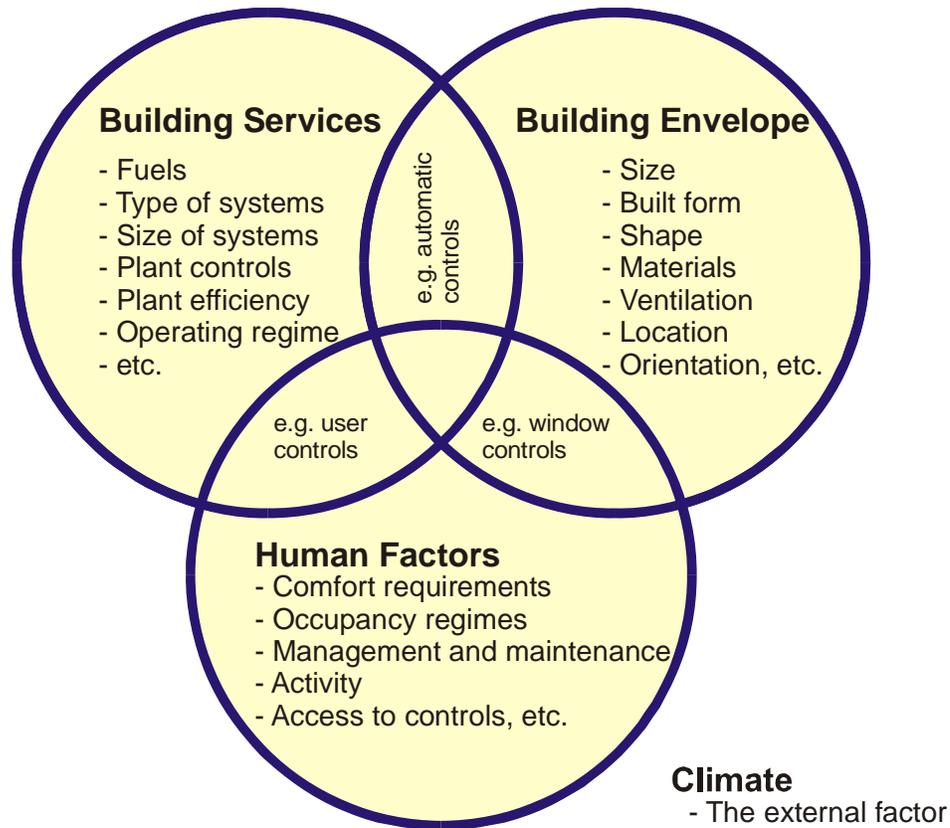


Figure 9. Key factors that influence energy consumption /CIBSE Guide/.

1.3. Integrated Design Process

The Integrated Design Process, IDP, creates a synergy of competencies and skills throughout the process by the inter-disciplinary work between architects, engineers, costing specialists, O&M personnel and others, right from the beginning of the process. It ensures that the different knowledge of specialists is introduced at an early project stage and takes into account a wide variety of opportunities and options from the very outset. It involves modern simulation tools, and leads to a high level of systems integration. It enables the designer to control the many parameters that must be considered and integrated, when creating more holistic sustainable buildings. All of this can allow clients to obtain a very high level of performance and reduced operating costs, at very little extra capital outlay.

The method copes as well with technical as with aesthetic problems that must be solved in an integrated building design, and focuses on the creative element in the process, in order to identify new opportunities and to derive innovative solutions in a new building design. Therefore the architect's artistic approach to the creation of

ideas; his ability to see new possibilities and his ability to work in a strategic and interdisciplinary manner, interacting with the engineer's strategic and creative ideas for developing energy and environmental concepts, are very important. Doing this, without losing creativity in the process, is always very important in designing new integrated building concepts.

This section is based on the work developed in the international project IEA-SHC Task 23 Optimization of Solar Energy Use in Large Buildings. This section presents the integrated design principles developed in IEA SHC Task 23 and is summarized from the following publications:

- Larsson, N. and Poel, B. (2003). Solar Low Energy Buildings and the Integrated Design Process – An Introduction, IEA SHC Task 23 Optimization of Solar Energy Use in Large Buildings. Available from <http://www.iea-shc.org/task23/> .
- Löhnert, G., Dalkowski, A., Sutter, W. (2003) Integrated Design Process – A Guideline for Sustainable and Solar-optimized Building Design. Berlin/Zug, April 2003. IEA SHC Task 23 Optimization of Solar Energy Use in Large Buildings. Available from <http://www.iea-shc.org/task23/>.

IEA SHC Task 23 participants and the authors are gratefully acknowledged. A detailed description of the project and a complete list of publication are available from the project website, see www.iea-shc.org/task23/.

1.3.1. Design Team

In the IDP process, the architect is not the only person to make decisions, although he retains his guiding function through his position as team leader and moderator. He/she gains knowledge of technical solutions while the engineers are simultaneously gaining insight into the complexity of the architectural design process.

An Integrated Design Process especially affects the design team as:

- the client takes a more active role than usual,
- the architect becomes a team leader rather than the sole form-giver and
- the mechanical and electrical engineers as well as the energy specialist take on active roles at early design stages

If these qualifications cannot be ensured, or if there is additional need for support of energy and integrated design process management, then the support of an experienced Facilitator, see Figure 10 can be used. In contrast to the role of the quite commonly involved project manager, the Design Facilitator should be a specialist in architectural and technical energy design solutions and integrated process co-ordination, and should also possess outstanding skills in communication, team management and mediation.

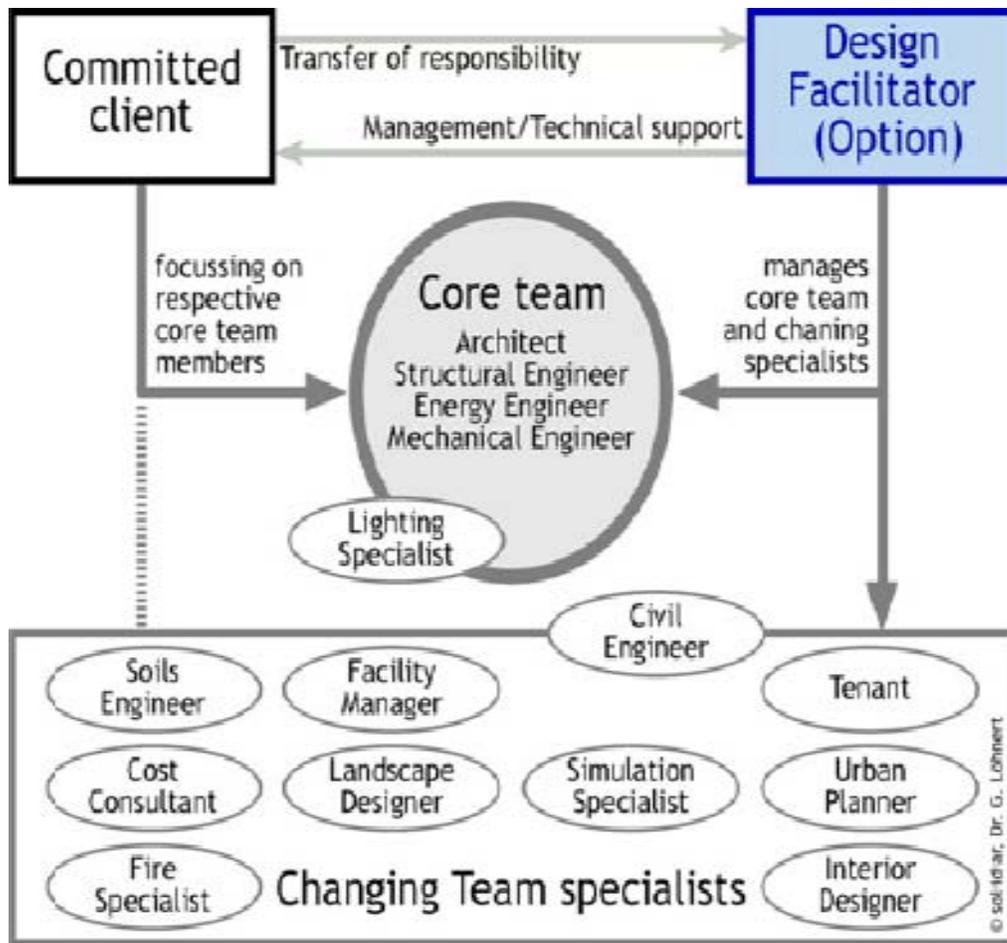


Figure 10. Example of integrated design team organization, (IEA SHC Task 23, 2003).

1.3.2. Design Process

The integrated design process works with the architecture, the design, functional aspects, energy consumption, indoor environment, technology, and construction e.g. It is important to consider the whole process, structuring it into clearly defined sequences to improve the overview of goals, activities, actors and products and to switch between them in a timely and content-based manner, because the roots of many problems can frequently be traced to faulty or inadequate preparation.

The traditional overall linear design procedure marked by milestones reflecting a series of rough phases is necessary both in terms of the organization of the collective decision making and for the efficient division of tasks and work. In this view, the sequential linear process is an organizational prerequisite with the building design logically structured into chronological sequences.

In contrast to this overall linear process, the intermediate workflows of involved actors in each rough phase are far from being linear. Such workflows can be characterized by iteration loops, see figure 11. These loops provide problem-oriented analyses of design alternatives and optimisation taking into consideration input from other specialists, influences from context and society that provide possibilities and/or

limitations to design solutions as well as evaluates the solutions according to the design goals and criteria.

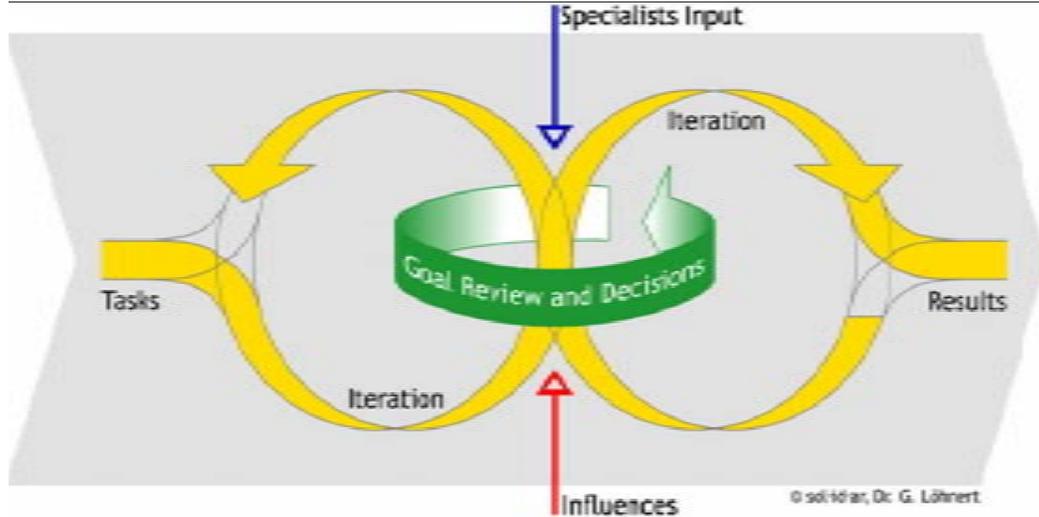


Figure 11. Principle of design iteration loop, (IEA SHC Task 23, 2003).

The actual design process is made up of a number of roughly-defined phases, which demand individual iterations within the phases, and is accompanied by a continuous review of project goals, objectives and criteria which serve as a “roadmap” throughout the entire design process.

The nature of these iterations varies between the phases depending on the depth of the problems considered and is characterized by shifts between problems defined and corresponding solutions obtained at different stages in the design process. Designers need to be mindful of the interfaces between the iterative workflows, which are characterized by initial tasks, (interim or partial) results and findings at the end. These transitions, acting as interfaces between two design phases, need to be organised by qualified project management which uses clear decisions and careful process documentation to prevent any losses of information.



Figure 12. Principle of integrated design process, (IEA SHC Task 23, 2003).

1.3.3. Main Design Phases

The **Integrated Design Process (IDP)** includes the following main phases:

Design Brief Development

This stage includes definition of design goals, objectives and criteria as well as preliminary feasibility studies. For sustainable building design it is especially important that the phase includes definition of energy targets, environmental targets, life cycle costs and requirements to undertake an integrated design. The outcome is the building design brief.

Pre-Design

Analysis of site potential including wind, sun, landscape and urban development plans. Analysis of clients' profile and chart of functions. Create a roadmap of principles of energy systems, renewable energy systems, indoor environment and construction solutions. The outcome is an analysis of the context, site and building design potentials and a roadmap of possible design strategies

Conceptual Design

Through the sketching process, architectural ideas and concepts are linked to principles of construction, energy and environmental building concepts, indoor environment as well as to functional demands. Different conceptual design solutions are developed and their relative merits are continuously evaluated, including their architectural qualities, against the goals in the building design brief. The outcome is an integrated building concept.

Preliminary Design

In this phase the building concept develops into specific architectural and technical solutions through sketches and more calculations, adjustments and optimisation until the design goals and objectives are met. Architectural, space and functional qualities, the construction and demands for energy consumption and indoor environment flow together in this phase. A new building has been created.

Detailed Design

In this phase the technical solutions are refined and design documents are created including final drawings and specification in cooperation with building companies, suppliers and product manufacturers. The outcome is a comprehensive description of the entire project.

Contracting and Execution

During the building construction, supervision is provided to ensure understanding of the importance of energy and environmental issues. This phase also includes quality control and partial commissioning. The outcome is a building constructed according to design goals and objectives.

Commissioning and Building Hand-Over

In this phase the building is commissioned to ensure proper function of all structural and technical systems and the building is handed over to the building owner and occupants.

Building Operation and Maintenance

Long-term high energy and environmental performance requires adequate building management and maintenance, continuous monitoring of building performance and evaluation of performance evolution in time.

1.4. Integrated Design Phases

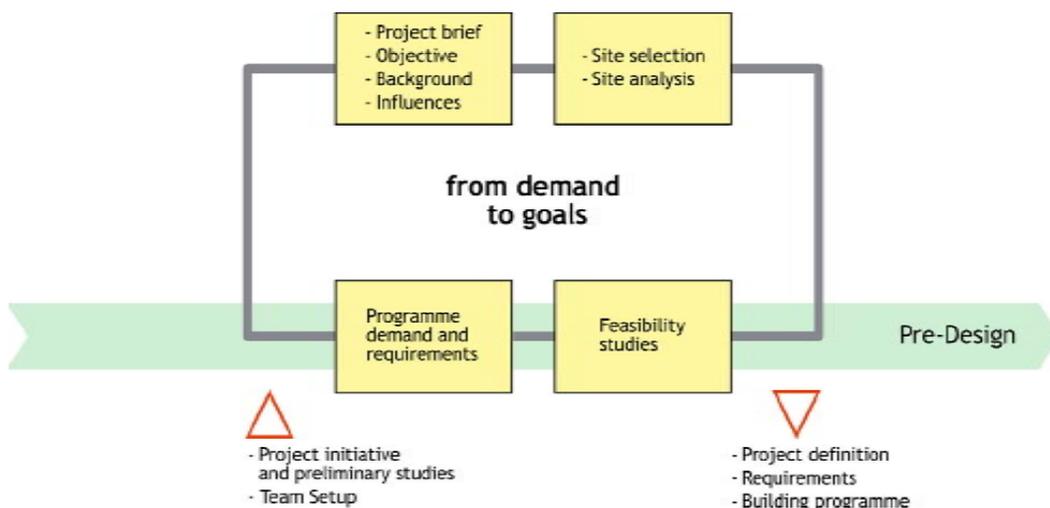
The following sections summarize important considerations to be applied during the different phases of the integrated design process. It contains detailed notes related to individual design phases for the purpose of expanding and supplementing the expositions regarding the recommendations concerning the overall process.

In addition to the actual recommendations, important optimisation steps for each design phase are presented in graphic form as “iteration loops”. Necessary input and output dimensions for the iterations are also described at this point, see figure 12.

This section is based on the work developed in the international project IEA-SHC Task 23 Optimization of Solar Energy Use in Large Buildings. This section presents the integrated design method developed in IEA SHC Task 23 and is summarized from the same publications as section 2.3.

IEA SHC Task 23 participants and the authors are gratefully acknowledged. A detailed description of the project and a complete list of publication are available from the project website, see www.iea-shc.org/task23/.

1.4.1. Design Brief Development



(IEA SHC Task 23, 2003).

Purpose and Goals

To describe and define the project and develop the building design brief including definitions of requirements including consensus goals, benchmarks and performance target values.

Relationship to other design phases

The starting point is the results of preliminary studies and a feasibility study for the building project.

Description of actors

The building owner/builder together with a preliminary design team, which is established with core design team members.

Description of activities

This stage includes definition of design goals, objectives and criteria as well as preliminary feasibility studies. For sustainable building design it is especially important that the phase includes definition of energy targets, environmental targets, life cycle costs and requirements to undertake an integrated design.

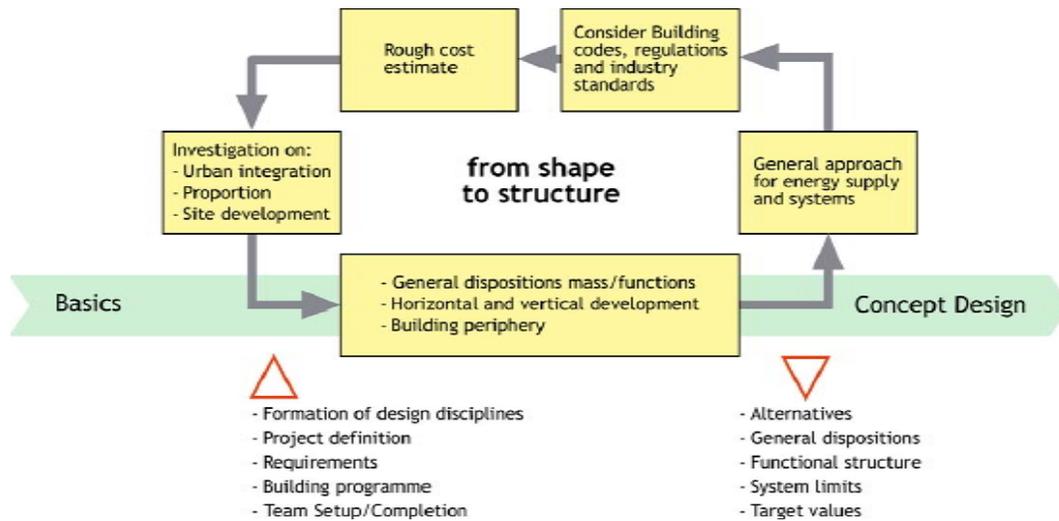
Activities include:

- Check client wishes and objectives for feasibility and completeness.
- Create a flexible functional programme capable of supporting mixed use requirements and expectations.
- Identify and analyse restrictions and options of fundamental importance to the project and weight them against one another. Arising goal conflicts should be discussed and documented carefully.
- Perform an analysis of the building site. The client or project manager and possible users should be actively involved at this stage.
- Use of innovative technologies should lead to an investigation of relevant norms, standards and guidelines in order to be able to better assess the scope of the project in organizational and technical terms.
- Coordinate basic structures, milestones and methods of communication as a basis for efficient co-operation between actors including the review of energy and environmental goals at appropriate times.
- Financial limits or budget reservations should be fixed after careful feasibility studies or (at a minimum) be based on comparison studies with comparable reference projects.
- Client commitment to supporting measures required for high performance should be translated into measurable benchmarks and confirmed by target values.
- A clear definition of sustainability-related goals should serve as a roadmap and can only be carried out by synthesising project-related aspects (risks and chances). A review of goals and objectives along with the program requirements for the project must be taken over by competent team members and can be assisted by assessment tools to ensure compatibility of design criteria.
- As key player, the client must be involved in the goal-defining process and has to be convinced of the meaning and complexity of this process. Working together, client and architect are responsible for synchronising the goal-defining process between individual actors and the entire design process.
- Appropriate selection of priorities and main focuses makes for an early definition of quality and influences throughout the course of a project.

Description of main products

The main products are a project definition and a building design brief

1.4.2. Pre-Design Phase



(IEA SHC Task 23, 2003).

Purpose and Goals

To analyse the site potentials including wind, sun and landscape, urban development plans. To analyse the clients' profile and develop ideas for chart of functions. Create a roadmap of principles of energy systems, renewable energy systems, indoor environment and construction solutions.

Relationship to other design phases

The starting point is the building design brief, the context and the completed design team.

Description of actors

The building owner, core design team members and financial experts

Description of activities

The pre-design phase encompasses an analysis of all the information that has to be procured before the designer of the building is ready to begin the sketching process, e.g. information about the site, the architecture of the neighbourhood, topography, vegetation, sun, light and shadow, predominant wind direction, access to and size of the area and neighbouring buildings. The designer has to consider demands coming from regional plans, municipality plans and local plans. Furthermore, it is important to be aware of special qualities of the area and the sense of the place; genius loci.

Through the analysis phase, detailed information is procured about the client's demands for space; logistics are discussed etc. The architectural demands a chart of functions which can lend inspiration to the design of the building. It is also decided at this stage if the new building is going to have an iconic character at the site or in the urban landscape.

It is also especially important to decide the principles for fulfilling the targets for energy use (heating, cooling, ventilation, lighting) and indoor environmental quality (thermal, comfort, air quality, acoustics, lighting quality) of the new building as well as criteria for application of passive technologies (natural ventilation, day lighting, passive heating, passive cooling). These criteria should be developed taking into account the local climatic conditions and the available local energy distribution network. Other criteria include wishes from client as life cycle assessments concerning materials, solar cells etc. so that these can be integrated required.

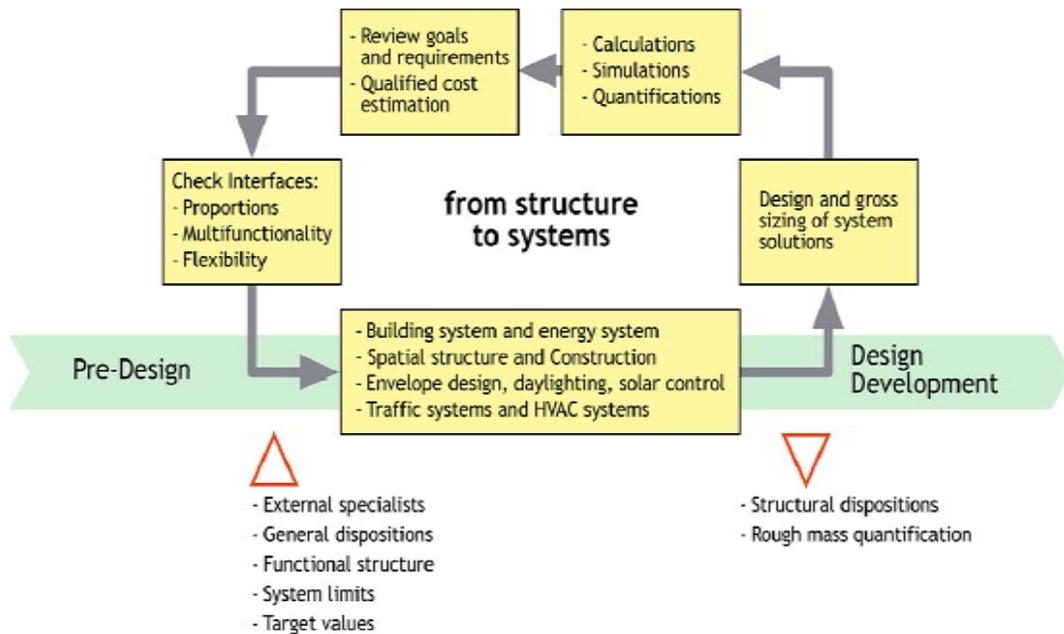
Additional activities include the following:

- A “kick-off” workshop is recommended for the entire project team, including the client, all design disciplines, financial experts and, if possible, occupants or operators to discuss and firm up specific sustainable goals.
- The overall goals and the building programme for the project have to be carefully examined for completeness and contradictions. Subsequently, the design team has to transfer clients' needs and demands into programme requirements; prescriptive and performance criteria and benchmarks for the design progress.
- All actors should agree on basic objectives and technical strategies regarding sustainable design, construction and operation performances. This presupposes that the actors' different perceptions of the building concept are considered seriously and are discussed adequately.
- In addition to technical aspects, initial cost estimates must be included in basic discussions on alternative design concepts and technologies.
- The project budget and costs are set by the client, but it is the design team which has to recommend cost allocations for building and energy systems, equipment and individual construction trades based on qualified estimates and evaluation.

Description of main products

The outcome is an analysis of the context, site and building design potentials and a roadmap of possible design strategies. The analysis phase goals and wishes to the building as well as a room programme is put into an architectural programme.

1.4.3. Conceptual Design Phase



(IEA SHC Task 23, 2003).

Purpose and Goals

Through the sketch-plan process, to link the architectural ideas and concepts to principles of construction, energy and environmental building concepts, indoor environmental concepts as well as the functional demands. To develop different conceptual design solutions and to evaluate their relative merits, as well as the architectural qualities, against the goals set out in the building design brief.

Relationship to other design phases

The work in this phase is based on the building design brief and a refinement of the analysis in the pre-design phase.

Description of actors

The core design team complemented by external specialists.

Description of activities

The conceptual design phase is the phase where the professional knowledge of architects and engineers is combined to provide mutual inspiration in the Integrated Design Process, so that the demands and wishes for the building are met. This applies equally to the demands for architecture, design, working or living environment and visual impact, as well as to the demands for functions, construction, energy consumption, indoor environmental conditions and other quality criteria to be fulfilled such as architectural quality, thermal comfort, view to the outside, lighting quality, etc.. During the sketch-plan phase all defined criteria and target values are considered in the development and evaluation of design solutions. As well as demands for logistics and other demands, which are described in the architectural programme, (Knudstrup, 2004).

As mentioned above, in this phase the professional inputs from architecture and engineering are flowing together in the Integrated Design Process and interacting with each other. The precondition for designing an energy-saving or sustainable building in an Integrated Design Process is as follows: in the sketchplan phase the designer must repeatedly make an estimate of how his or her choices regarding the form of the building, the plans, the architectural programme, the orientation of the building, the construction and the climate screen influence the energy consumption of the building in terms of heating, cooling, ventilation and daylight – and how these choices inspire each other. The mutual influence and inspiration of all the above parameters must meet the demands which have been set up for the architectural, functional and technical aspects of the building, (Knudstrup, 2004).

The consequences of the technical choices are determined by means of rather simple calculation methods/models, which make it possible to compare and select solutions. From these calculations the group gains an insight into the parameters that really matter to the optimisation of the energy end indoor environmental performance. In this way the group can sketch out various well-founded solutions. At the same time they make an estimate of which of the sketchplans for the building meet the demands of architectural expression, and which do not, and with that in mind they make their choices.

Typically the different solutions have different strengths and weaknesses when the fulfillment of each of the different design criteria and target values is evaluated.

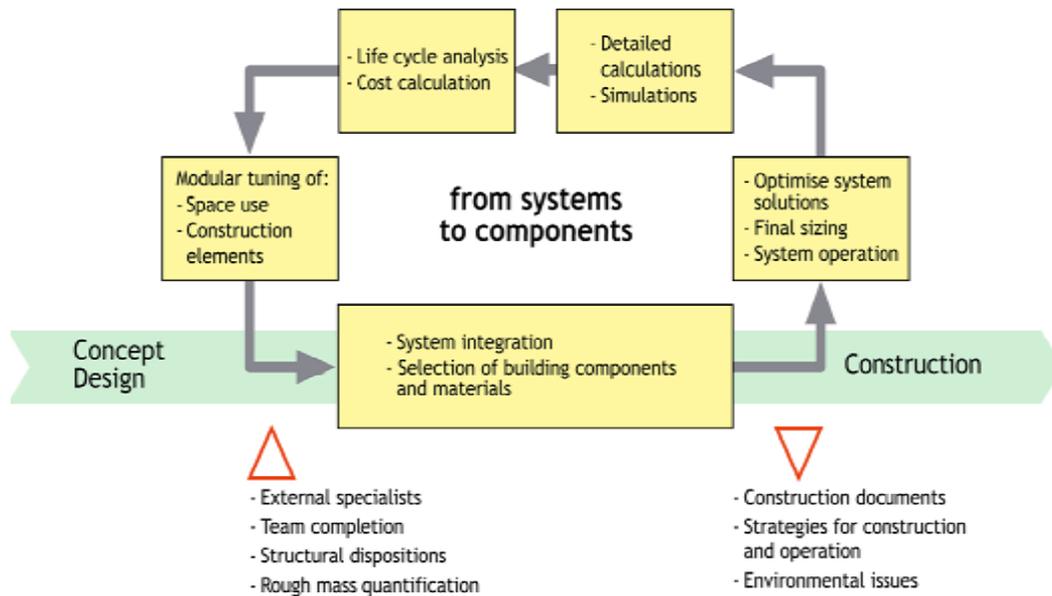
Additional activities include:

- Alternative design and system options have to be evaluated in terms of overall energy and environmental implications by identifying opportunities to take advantage of diversity in the initial design and sizing of equipment and controls.
- The development of different scenarios include a reference building, different owner/tenant requirements, already fixed and still “open” building elements. An anticipated future expansion or change should also reflect the possibly contradicting requirements between owner occupied and institutional or public developments versus speculative investor type project with unknown users.
- Environmental and energy **goals** have to be reviewed at appropriate points during design phase and verified against specific performance benchmarks identified in earlier stages.
- Preliminary assumptions have to be developed for the building envelope, natural lighting, water supply and disposal, acceptable building materials, etc. and capacities for mechanical systems (heating/cooling, ventilation and heat recovery) should be estimated with regard to reliability, flexibility, and costs.

Description of main products

The outcome is an integrated building concept.

1.4.4. Preliminary Design Phase



(IEA SHC Task 23, 2003).

Purpose and Goals

To further develop and refine the integrated building concept into specific architectural and technical solutions through sketches and more calculations, adjustments and optimisations until the design goals and objectives are met.

Relationship to other design phases

The work is based on the developed integrated building concept.

Description of actors

The core design team complemented by external specialists.

Description of activities

The preliminary design phase is the phase where the new building finds its final form, and where the demands in the aims and programme are met. Here the designer reaches a point in the design process where all parameters considered in the sketching phase flow together or interact – architecture, plans, the visual impact, functionality, company profile, aesthetics, the space design, working environment, room programme, principles of construction, energy solutions and targets and indoor environment technology form a synthesis (Knudstrup, 2004).

In the preliminary design phase the various parameters used in the project seen in Figure 13, should be optimised, and technical calculation models should document the final calculations regarding the energy and indoor environmental performance of the building. In this way the project reaches a phase where every item “falls into place”, and other possible qualities may be added (Knudstrup, 2004).

The project finds its final form and expression and a new building with – hopefully good – architecture, architectural space, aesthetic, and visual impacts, functional and technical solutions and qualities has been created.

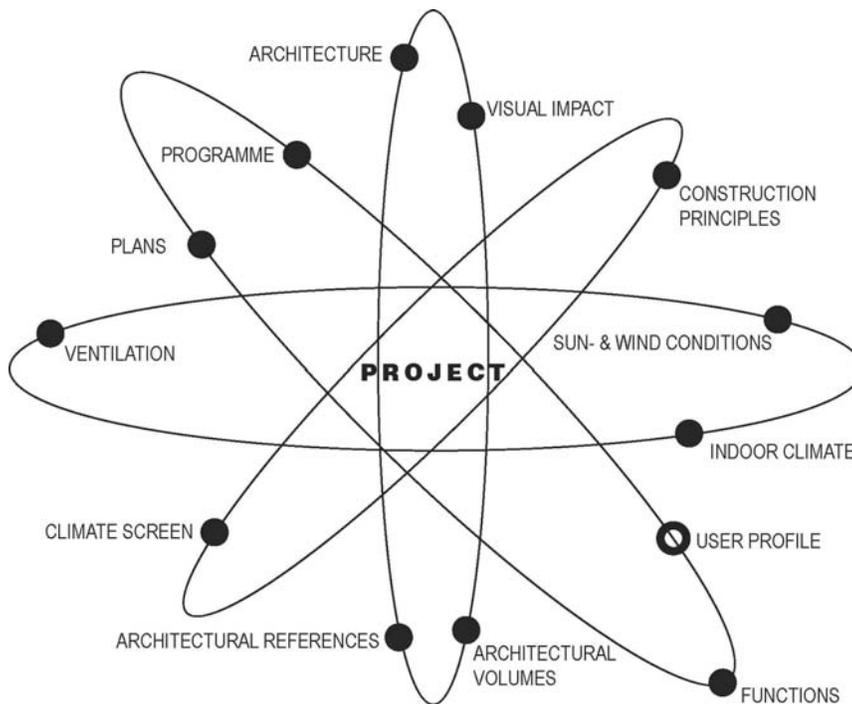


Figure 13. Illustrate the various parameters that are integrated in the Integrated Design Process (Knudstrup, 2004).

Additional activities include:

- The requests for components and materials pre-selected in previous phases have to be defined in accordance with the agreed-upon building structure and system. In particular, the development and use of innovative components should be examined if necessary by simulation and testing.
- Specifications of materials must be checked separately for environmental performance, such as high recycled content, ease of recycling and renewability. Additional information should be requested from producers.
- Potentials originating from a simplification of HVAC systems should be examined and identified in terms of their positive effects on building operation, maintenance, and utilisation.
- System optimisation includes fine-tuning the system components and evaluation of energy/cost efficiencies and performance of the entire HVAC equipment.
- Detailed drawings, calculations and distribution plans include mechanical, plumbing, electrical systems and definition of building thermal and electrical loads.
- Materials and details have to be evaluated in terms of energy and environmental implications. This includes detailed construction drawings on thermal performance of individual elements of the wall, roof and glazing;

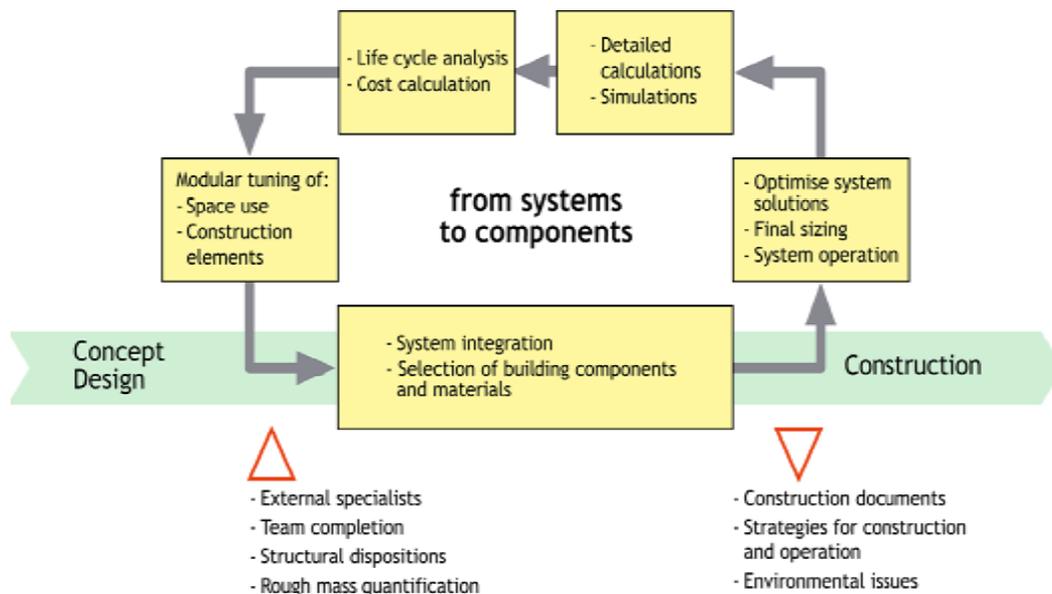
thermal resistance and thermal breaks; tightness of building envelope, vapour barriers and control of condensation, etc.

- Finally the high performance building strategies should be analysed with regard to their energy and cost performance, in order to review the environmental and energy goals and to check against specific performance benchmarks and target values identified early in the project.

Description of main products

The outcome is the specification for architectural solutions; structural and technical solutions and operation strategies. A performance report based on simulations should ensure fulfillment of the energy and environmental criteria and target values.

1.4.5. Detailed Design Phase



(IEA SHC Task 23, 2003).

Purpose and Goals

To refine the technical solutions and create design documents including final drawings and specification in cooperation with building companies, suppliers and product manufacturers.

Relationship to other design phases

Continuing the effort in the preliminary design phase.

Description of actors

The core design team complemented by external specialists, contractors, suppliers and product manufacturers.

Description of activities

The detailed design phase includes the establishment of the design documents including drawings and specifications, in a detailed form through discussions and

exchanges of information with building companies, suppliers, and product manufacturers. The final construction documents and specifications have to include all criteria, measurement and validation requirements in detail as well as descriptions and explanations necessary for energy and environmental performance. It is especially important that the bid documents should ensure that high performance goals and execution procedures are translated into clear project requirements. The results of energy and environmental analyses should be prepared to affirm design performance, including energy simulations and calculations and cost/benefit investigations.

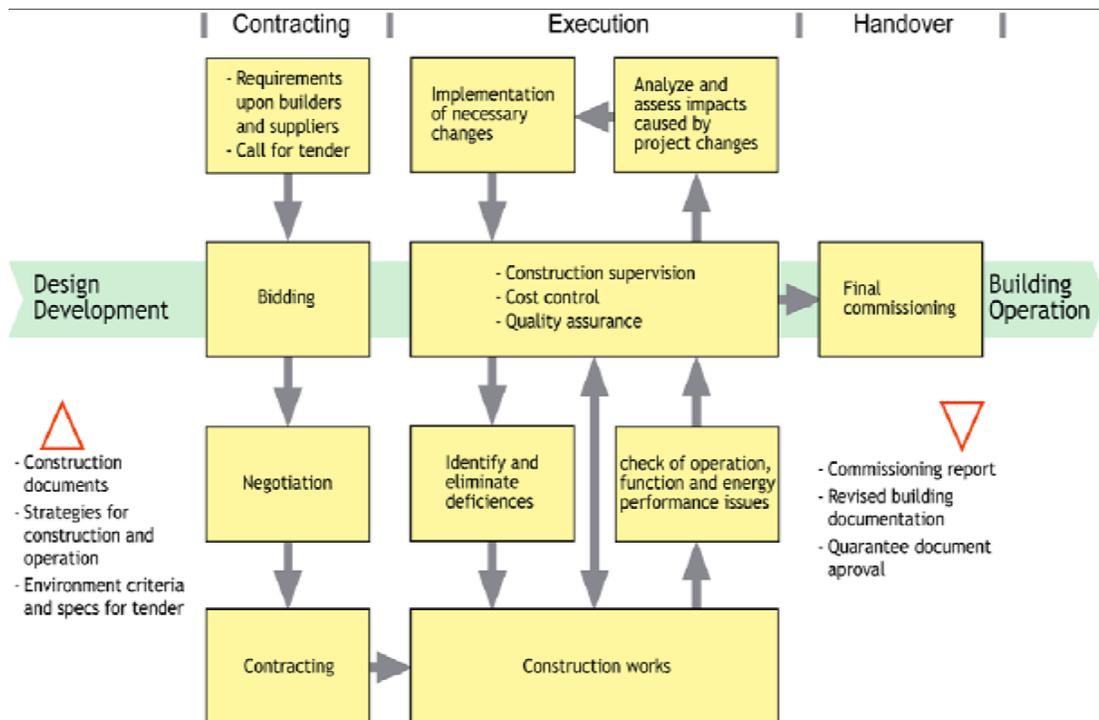
Additional activities include:

- Additional information about and descriptions of the construction processes will increase the quality of the design documents and prevent possible misinterpretations, misunderstandings and aggravations which can often lead to cost increases and/or postponements.
- Efficient management of correspondence and building documents accepted and tested by the actors involved is imperative in the context of complex projects and will guarantee that all participants will be kept informed of current status at all times.
- A final commissioning plan for the owner or contractor must be provided and should include all relevant building construction elements and technical systems.
- Coordination and quality control during construction must be ensured. The design intent, the scope of works and the specific requirements on the contracts with construction companies, suppliers and manufacturers, including contractors and subcontractors must be examined.
- New developments of building components may require procedures for on-site or off-site testing of energy performance and quality e.g. by testing prototypes (mock-ups) of building or construction elements.

Description of main products

The outcome is a comprehensive description of the entire project, including separate documents and drawings for construction trades and disciplines; clear requirements for the construction process and schedule; control and commissioning procedures and a report on final energy and environmental analyses.

1.4.6. Design support for Contracting and Execution



(IEA SHC Task 23, 2003).

Purpose and Goals

To provide supervision to ensure understanding of the importance of energy and environmental issues during the building construction period. This phase also includes quality control and partial commissioning.

Relationship to other design phases

The work is based on the comprehensive description of the entire building project from the detailed design phase.

Description of actors

The core design team, contractors, suppliers and product manufacturers.

Description of activities

The design supervision should be done by persons in close touch with, and instructed by, the designer of the project, to guarantee understanding of the importance of energy and environmental issues and their interrelation within real physical structures. Construction supervision includes ongoing control and assistance to contractors. It is advisable to provide potential key players with information concerning the concept and the objectives of the project which are not necessarily contained in the building documents, in order to enable them to make more informed bids and execution.

Additional activities include:

- Tender and contract documents should be developed in a procedural and problem-oriented language that requires contractors and subcontractors to verify and document specific high performance goals during construction.

- Alterations of the tender and building documents must be transmitted and incorporated completely into the design (contract) documents. All changes should be checked as carefully as was the original design version. A fully inclusive set of relevant drawings and building documents must be provided on the construction site, continuously updated and available for all persons at any time. This concerns especially energy and environmental information.
- Special requests for control and commissioning procedures, justified on the basis of energy efficiency or environmental project goals, must be comprehensively defined as part of the call for tenders.
- Spot checks and partial commissioning during the construction phase with corresponding quality tests (blower door, thermal photographs etc.) are recommended for the validation of energy or environmental performance at crucial points in the progress and in cases of unexpected incidents.
- The commissioning of partial systems, components or construction elements (e.g. of thermal quality of building envelope or air tightness) must be tailored to the proper point in time during the construction process when it is still possible to easily avoid problems which might occur at a later stage.
- After completion, an updating of the design data should be routinely performed in order to provide concrete information for future facility management and the optimisation of building operation.

Description of main products

The outcome is a building constructed according to design goals and objectives. In addition, there will be a building construction diary including reports and protocols of partial commissioning, update of drawings and other building documents.

1.4.7. Design support for Commissioning and Building Hand-Over

Purpose and Goals

To commission the building to ensure proper function of all structural and technical systems and to evaluate actual building performance.

Relationship to other design phases

The work is based on the updated description of the entire building project from the execution phase as well as the defined requirements, consensus goals and performance target values.

Description of actors

An independent commissioning agent (if possible).

Description of activities

All structural and technical systems are commissioned to ensure proper functioning. The performance of each building system should be evaluated according to the design intent. All tests described (air tightness, etc.) and partial commissioning of separate systems must be completed and all defects must be eliminated before the final commissioning starts.

In the commissioning phase it is recommended that an independent commissioning agent be put in charge of the commissioning process as, under certain circumstances,

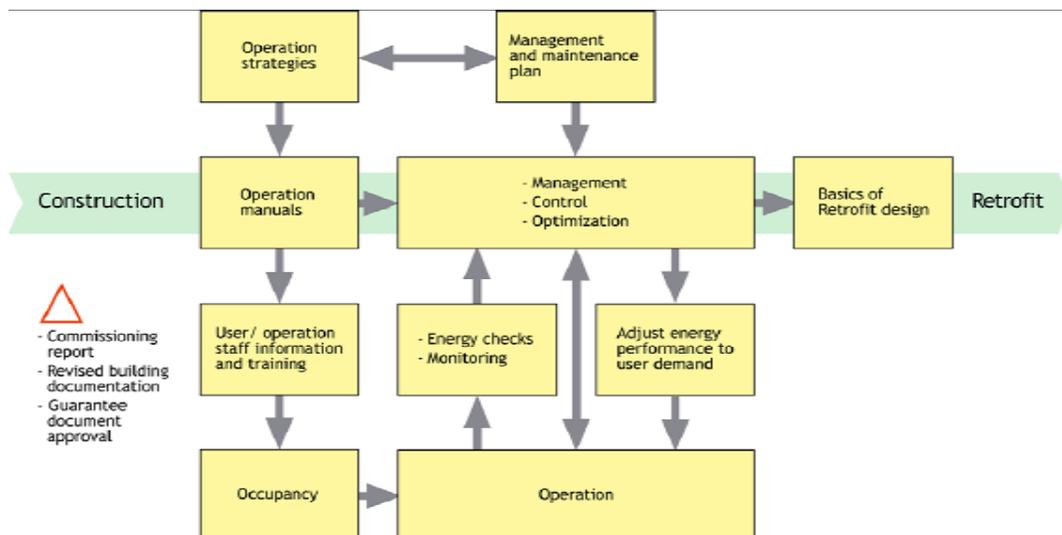
hidden deficiencies which would otherwise not become evident until operation has actually begun can be eliminated at once.

The facilities manager should take part in the commissioning procedure in order to become familiar with the systems. If the operating personnel are included in the commissioning process, then the additional costs of familiarization and training (which will be required in any case) can be reduced.

Description of main products

The building is handed over to the building owner and occupants. A commissioning report documents the function of all structural and technical systems and evaluates building performance according to defined energy and indoor environmental criteria and goals in the design brief. In addition, the designers should submit to the building operator(s) and owner(s) updated project documentation in addition to information concerning their experience to date with the project.

1.4.8. Design support for Building Operation and Maintenance



(IEA SHC Task 23, 2003).

Purpose and goals

To continuously monitor building performance and to evaluate the performance evolution over time.

Relationship to other design phases

The work is based on the updated description of the entire building performance from the commissioning phase.

Description of actors

Building services personnel.

Description of activities

Activities include development of an operational plan that ensures a smooth-running building operation and increases the degree of acceptance/understanding of occupants. It is desirable that the architect and the energy advisor be consulted on issues that

arise during initial building operations. Evaluation of building behaviour according to original goals should be done at the end of warranty period. Failures should be analysed seriously with the assistance of the designers and adjusted.

The development of strategies for the optimisation of operating procedures (control/regulation), of upkeep (cleaning, repair, replacement) and the adjustment of maintenance and repair cycles should be coordinated to meet specific demands on the parts of the users or unusual construction features.

Building operation and maintenance methods and daily routines should include a continuous review of energy and environmental performance. Energy efficient operations for changing climate and tenant demands must be refined.

Description of main product

A continuously high building performance according to design intent.

1.5. Integrated Design Methods and Tools

In the development of a whole building concept or integrated building concept, a design approach is needed which will enable the designer(s) to control the many parameters that must be considered and integrated, when creating more holistic building concepts. In order to facilitate this design approach, different types of design methods and tools are needed that, based on the selected design strategy, make it possible in a strategic way to select the most suitable technical solutions for the specific building and context

1.5.1. Classification of design methods and tools

Five main categories of design methods and tools can be identified: design process methods/tools, design strategy methods/tools, design support methods/tools, design evaluation methods/tools and simulation tools.

The *design process methods/tools* provide guidelines on how to organise the work process itself, i.e. who should take care of what tasks at what stages of the development and design of an Integrated Building Concept. It is necessary that the methods allow for consideration and solution of technical as well as aesthetic problems and that they focus on the creative element in the process, in order to identify new opportunities and to work strategically in creating innovative solutions in a new building design.

The *design strategy methods/tools* are concerned with what issues should be considered at different stages of the development of an Energy and Environmental Building Concept.

The *design support methods/tools* are typically used in the early stages of the design to get an idea of what approaches and technical solutions are the most promising for the given project and should be included in the developed Energy and Environmental Building Concept.

The *design evaluation methods and tools* are typically used later in the design process to check the performance of a given design concept and technical solutions.

Simulation tools are used in all stages of design in order to predict the performance of the building and technical systems. Computer simulation tools for predicting energy use, indoor environmental quality and impact on the environment are typically used as

basis in the different categories of design methods. In fact, in order to succeed in creating effective integrated building concept, it is often very useful to apply advanced computer simulation tools even in the early design stages.

There are no sharp borders between the different types of design methods and tools. For example, the design support methods and tools may in some cases also be used as design evaluation methods and tools, and vice versa.

Sections 2.3 and 2.4 have described an integrated design process method. A detailed description of design strategy and support methods and tools as well as simulation tools can be found in Educational Package 9 Integrated Building Systems Analysis. Therefore only a method for design evaluation and decision making will be described in this chapter.

1.5.2. Method for design evaluation and decision making

The integrated design process is a holistic method to optimize building performance which enables the designer to control the many parameters that must be considered and integrated when creating sustainable buildings. The method copes with technical as well as aesthetic problems, which implies evaluation and weighting of very different building performance characteristics that are often non-comparable.

This section is based on the work developed in the international project IEA-SHC Task 23 Optimization of Solar Energy Use in Large Buildings. This section presents the principle and method of MCDM-23, which is a method for specifying and prioritizing criteria as well as evaluation and weighting of design goals in the integrated design process and is summarized from the following publications:

- Andersen, I. (2000). A Multi-Criteria Decision Making Method for Solar Building Design. PhD Dissertation 2000:23, Department of Architecture, History and Technology, NTNU, Trondheim, March 2000.
- Balcomb, D., Andresen, I., Hestnes, A. G. And Aggerholm, S. (2002). Multi-Criteria Decision Making (MCDM-23) - A Method for Specifying and Prioritising Criteria and Goals in Design. IEA SHC Task 23 Optimization of Solar Energy Use in Large Buildings. Available from <http://www.iea-shc.org/task23/>.

IEA SHC Task 23 participants and the authors are gratefully acknowledged. A detailed description of the project and a complete list of publication are available from the project website, see www.iea-shc.org/task23/.

Purpose and brief description

The purpose of the MCDM-23 method is to aid in organizing information required for decision-making. The method proposed consists of six steps. The first three are carried out in a first phase, prior to initiation of design. The last three are carried out in a second phase, after generating schemes and/or design solutions, when making the decisions. The six steps are:

Step 1. Select main design criteria and sub-criteria

Step 2. Develop measurement scales for the sub-criteria

Step 3. Weight the main criteria and sub-criteria

Alternative design solutions are generated

Step 4. Predict Performance

Step 5. Aggregate scores

Step 6. Analyse results and make decisions

In the first phase, the design team decides on the criteria to be used in the project; determines their relative importance and the measurements scales to be used. Since there are usually quite a few criteria, it is helpful to group them as 5 to 8 main criteria, each with several sub-criteria. This process is an extremely valuable activity in itself as it helps the design team to clarify their objectives and directs them towards common aims.

In the second phase, the design team uses the method to evaluate the relative merits of two or more alternative design solutions. This is done by determining scores for each alternative for each criterion, using measuring scales defined in the first phase.

Depending on the design phase this might require performing computer simulations to determine energy use; estimating construction costs; determining probable indoor air quality; judging relative architectural merit or forecasting how adaptable each scheme would be to changes in building use or clients. The scores are then aggregated into several overview presentations: (1) a single score for each design alternative design; (2) a star diagram for each alternative design that shows its scoring graphically; (3) a bar chart for each design alternative that give more detail about the weighted results, and (4) summary worksheets that show the details and compare the alternatives side-by-side. In most cases the design team are wary of basing a decision on a single score and want to see all of these outcomes.

During the process, criteria may be added, removed, or reformulated. This may require the design team to go back and redo a part, or all, of the procedure several times. This should be considered a useful outcome, indicating that the discussion and analysis of the design problem and the objectives has produced a deeper understanding of the design project. It is important to remember that the primary goal is not to provide definitive answers, but to enhance the ability of all participants to comprehend the problem at hand.

Several phases of building design, particularly during the early stages of design, tend to be iterative or cyclical in nature. A typical design cycle is shown in Figure 14.

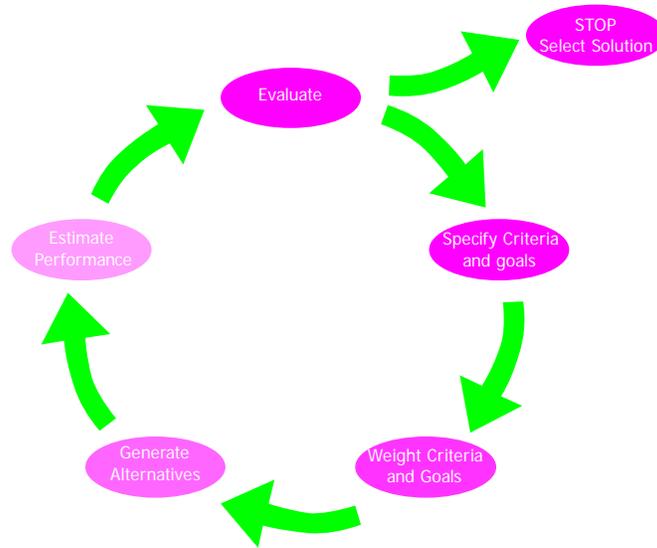


Figure 14. Iterative design cycle used in the MCDM-23 method. (IEA SHC Task 23, 2003).

Any such design cycle might benefit from using the MCDM-23 method, both for structuring, the design work and as part of the evaluation phase. It is recommended that a trimmed-down or simplified version of the method be used during the early phases of design and then a fuller, more comprehensive version later in the process, i.e. in the preliminary design phase. In the early phases, i.e. a complete energy analysis may not be warranted, but would be required at a later phase.

Typically, the designers produce two or more design alternatives at the end of the preliminary design phase in preparation for a design critique. These would be fairly complete descriptions, with site layouts, architectural drawings/sketches, and cost estimates. This would be an ideal time to use the MCDM-23 method to help in deciding which alternative to pursue in the design development phase; or the team may elect to create a new design, choosing from the best features of the best alternatives while avoiding the key problems with the leading alternative.

Step 1. Select main design criteria and sub-criteria

The number and nature of the criteria will vary from case to case. Some criteria will be quantifiable, such as annual resource use; others will be qualitative, such as architectural expression; see, for example. Table 2.

Table 2. Example of main design criteria and sub-criteria

Main design criteria	Sub-criteria
Life cycle cost	Construction cost
	Annual operation cost
	Annual maintenance cost
Resource use	...
	Annual electricity
	Annual fuels
Environmental loading	...
	CO ₂ -emissions from construction
	Annual CO ₂ emissions from operation
Indoor climate	...
	Air quality
	Lighting (incl. daylight)
	Thermal comfort
Functionality	Acoustic
	Functionality
	Flexibility
Architectural expression	Public relations value
	...
	Identity
	Scale/proportion
	Integrity/coherence
	Integration in urban context
	...

Checklists of criteria may be used to help the search and to ensure that no important issues have been overlooked. It is recommended to start out broadly with general, strategic criteria, and then narrow in, proceeding to specific criteria until a level is reached that is reasonable. In order to have a manageable number of criteria, the number of main design criteria should not be more than 8 and there should not be more than 30 sub-criteria in total. The exact selection of criteria will be dependent upon the context and, also, on the design phase. Even if the main design criteria are the same, the sub-criteria may differ from design phase to design phase. In the pre-design phase, the criteria need to be quite general while in the concept and preliminary design phase, when certain decisions already have been made, more building specific criteria may be considered.

Step 2. Develop measurement scales for the sub-criteria

A scale for each sub-criterion is necessary to be able to measure the performance. A measurement scale is a way to convert a value into a score. A value can be a number or a phrase, depending on whether the criterion is quantitative (annual energy use, life cycle cost, or carbon emissions) or qualitative (architectural expression or functionality). Some criteria, such as indoor air quality, can be characterized either way.

All criteria are ultimately converted to a qualitative scale, using the familiar scale of 4 to 10. In the upper end a score of 10 means that the building rates as "excellent", i.e. the building is the "best reasonable attainable" with regard to the particular criteria. In the lower end a score of 4 means that it is just possible to construct a building that scores so poorly. For example, the maximum building energy use allowed by regulation could be the lower bound.

The next step is to create a measurement scale for each of the criteria, indicating the assessment of the merit of achieving particular scores. The scale should be divided into intervals that are felt to be equal; i.e. the utility of a unit step on the scale must be the same whether it is at one or the other end of the scale. The process of creating measurement scales generate much discussion, causing participants in the process to focus on the interpretation of the criteria they have defined. Scaling the objectives of a problem in this manner not only helps the design team arrive at uniform measurement scales but is also a way to define the general nature and context of the problem. Table 3 and 4 show two examples of scales – a quantitative and a qualitative.

Table 3. Example of measurement scale for energy use (a quantitative criteria).

Score	Judgement	Annual energy use kWh/m ²
10	Excellent	80
9	Good to Excellent	100
8	Good	120
7	Fair to Good	140
6	Fair	160
5	Acceptable to Fair	190
4	Marginally acceptable	250

Table 4. Example of measurement scale for flexibility (a qualitative criteria).

Score	Judgement	Flexibility
10	Excellent	Different clients without changes
9	Good to Excellent	Different clients by: moving adjustable partitions or adding installations prepared for
8	Good	Different clients by moving adjustable partitions and adding installations prepared for
7	Fair to Good	Different clients by rebuilding non-load bearing partitions or some installations
6	Fair	Different clients by rebuilding non-load bearing partitions and some installations
5	Acceptable to Fair	Different clients by rebuilding some load bearing partitions or several installations
4	Marginally acceptable	Different clients by rebuilding some load bearing partitions and several installations

Step 3. Weight the main criteria and sub-criteria

The main design criteria weights reflect the central priorities of the project. The weights chosen will be critical in comparing alternative schemes. There are different ways of eliciting weights. The grading method, works with the weights directly. The criteria weights are determined on a 10-point scale similar to the one used for scoring performance. The decisionmaker expresses the importance of criteria in grades on the scale 10, 9, 8,...4. The most important criterion receives a grade of 10. All the other criteria are compared to this, e.g. if a criterion is felt to be somewhat less important than the most important one, it receives a grade of 8. A useful tool is to visualize the weights in a chart. The procedure for weighting sub-criteria is the same as for weighting the main criteria. The most important sub-criterion is selected and the others are then compared to it using the 4-to-10 scale.

Table 5. Definition of weights for main design and sub-criteria

Grade	Relative Importance (Compared with the most important criteria)
10	Of equal importance
9	
8	Somewhat less important
7	
6	Significantly less important
5	
4	Not important

Step 4. Predict Performance

The levels of predicted performance of the proposed solutions with respect to the criteria are determined. The level of detail should be chosen based on an estimation of the available time and resources and the accuracy required.

In the pre-design phase, where the criteria are quite general and the level of detail might be limited, the performance prediction is often based on databases, rules of thumb, experience or expert judgement.

In the concept and especially in the preliminary design phase, where certain decisions already have been made and more building specific criteria can be considered the performance prediction can be based on simple calculations or on computer simulations.

Performance scores for the qualitative criteria must normally be decided by the team. It is best if the decision on performance score can be taken in consensus by the design team.

Step 5. Aggregate scores

The simple additive weighting model is used to aggregate the scores into one score based on the criteria weights:

$$S = \sum_{j=1}^m w_j s_j \quad (\text{Total score} = \text{sum of: normalised criterion weight} \times \text{criterion score})$$

where S is the total score, m is the number of criteria, w_j is the normalized weight of the criterion, and s_j is the score for the criterion. The weights in the sum are first normalised by dividing the individual weight with the total sum of weights. This is used first at the sub-criterion level to obtain the criteria scores and again at the main level to calculate the total score.

Table 6. Example of aggregating scores of the sub-criteria under the main criterion: Life cycle cost.

Sub-criteria	Weight	Norm. Weight	Score	Main Criteria score
Construction cost	10	0.40	9	3.60
Annual operation cost	8	0.32	7	2.24
Annual Maintenance cost	7	0.28	5	1.40
Total: Life cycle cost	25	1.00		7.24

Table 7. Example of aggregating scores of the main design criteria to a total score..

Main Design criteria	Weight	Norm. Weight	Score	Total score
Life cycle cost	8	0.19	7.2	1.37
Resource use	5	0.12	6.5	0.78
Environmental loading	6	0.14	5.8	0.81
Indoor climate	7	0.17	6.9	1.17
Functionality	10	0.24	8.1	1.94
Architectural expression	6	0.14	8.6	1.20
Total: Life cycle cost	42	1.00		7.27

Step 6. Analyse results and make decisions

A star diagram is recommended for presenting the overall performance of an alternative. In this diagram it is possible to show multiple dimensions, thus all the individual performance measures can be gathered into one picture. The performance on each criterion is plotted on each “finger”. The centre of the star usually designates the minimum score of 4 for each criterion. The outer unit polygon represents the maximum score of 10 for each criterion. A star diagram should be produced for each alternative. By visual inspection of these diagrams, the design team can get a quick understanding of the big picture. Although the star diagram may be used to give an indication of the overall performance of an alternative, it should be used with caution. This is because the main criteria are shown as if they are all equal whereas weights might have been used in the final score computation.

The design team should study their results, come to a conclusion regarding their recommendation. The most important use of the method is to structure the discussions

and to help the design team reach a common understanding of the problem at hand and of the value of the various solutions.

In the early design phases it may be at this point that a new design solution should be developed that combines the best features of the leading solution while eliminating some of its problems. In the final design phase the design team presents the results as their recommendation to the client for a final decision. If the presentation and logic are clear, and if the team and the client were working toward commonly agreed goals, the conclusion will usually be evident.

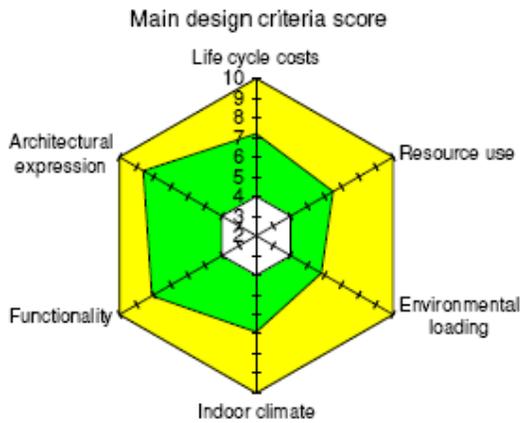


Figure 15. Example of star diagram to present overall performance of a design alternative.

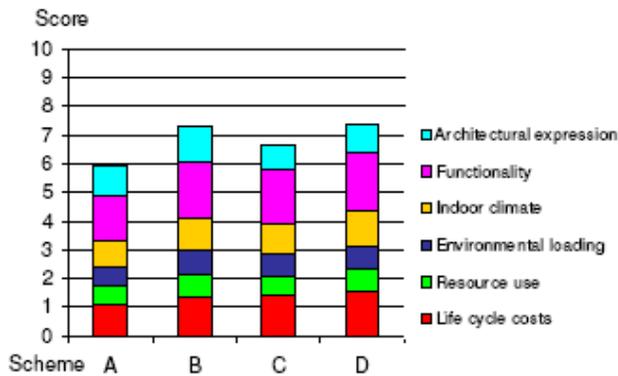


Figure 16. Example of a diagram to compare overall performance of four design alternatives.

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