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Heiselberg, Per; Van der Aa, A.

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Strategies for Integrative Building Design

Per Heiselberg, Aalborg University, Aalborg, Denmark, ph@civil.aau.dk

Ad van der Aa, Cauberg-Huygen, Rotterdam, The Netherlands, a.vanderaa@chri.nl

1 Introduction

The building sector is identified as providing the largest potential for CO₂ reduction by 2020 and many countries across the world have set very ambitious targets for energy efficiency improvements in buildings. To successfully achieve these targets it is necessary to identify and develop innovative building and energy technologies and solutions for the medium and long term which facilitates considerable energy savings and the implementation and integration of renewable energy devices within the built environment.

Environmental design and control of buildings can be divided into two very different approaches. In the usual “exclusive” approach energy efficient building concepts are created by excluding the indoor environment from the outdoor environment through a very well insulated and air tight building construction. Acceptable indoor environmental conditions are established by automatic control of efficient mechanical systems. Next to this, there is a growing interest for developing buildings that cooperate with nature and make use of the available environmental conditions. In this “selective” approach energy efficient building concepts are created by using the building form and envelope as an intermediate between the outdoor and the indoor environment. Acceptable indoor environmental conditions are established by user control of the building envelope and the mechanical systems. It is important that the building is responsive to the fluctuations in the outdoor environment and the changing needs of the occupants, which means that the building should have the ability to dynamically adjust its physical properties and energetic performance. This ability could pertain to energy capture (as in window systems), energy transport (as air movement in cavities), and energy storage (as in building materials with high thermal storage capacity).

In a responsive building an optimum must be found between the, sometimes contradictory requirements from energy use, health and comfort. From the viewpoint of human coexistence with nature the approach is to make buildings “open” to the environment and to avoid barriers between indoors and outdoors, where from the viewpoint of energy savings the approach, for certain periods, is to exclude the buildings from the environment. The area between indoors and outdoors herewith becomes a more or less hybrid zone where the energy gains are not only rejected, but are stored, tempered, admitted or redirected, depending on the desired indoor conditions. Nowadays we are able to measure and control the performance of buildings, building services and energy systems with an advanced building management system (BMS). This opens a new world of opportunities. Buildings no longer act as ridged objects that need a large heating installation in winter and big cooling equipment during summer to “correct” the indoor climate, but buildings become an additional “living” skin around occupants, keeping them in contact with nature, but at the same time protecting them when necessary.

However, this design approach requires that building design completely changes from design of individual systems to integrated design of responsive building concepts, which should allow for optimal use of natural energy strategies (daylighting, natural ventilation, passive cooling, etc.) as well as integration of renewable energy devices. Design teams including both architects and engineers must be formed and the building design developed in an iterative process from the conceptual design ideas to the final detailed design. However, a number of barriers appear when the borderline between architecture and engineering is crossed; the design process contains a lot of challenges to those who participate in the process.

2 The Integrated Design Philosophy

2.1 From component to concept

Efforts to minimize the building energy efficiency over the last decades have focused on efficiency improvements of specific building elements and building services equipment (component level). Significant improvement has been made. However the performance of individual elements is often heavily depending on the performance of the system they are part of. I.e. the performance of a heat pump depends on the performance of whole heating and cooling system which consists of a source, a distribution and a delivery part. The performance of a well insulated window no longer only depends on the insulation level of the glazing, but also on the window frame, the spacers etc. Innovations are shifting from component level to system level.

But also the system level approach is no longer appropriate. Buildings have become integrated concepts in which advanced systems work together to reach an optimal performance in terms of energy, comfort and health. And particularly on the overlapping field of building technology and building services, the responsive building elements, lies a great future potential to achieve the next steps in energy savings.

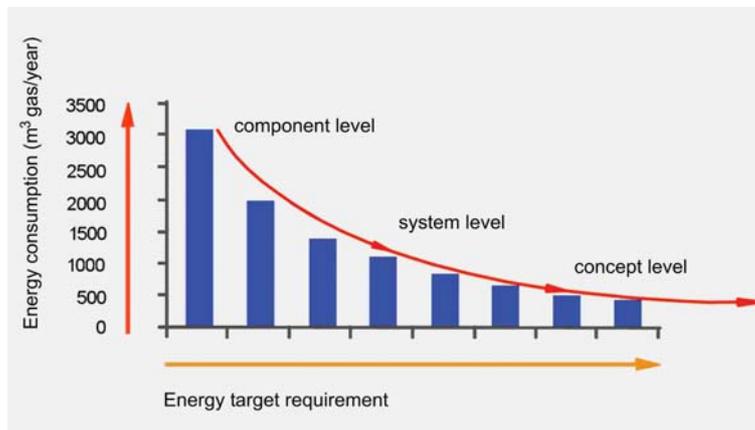


Figure 1 Increasing energy demands

With the integration of responsive building elements and building services, building design completely changes from design of individual systems to a design of integrated building concepts.

2.2 The responsive building concepts

Responsive building concepts in this paper are design solutions in which an optimal environmental performance is realized in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality. It follows that building concepts are design solutions that maintain an appropriate balance between optimum interior conditions and environmental performance by reacting in a controlled and holistic manner to changes in external or internal conditions and to occupant intervention and that develop from an integrated multidisciplinary design process.

An 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:

- an architectural building concept,
- a structural building concept and
- an energy and environmental building concept

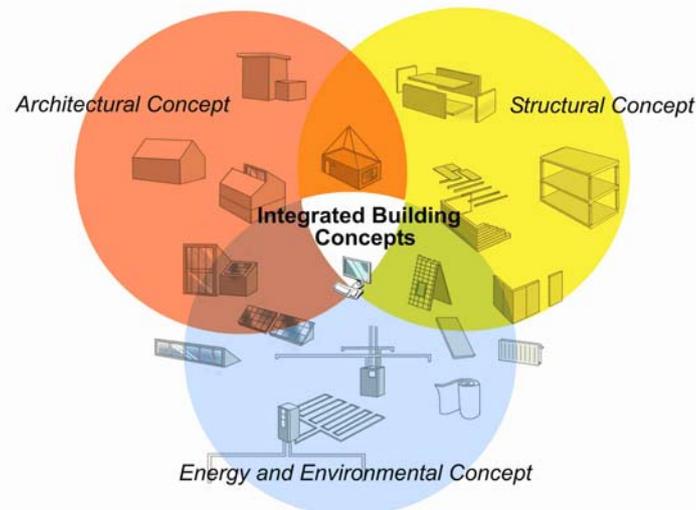


Figure 2 Integrated building concepts

This corresponds to the professions involved in the building design 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.

2.3 The integrated design process

A responsive building concept can only be developed by an integrated design approach. 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 utilization 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.

In a sequential design process the engineer at the later stages of design more or less act in a reactive way, thus correcting the architectural design. The risk that poor design concepts are developed are 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.

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 optimization 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.

2.4 Implementation barriers

A number of barriers appear when the borderline between architecture and engineering is crossed. 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 rely 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 often are non-comparable, which 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.

3 Design Strategy

3.1 Boundary conditions

As in the classical design approach a sustainable design should start with an thorough analysis of the environmental conditions and determine the beneficial environmental design conditions as location of the building, sheltering, optimal orientation, solar and wind optimization and protection, ground coupling possibilities etc. This mostly takes place in relation to the architectural and esthetical design considerations, but is the first step in achieving an more energy saving design.

Next to it, comfort requirements and IAQ need to be considered. Fixed and uniform conditions as stated in the last decades can be transformed in adaptive conditions, related to the place, function, time and activity in the building. Also the considerations regarding local climates can lead to large energy saving potential.

3.2 Technical Solutions

In order to reach an integrated technical design solution and to develop an Energy and Environmental Building Concept it is necessary to define and apply a certain design strategy. In the IEA ECBCS Annex 44 project the design strategy is based on the method of the Trias Energetica method described by Lysen (1996). This Trias Energetica approach has been extended within the Annex 44 work with technologies that will be applied, depending on the design step

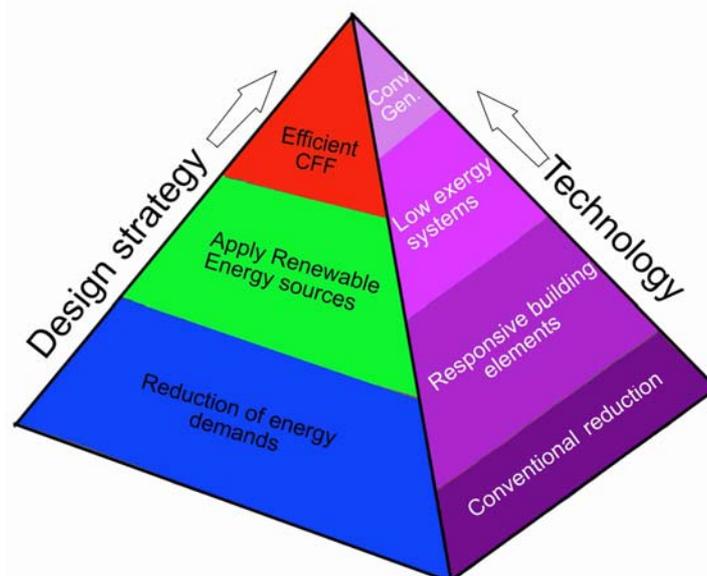


Figure 3 Illustration of IEA ECBCS Annex 44 Design Strategy and corresponding technologies

The left side of the pyramid shows the design strategy, and the right side of the pyramid shows the technical solutions in each of the steps. The figure clearly positions the responsive building elements as a technology that falls in the first step “reduction of energy demands” as well as in the second step “application of renewable energy sources”. An integrated design strategy, starts at the bottom of the pyramid and applies the strategies and technologies as follows:

Step 1. Reduce energy demand. Optimize building form and zoning, apply well insulated and air tight conventional envelope constructions, apply efficient heat recovery of ventilation air during heating season, apply energy efficient electric lighting and equipment, ensure low pressure drops in ventilation air paths, 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.

Step 2. Apply renewable energy sources. Provide optimal use of passive solar heating, day lighting, 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.

Step 3. 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. 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.

3.3 Application of the design strategy

A roadmap for application of the design strategy in the various design stages is given in table 1. The heating cooling, lighting and ventilation design of buildings always involves all steps, 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.

Step 1: Basic design focusing on reduction of energy demands. In the first state of the design the focus primarily is on the reduction of demands for heating, cooling, lighting and ventilation by means of reducing internal heat loads and optimization of daylighting and reducing the heating, cooling and ventilation energy.

Priority in this is the reduction of internal and external heat loads. The internal heat loads can be reduced by the use of energy saving equipment as computers, copiers etc and by installing energy saving electric lighting. Most effective in this is the maximizing the daylight autonomy of rooms and thus reducing the energy use for electric lighting. As the efficacy of daylight is much higher than artificial light this counts both for reduction of electric energy consumption for lighting as for reducing the energy consumption for cooling.

The next step is to find an optimum in reducing the heating and cooling gains by an optimal surface to volume ratio, zoning, shading, insulation level and a demand controlled ventilation level. A special effort is required when applying long term heat storage. In that case heating and cooling gains over a year need to be tuned to each other to avoid long term imbalance. Decisions at the first step determine the size of the heating, cooling and lighting loads and good fabric design is essential for minimizing the need for services. Poor decisions at this point can easily double or triple the size of the mechanical equipment 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 they 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.

Table 4-1 Typical design considerations at each design phase

	Heating	Cooling	Lighting	Ventilation
<i>Step 1</i>	<i>Conservation</i>	<i>Heat Avoidance</i>	<i>Daylighting</i>	<i>Source Control</i>
Basic Design	<ol style="list-style-type: none"> 1. Surface to volume ratio 2. Zoning 3. Insulation 4. Infiltration 	<ol style="list-style-type: none"> 1. Façade Design 2. Solar Shading 3. Insulation 4. Internal heat gain control 5. Thermal mass 	<ol style="list-style-type: none"> 1. Room height and shape 2. Zoning 3. Orientation 	<ol style="list-style-type: none"> 1. Surface material emission 2. Zoning 3. Local exhaust 4. Location of air intake
<i>Step 2</i>	<i>Passive Heating</i>	<i>Passive Cooling</i>	<i>Daylight Optimization</i>	<i>Natural Ventilation</i>
Climatic Design	<ol style="list-style-type: none"> 1. Direct solar heat gain 2. Thermal storage wall 3. Sunspace 	<ol style="list-style-type: none"> 1. Free cooling 2. Night cooling 3. Earth cooling 	<ol style="list-style-type: none"> 1. Windows (type and location) 2. Glazing 3. Skylights, light-wells 4. Light shelves 	<ol style="list-style-type: none"> 1. Windows and openings 2. Atria, stacks 3. Air distribution
<i>Step 3</i>	<i>Application of Responsive Building Elements</i>	<i>Application of Responsive Building Elements</i>	<i>Daylight Responsive Lighting Systems</i>	<i>Hybrid Ventilation</i>
Integrated System Design	<ol style="list-style-type: none"> 1. Intelligent facade 2. Thermal mass activation 3. Earth coupling 4. Control strategy 	<ol style="list-style-type: none"> 1. Intelligent facade 2. Thermal mass activation 3. Earth coupling 4. Control strategy 	<ol style="list-style-type: none"> 1. Intelligent façade 2. Interior finishes 3. Daylight control strategy 4. ... 	<ol style="list-style-type: none"> 1. Building integrated ducts 2. Overflow between rooms 3. Control strategy 4. ...
<i>Step 4</i>	<i>Low Temperature Heating System</i>	<i>High Temperature Cooling System</i>	<i>High Efficiency Artificial Light</i>	<i>Low Pressure Mechanical Ventilation</i>
Design of Low Exergy Mechanical Systems	<ol style="list-style-type: none"> 1. Application of renewable energy 2. Floor/wall heating 3. ... 	<ol style="list-style-type: none"> 1. Application of renewable energy 2. Floor/wall cooling 3. ... 	<ol style="list-style-type: none"> 1. LED 2. ... 	<ol style="list-style-type: none"> 1. Efficient air distribution 2. Low pressure ductwork, filtration and heat recovery 3. Low pressure fan 4. ...
<i>Step 5</i>	<i>Heating System</i>	<i>Cooling System</i>	<i>Artificial Lighting</i>	<i>Mechanical Ventilation</i>
Design of Conventional Mechanical Systems	<ol style="list-style-type: none"> 1. Radiators 2. Radiant panels 3. Warm air system 	<ol style="list-style-type: none"> 1. Cooled ceiling 2. Cold air system 	<ol style="list-style-type: none"> 1. Lamps 2. Fixtures 3. Lighting control 	<ol style="list-style-type: none"> 1. Efficient air distribution 2. Mech. exhaust 3. Mech. ventilation
Step 6	Intelligent Control Advanced sensor techniques, model based and adaptable control algorithms, user interface, ...			

Step 2: Climatic design through optimization of passive technologies. The second step involves optimization of natural and “free” gains from sun, wind and thermal storage through application of direct solar gains, free cooling, thermal mass application and natural ventilation. Effective functioning of these measures directly relates to the outdoor climate as available wind and sun conditions, day-night rhythm and earth temperature. Proper decisions at this point can greatly reduce the loads as they were created during the first step leading to the wanted reduction in size and complexity of the building services.

Step 3: Integrated system design and application of responsive building elements. Step 3 contains the design of integrated systems with responsive building elements. In this step the activation of building elements by building services enhances the further employment of building components. Energy gains in building elements are actively controlled by changing and influencing the physical behaviour and properties of the building components..

Step 4: Design of low exergy mechanical systems. To realise the comfort conditions required, mechanical systems for heating, cooling, lighting and ventilation are applied to handle the loads that remain from the combined effect of the previous steps. To enhance the application of renewable energy sources priority lies with low exergy mechanical systems. This counts for the energy generation part, the energy distribution part and the energy delivery part of the mechanical systems. Hereby a tuning of generation, distribution and delivery is crucial to reach an efficient and optimal performance.

Step 5: Efficient design of conventional mechanical systems. Step five consists of designing the (conventional) building services. Herewith it is important to ensure 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.

Step 6: Design of intelligent control for optimized operation. Definitely more than in the past the intelligent control of the energy transport is crucial to come to a proper and efficient operation of the building, building services and renewable energy systems to reach an optimal energy efficiency. The systems therefore needs to be fed with the design considerations and must be able to tune to the different external and internal climate conditions and the comfort requirements of the building occupants. Advanced sensor techniques together with sophisticated control algorithms are still under development and need further improvement which is also the case for interfaces for user control and user/system interaction.

4 The IEA ECBCS Annex 44 Integrated Design Process

4.1 The iterative process

The Annex 44 integrated design process (IDP), creates a synergy of competencies and skills throughout the process by the inter-disciplinary work between architects, engineers, and others right from the beginning of the process. It ensures that different knowledge of specialists is introduced at an early project phase 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. The building design is developed in an iterative process from the conceptual design ideas to the final detailed design.

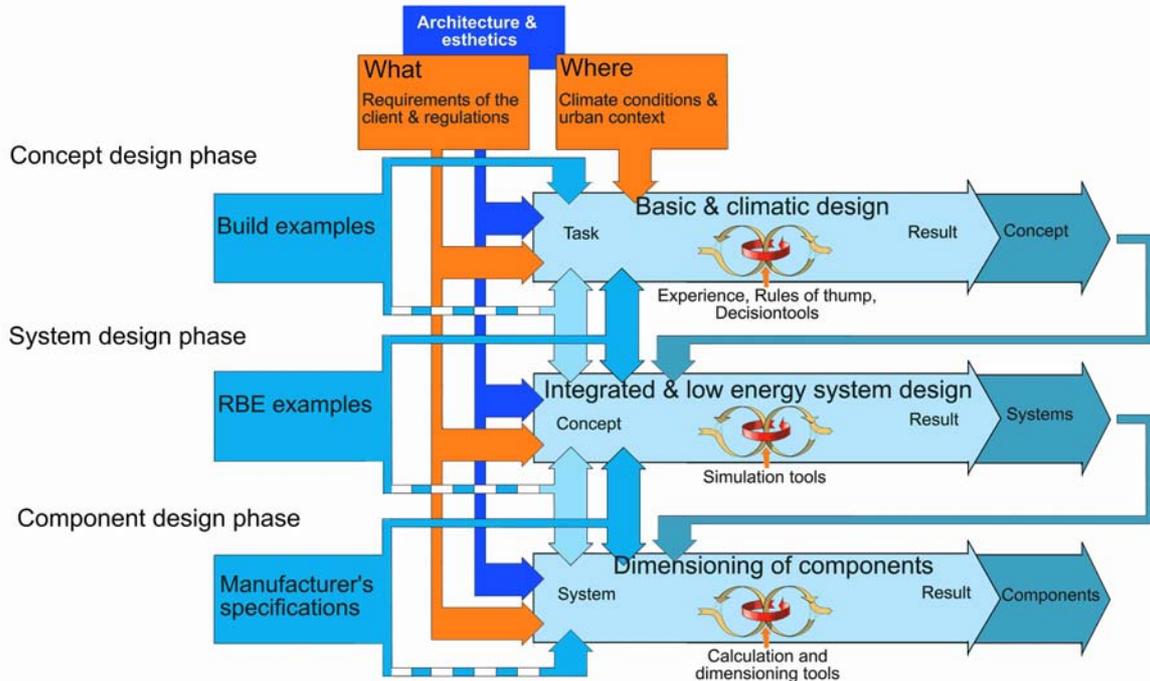


Figure 4 Design Process of Responsive Building

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. The intermediate workflows in each rough phase can be characterized by iteration loops.

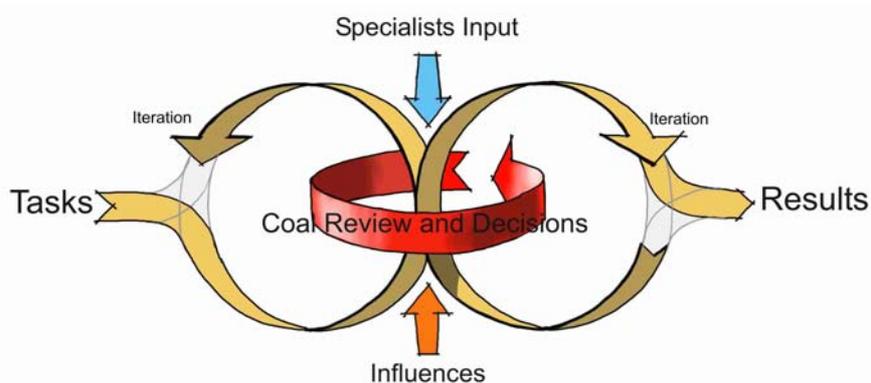


Figure 5 Iteration loops in design process stages

The loops provide problem-oriented analyses of design alternatives and optimization based on the design strategy presented in Figure 6 a t/m c (split up figures from figure 4), and 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.

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

4.2 Main design phases

The Annex 44 integrated design process includes the following main phases:

Phase 1: Where to built and what to built; It is essential to understand the climate characteristics of the building site for responsive building design. The climate data is useful not only for estimating

heating- and cooling load of the building but also for creating passive design concepts. Analysis of site potential including wind, sun and landscape, urban development plans, analysis of clients' profile and chart of functions create a roadmap of energy system principles, renewable energy systems, indoor environment and construction solutions. The outcome is an analysis of the context, site and building design potential and a road map of possible design strategies.

Phase 2: Development of design concept. Through the sketching process architectural ideas and concepts, functional demands as well as principles of construction are linked to energy and environmental building concepts and indoor environment through application of the design strategy. Different conceptual design solutions are developed and their relative estimated merits are continuously evaluated, including architectural qualities, against the goals in the building design brief. The outcome is an integrated building concept.

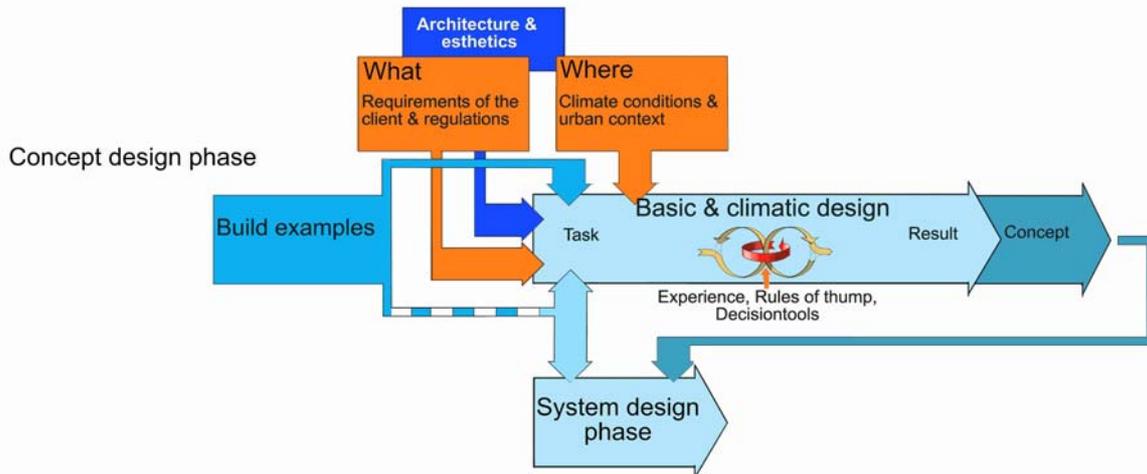


Figure 6a Design Process for the Concept Design Phase of Responsive Building

Phase 3: System design and preliminary performance evaluation. In the system design phase the building concept develops into specific architectural and technical solutions and systems through sketches, more calculations and adjustments. Architectural, space and functional qualities, the construction and demands for energy consumption and indoor environment converge in this phase. The basic building form and its site location are determined after a series of functional analysis, design strategy step 1. At the same time by applying step 2-4 in the design strategy, a frame of responsive design is built considering various ideas of integration of passive- and active systems as reflected in the design concept explicitly with consideration of RBE's and renewable energy technologies.

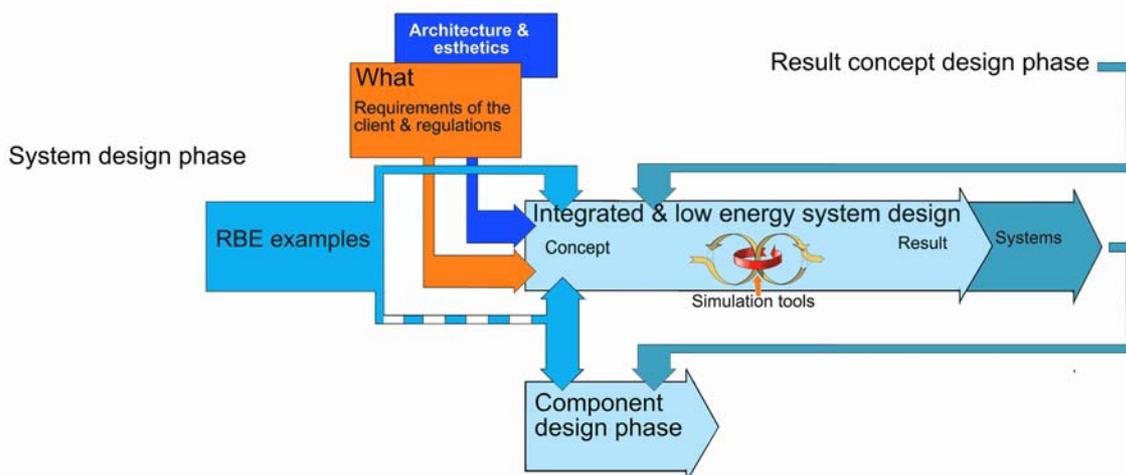


Figure 6b Design Process for the System Design Phase of Responsive Building

Phase 4: Component design. In this phase after the performance of system design is confirmed, the final design will be completed. Here technical solutions are refined and design documents are created including final drawings and specifications in cooperation with building companies, suppliers and product manufacturers. The outcome is a comprehensive description of the entire project.

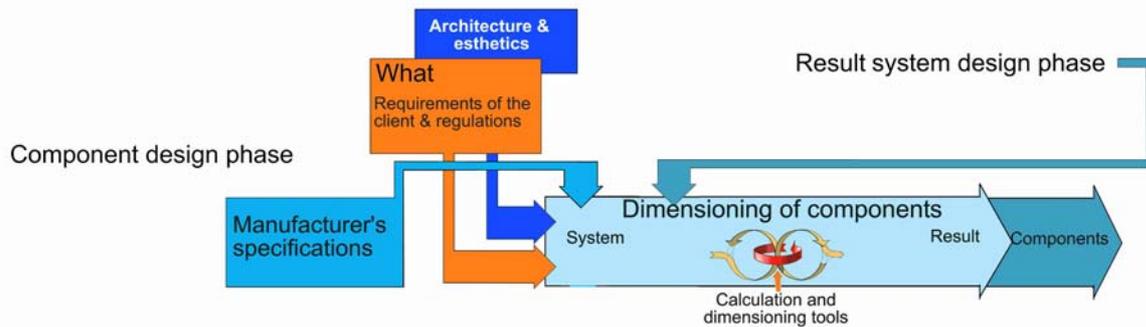


Figure 6c Design Process for the Component Design Phase of Responsive Building

Phase 5: Operation and management. 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 overcome this and the underlying reasons for conflict should be identified and eliminated to prevent carrying a flawed design forward.

5 Acknowledgement

The content of this paper is based on a recently completed research project (IEA ECBCS Annex 44), which has dealt with these issues and three publications addressing the challenges can be downloaded from the IEA ECBCS website (www.ecbcs.org/annexes/annex44.htm):

- Designing with responsive building components – an expert guide for rethinking new buildings.
- Responsive Building Concepts – Expert Guide part 1
- Responsive Building Elements – Expert Guide part 2

6 References

- Lysen, E.H. (1996) *The trias energetica: Solar Energy strategies for Developing Countries*, Eurosun Conference, Freiburg, Germany.
 IEA-ECBCS Annex 44 “Integrating Environmentally Responsive Elements in Buildings”
www.civil.aau.dk/Annex44