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INTEGRATING RESPONSIVE BUILDING ELEMENTS IN BUILDINGS

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Summary

There is a global need for a more sustainable building development. About 50% of energy is used in buildings indicating that buildings provide a considerable potential for operational energy savings. Studies were conducted with the following objectives:

- to perform a state-of-the-art review of responsive building elements, of integrated building concepts and of environmental performance assessment methods
- to improve and optimize responsive building elements
- to develop and optimize new building concepts with integration of responsive building elements, HVAC-systems as well as natural and renewable energy strategies
- to develop guidelines and procedures for estimation of environmental performance of responsive building elements and integrated building concepts

This paper introduces the ideas of this collaborative work and discusses its usefulness for Hong Kong and China. Special focus was put on the description of the climate in China and a review of barriers to implement building elements and of integrated building concepts.

1. Introduction

Energy usage for room heating, cooling and ventilation still accounts for more than one third of the total, primary energy demand in the industrialized countries, and is in this way a major polluter of the environment with CO₂ and greenhouse-gases. To successfully achieve the targets set out in the Kyoto protocols it is necessary to identify innovative energy technologies and solutions for the medium and long term which facilitates the implementation and integration of low carbon technologies, such as renewable power generation devices within the built environment. Deployment of low carbon technologies still faces major barriers in the built environment especially in relation to

- costs, building logistics,
- technological challenges,
- lack of understanding and knowledge and
- absence of requisite skills.

Moreover, there is world wide growing concern about the type of energy used for different purposes.

Research into building energy efficiency over the last decade has focused on efficiency improvements of specific building elements like the building envelope, including its walls, roofs and fenestration components (windows, daylighting, ventilation, etc.) and building equipment such as heating, ventilation, air handling, cooling equipment and lighting. In the framework of IEA research in ECBCS Annexes has focused on:

- the optimization of the building envelope - Annex 32 "Integral Building Envelope Performance Assessment"
- the optimization of ventilation by intelligent hybrid ventilation - Annex 35 "Control Strategies for Hybrid Ventilation in New and Retrofitted Office Buildings (HybVent)"
- the optimization of the heating and cooling system by low temperature heating and high temperature cooling - Annex 37 "Low Exergy Systems for Heating and Cooling"

Significant improvements have been made, and whilst most building elements still offer opportunities for efficiency improvements, the greatest future potential lies with technologies that promote the integration of active building elements and communication among building services. In this perspective Whole Building Concepts are defined as solutions where reactive building elements together with service functions are integrated into one system to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality. Reactive Building Elements are defined as building construction elements which are actively used for transfer of heat, light, water 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, ventilation and energy storage. The development, application and implementation of reactive building elements are considered to be a necessary step towards further energy efficiency improvements in the built environment (Annex44).

With the integration of reactive building elements and building services, building design completely changes from design of individual systems to integrated design of "whole building concepts, augmented by "intelligent" systems and equipment. Development of enabling technologies such as sensors, controls and information systems are needed to allow the integration. Design strategies should allow for optimal use of natural energy strategies (daylighting, natural ventilation, passive cooling, etc.) as well as integration of renewable energy devices (Annex44).

The annex will, based on the knowledge gained in the work so far (particularly the results of IEA Annexes 32, 35 and 37, SHC Task 23), address the following objectives:

- Define state-of-the-art of reactive building elements
- Improve and optimize reactive building elements and technologies
- Develop and optimize new building concepts with integration of reactive building elements, building services as well as natural and renewable energy strategies

- Develop tools for the early assessment of the impact of reactive building elements on the environmental performance of buildings
- Develop guidelines for procedures and tools for detailed simulation of environmental performance of reactive building elements and integrated building concepts

2. Climate

China is a large country with a vast territory and complex topography. The main feature of the climate of China is its diversity and complexity which together lead to the existence of a great number of climate types (Zhang and Lin 1992). China is a large country with an area of about 9.6 million km². About 98% of the land area stretches between a latitude of 20°N to 50°N, from subtropical zones in the south to the temperate zones (including warm-temperate and cool-temperate) in the north (Zhang and Lin 1992). The maximum solar altitudes vary a great deal and there is a large diversity in climates, especially the temperature distributions during winters. As China is located on the southeastern sector of the Eurasian continent towards the Pacific Ocean, air masses of either continental or maritime origin will affect its climate. The monsoons represent the overwhelming climate and weather regime for China which govern the climatic conditions throughout the year (Zhang and Lin 1992). In general, winter monsoon from mid-Siberia and Mongolia brings cold and dry air masses to China during the winter period; summer monsoon from the subtropical anticyclone in the Northwest Pacific and the cross-equatorial flow from the southern hemisphere generates precipitation and warm weather during the summer period (Hui and Cheung 1997). The two distinguished monsoons together create large differences in seasonal climatic conditions. Besides, characteristics associated with continental climates can be identified with warmer summer, cooler winter and a larger annual temperature range than other parts of the world with similar latitudes. China also has a complex topography ranging from mountainous regions to flat plains. These diversities and complexities have led to many different climates with distinct climatic features.

Different data are required for defining the climatic characteristics based on the intended application. Building designers are usually interested in those climatic variables which affect the indoor thermal comfort and the heat transfer through building fabrics and via ventilation. Weather data crucial to building designs and energy analysis include temperature (drybulb and wet-bulb), solar radiation (global, direct and diffuse) and wind conditions (speed and direction) (Lam et al. 2005).

2.1 Climatic data

For the purpose of building thermal design, the climate of China can be classified into five main types as shown in Figure 2, and the country can be divided into several climatic regions as shown in Figure 1 (Givoni 1992; Olgyay 1963). The zoning is based on the monthly average temperatures of the coldest and hottest months of the year (usually January and July, respectively), and the number of days with the daily average temperature below 5 °C and 25 °C. While the latitudinal and longitudinal distances represent an important climate-controlling factor, the physio-geographical setting and landforms will also affect the climate at a particular location (Hui and Cheung 1997).

Table 1: Climatic data for

Location	Lat. (north)	Long. (east)	Elev. (m)	Dry-bulb temperature (° C)				Rel. humidity (%)		Sunshine Hours
				Annual average	Annual diff.	HMA	CMA	HMA	CMA	
Hong Kong	22° 18'	114° 10'	33	23	13	28.8	15.8	80	71	1948.1
Guangzhou	23° 08'	113° 19'	6.6	21.8	15.1	28.4	13.3	83	70	1906
Kunming	25° 01'	102° 41'	1891.4	14.7	12.1	19.8	7.7	83	68	2470.3
Shanghai	31° 10'	121° 26'	4.5	15.7	24.3	27.8	3.5	83	75	2014
Beijing	39° 48'	116° 28'	31.5	11.5	30.4	25.8	-4.6	78	45	2780.2
Harbin	45° 41'	126° 37'	171.7	3.6	42.2	22.8	-19.4	77	74	2641

CMA = coldest month average; HMA = hottest month average; annual diff. = HMA - CMA

Table 1 gives a summary of the major climatic conditions for seven cities in China (including Hong Kong); their geographical locations are also shown in Figure 1.

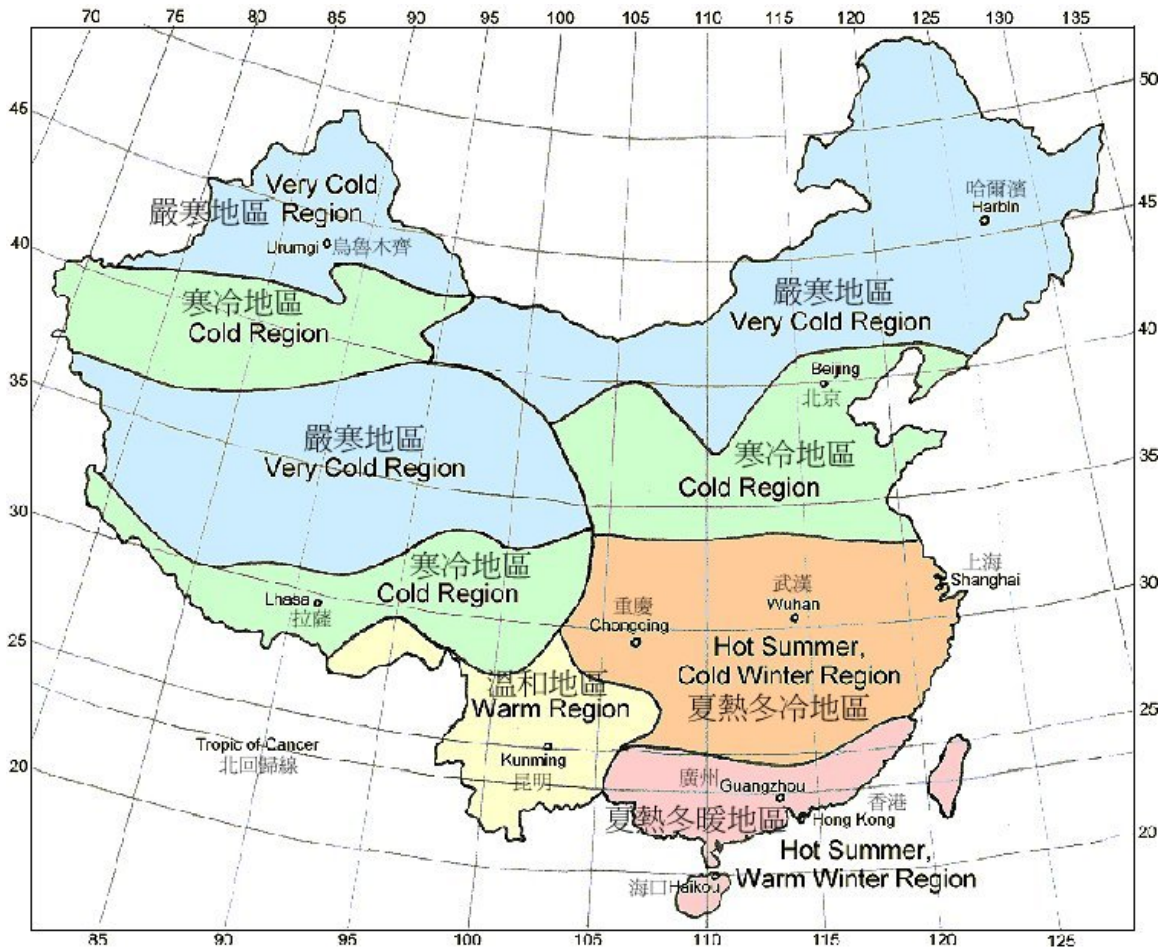


Figure 1: Climate zones of China (Hui and Cheung 1997)

A new approach for building design that tries to take aspects of sustainable development into account has to consider the local climatic factors. Therefore, a weather data analysis for the different locations was carried out. Cooling degree hours and days (CDD), heating

degree hours and days (HDD) and solar excess hours and days (SED) for each month are given in Fig 1. A degree hour is the difference in temperature above or below the reference temperature during the course of one hour and can be calculated if hourly temperature data are available.

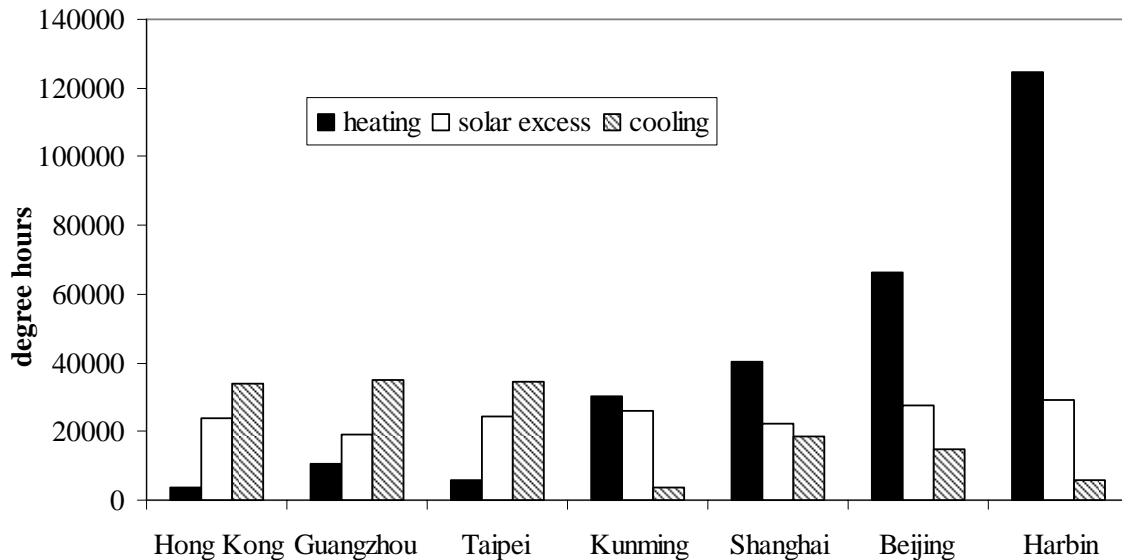


Figure 2: Degree hours

2.2 High-rise building development

The seasonal and daily climate in respect to mean temperature, humidity and wind speed distribution in Hong Kong is sub-tropical (Haase and Amato 2005; Lam 1999). Since the building types and the climate are very special in warm and humid climates (Lam 1995; Lam 1999; Li and Lam 2000) Hong Kong can help to act as a model for modern urban environment that is dense and high-rise with usually 40 floors and above (Close 1996b). However, as tall buildings are getting predominant in Chinas modern cities, more attention should be paid to designing them in an ecologically responsive way (ref. Smith 2000). This includes the importance of a careful building design that ensures optimised energy conservation but also the utilization of solar radiation to meet the energy needs in the building. Hong Kong's building stock analysis can help to focus on the main issues related to tall building energy consumption in southern China.

3. State-of-the-art

The improvement of responsive building element concepts including assessment of the advantages, requirements and limitations is important. This work focuses on systems that have the potential to be successfully integrated with integrated building concepts.

3.1 *Climate responsive building elements*

The main objective is to define state-of-the-art of responsive building elements and to improve and optimize the environmental performance of responsive building elements. The first step is the review of existing technologies including both new build as well as retrofit applications. Next, technical barriers, requirements and limitations related to climate, building use and building scale environment, including emphasis to urban environment are reviewed. Finally, experimental procedures and application of simulation tools for performance evaluation are reviewed.

A systematic classification of existing responsive building elements is being developed at the moment (Annex44).

3.2 *Climate responsive building concepts*

This task focuses on development of integrated building concepts where responsive building elements, energy-systems and control systems are integrated into one system to reach an optimal environmental performance.

The objective is to develop and optimize new building concepts with integration of responsive building elements, energy-systems and control strategies. The first step is to review the integrated building concepts including:

- Related design processes and guidelines
- Technical barriers and opportunities for integration of responsive building elements and energy-systems in building concepts
- Existing integrated design and simulation tools
- Application of responsive building elements and integrated concepts in existing buildings (case studies)

4. Barriers for integration in buildings

The main target groups are manufacturers of building elements/contractors, designers (architects and engineers), but also end-users and building owners.

In order to create effective and useful information on how to integrate new building elements and concepts it is essential to investigate the implementation barriers.

Therefore, the efforts should focus on

- Inventory of potentials and barriers for integration of responsive building elements and energy-systems in integrated building concepts, based on the combined analysis above for standards and building regulations, working tradition,
- lack/need for cooperation between designers (architects, engineers, manufacturers),
- lack/need of theoretical guidelines/tools,
- lack/need of databases and practical demonstrations (laboratory or full scale)

The major barrier to promoting responsive building elements and concepts is the lack of incentives to do better. From supply to end use, in public and private sectors, from building procurement through to disposal, disincentives and obstacles to energy efficient concepts arise (Burnett and Deng 1994). These impediments are seldom technical but

rather they originate from economic, regulatory or other circumstances. The following applies to all types of buildings with focus on air-conditioned complexes.

4.1 Context for buildings in Hong Kong

Generally, there is a low priority given to environmental issues. A low level of public awareness or concern has been observed but different measures like the promotion of energy efficiency and the very successful rating system HK-BEEAM improved the situation over the last couple of years.

High land cost (up to 80% of total building cost) demand fast track development and maximizing usable floor area (minimizing floor to floor height). High rents and lease conditions which do not encourage good environmental performance make the situation worse. There are several Codes of Practice released but there is no overall energy standard for buildings. A performance based energy code is under development (ref. emsd 2005).

The high density of Hong Kong with up to 6000 inhabitants per sqkm results in a very close proximity of buildings. This limits the use of daylight and natural ventilation (Ng 2003).

There are no incentives for saving energy. This has mainly two reasons. One is that the long standing Scheme of Control with the Government, effective through to 2008, provides for the electricity utilities' to earn a fixed percentage return of average net fixed assets. Therefore, there is little motivation for the utilities to promote to save energy. The other is the relatively low cost of energy compared to other operating costs such as rents and salaries (Burnett and Deng 1994).

But there exists an energy efficiency scheme and some activity in promoting Demand Side Management (clp; HKE).

There is also a widely adopted perception that improved efficiency should be justified solely from saved energy costs, rather than overall productivity benefits, and with a short payback period of 3 to 7 years.

4.2 New building design

Burnett (1994) identified several barriers in implementing energy efficiency in new building design (Burnett 1994):.

- Many developments are of speculative nature with emphasis on low first cost and visual rather than functional aspects. The developer is not generally the occupier of a building and has little incentive to reduce operating costs but every incentive to reduce capital cost.
- Ill-defined Client requirements as manifest in limited design brief, changes subsequent to key design decisions. Poor co-ordination of tenant fit-out with core building design.
- Competitive design fees, to fragmented design teams focused maximizing commissions or meeting deadlines. Designers and builders tending to reduce risk through standard practice.
- Conservative design approaches (oversizing of major plant items, etc.), with lack of integration of systems and detailing to achieve efficient operation.
- Lack of experience with new techniques and technologies, and sourcing difficulties.

- Inadequate commissioning and little follow-up after construction.

These difficulties have to be addressed in the development, application and implementation of reactive building elements. The consideration of climate responsive concepts in new planned buildings are considered to be a necessary step towards further energy efficiency improvements in the built environment.

4.3 Opportunities for upgrading building performance

Most efforts to improve energy efficiency tend to target new buildings. Despite the large scale of building development existing buildings should not be forgotten in the energy equation, there are significant opportunities from upgraded operations, during refurbishment and fit-out to improve energy efficiency using tried and tested energy efficient technologies.

4.3.1 Building envelope

The utilization of natural ventilation and daylight for buildings located at less congested sites provides several advantages. Ng conducted research which resulted in a review of the related building regulations (Ng 2003). It is possible to use low-energy transmittance, high light transmitting glazings to separate visible from infrared radiation and 'smart glass' which is responsive to Hong Kong climate. Most windows in Hong Kong are either reflective, causing glare to the outside, or dark and heat absorbing, thus increasing the use of artificial light and the cooling load (Li and Lam 2001). It is recommended to use appropriate sun-shading, including deep recesses in the facade, shading elements, etc., to reduce solar penetration, thereby allowing larger glazing area (Lam and Li 1998). It is also recommended to provide secondary shelters or solar shading (to harness solar energy) on roofs (Hui 2001). The use of climate responsive elements like ventilated facades have a great potential in Hong Kong's climate (Haase and Amato 2005).

4.3.2 HVAC systems

Air-conditioning is a major energy user in commercial buildings in HK. The application of district cooling systems for clusters of buildings can help to improve with economy of scale. The use of potable water for chillers to significantly reduce a/c energy is restricted by the building regulations (emsd). Apart from some buildings near the seafront or with access to well water, most chillers use air cooling. Seawater cooled chillers have attainable efficiencies of 0.6-0.7 kW/ton compared to air cooled efficiencies of 1.1-1.3 kW/t, but seawater cooling is being compromised by the pollution and higher temperatures caused by reclamation. However, increase in water consumption would exacerbate the drain on future water resources (Burnett 1999).

The use of reliable data on energy use by lighting and office equipment is often not given leading to over sizing and contributing to overcooling in buildings in summer (Chan et al 1998). Spare capacity allows for breakdowns and load growth, but failure to match unit sizes with cooling load profile means large units operate inefficiently at low output. Savings potential from a better match is up to 16% (Yik et al 1998). Performance monitoring and then optimizing control of operating efficiency of existing chiller plant is

also needed (Burnett 1999). Further improvements are expected by using other climate responsive elements like Thermal mass activation and Phase Change Materials (PCM).

5. Conclusions

This paper introduced the ideas of the collaborative work of the new Annex44 of the Energy Conservation in Buildings and Community Systems (ECBCS) programme of the International Energy Agency (IEA) and discusses its usefulness for Hong Kong and China. Special focus was put on the barriers for integrating climate responsive elements and concepts in the building. A state of the art review of different building elements and of integrated building concepts is under development and will soon be published.

6. Future work to be done

Improvement of concepts for responsive building elements

- Qualitative and quantitative investigation of environmental performance of existing technologies by means of case studies and site measurements, laboratory tests and simulation exercises
- Development and optimization of improved concepts and technologies, especially with regard to implementation in integrated building concepts
- Analyses of robustness and performance sensitivity to differences in boundary conditions (outdoor climate, building use, occupant behavior)
- control strategies and implementation strategies in integrated building concepts

The results will be:

- State-of-the-art of responsive building elements, experimental procedures and application of simulation tools
- Responsive building elements with improved environmental performance and guidelines for their optimal use
- Improved implementation strategies for responsive building elements in integrated building concepts
- Guidelines for application of methods and tools for estimation of environmental performance of responsive building elements
- Information on experimental procedures for evaluation of environmental performance of responsive building elements
- Documentation of results
- Manufacturers' Guide: Guidelines for development, optimization and performance assessment of responsive building elements including examples of application in integrated building concepts

Development and environmental performance assessment of integrated building concepts

- Define performance criteria for integration of responsive building elements in different types of buildings
- Develop and optimise control strategies at system (building) level and communication with BEMS or other building services systems

- Develop new integrated building concepts according to differences in building type, building use, occupant behavior, climate, location, energy sources, services, etc., based on environmental performance assessment,
- analysis of performance sensitivity and cost analysis.

The results will be:

- State-of-the-art of integrated building concepts, design processes as well as design and simulation tools
- Guidelines for integration of responsive building elements and energy-systems in integrated building concepts including a database of “good” solutions and recommendations on how to avoid sensitive solutions, overcome barriers and reduce cost.
- New integrated building concepts
- Information and guidelines on procedures and use of tools for assessment of environmental performance of integrated building concepts

Documentation of results

- Experts’ Guide: Detailed guidelines for design and analysis of integrated building concepts, and integration strategies of responsive building elements and energy systems. Provide guidelines for optimum use of simulation methods and tools to assess environmental performance and robustness of integrated building concepts.

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