Renewable and Sustainable Energy Reviews 25 (2013) 483–493

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Climate adaptive building shells: State-of-the-art and future challenges

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ARTICLE INFO

Article history:
Received 12 August 2011
Received in revised form
8 April 2013
Accepted 20 April 2013
Available online 5 June 2013

Keywords:
Climate adaptive building shells
Building performance
Advanced façades
Responsive architecture

ABSTRACT

Successful building design is becoming an increasingly complex task, due to a growing demand to satisfy more ambitious environmental, societal and economical performance requirements. The application of climate adaptive building shells (CABS) has recently been put forward as a promising alternative within this strive for higher levels of sustainability in the built environment. Compared to conventional façades, CABS offer potential opportunities for energy savings as well improvement of indoor environmental quality. By combining the complementary beneficial aspects of both active and passive building technologies into the building envelope, CABS can draw upon the concepts of adaptability, multi-ability and evolvability. The aim of this paper is to present a comprehensive review of research, design and development efforts in the field of CABS. Based on a structured literature review, a classification of 44 CABS is made to place the variety of concepts in context with each other, and concurrent developments. In doing so, the overall motivations, enabling technologies, and characteristic features that have contributed to the development of CABS are highlighted. Despite the positive perspectives, it was found that the concept of CABS cannot yet be considered mature. Future research needs and further challenges to be resolved are therefore identified as well.

Contents

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1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.04.016

1. Introduction

Last decades, the design of low-energy buildings has diverged into two alternative directions: active technologies and passive design strategies [1–3]. The first approach aims at enhancing the level of sustainability in the built environment via the introduction of innovative technical devices. Such devices are used for decentralized generation and supply of energy from renewables, or for conversion of resources at higher overall efficiencies [4]. The term passive on the other hand refers to buildings where the design of construction and shape of the building itself, as opposed to its servicing, play major roles in capturing, storing and distributing wind and solar energy, normally with the aim of displacing fossil fuels for space conditioning and lighting [5–7].

Apart from the energy conservation agenda [8], the building sector simultaneously gets confronted with an increasing need to develop spaces that are as healthy, productive and pleasant as possible, and all that in a cost-effective way. Seen in the light of these ongoing developments, it is debatable whether either the active, or the passive track independently can fulfill these integrated goals.

In the challenge of harmonizing energy performance within the wider scope of overall building performance, it may be worthwhile to reconsider the role of the building's enclosure. Most of the conventional building shells are designed with a central focus on providing shelter and protection. This is often accomplished by making the indoor environment to a large extent insensitive to its surroundings. The inconvenient consequence is that considerable mechanical and electrical systems are to be installed for providing heating, ventilation, air-conditioning (HVAC) and artificial lighting, in order to satisfy comfort requirements at the expense of energy consumption and the use of other natural resources.

Building shells are located at the boundary between inside and outside, and are therefore subject to a range of variable conditions. Meteorological conditions change throughout the day and the year, and this also applies to occupancy and comfort wishes. Conventional building shells, typically have static properties, and no ability to behave in response to these changes. Making the shift to climate adaptive building shells (CABS) offers opportunities to take advantage of the variability that is available, and therefore would allow for a transformation from ‘manufactured’ to ‘mediated’ indoor climates [9]. By embodying the paradox of combining the complementary aspects of passive design with active technology, CABS offer a high potential to reduce the energy demand for lighting and space conditioning. At the same time, also positive contributions to indoor air quality and thermal and visual comfort levels can be expected.

Architecture has not always considered the ambient environment an adversarial constraint in the design process. Many cases of bioclimatic and ancient vernacular architecture show good examples of how building design can deliberately take advantage of available conditions in the exterior environment [10]. Also the prospect for adaptive rather than static façades is already being pursued for some time. Back in 1981, Mike Davies speculated on the potential of CABS with his visionary concept of a ‘polyvalent wall’ [11]. For many years however, technological restrictions have prevented CABS from being considered a viable alternative [12,13]. By taking advantage of rapid advances in material sciences, contemporary professionals now have plenty of options available for making façades adaptive [14–20]. A parallel trend of dropping prices for hardware, sensors and actuators make that CABS now also become more attractive from an economical point of view [21,22]. The “development, application and implementation of responsive building elements” is a necessary step towards further energy efficiency improvements in the built environment, according to a recently completed project of the International Energy Agency—Energy Conservation in Buildings and Community Systems Programme (IEA-ECBCS) [23].

Discourse on the topic of CABS is thus far mainly centered around iconic examples, including the diaphragm shutters of Jean Nouvel's Arab World Institute in Paris (Fig. 1), and Rolf Disch's rotating Heliotrop in Freiburg (Fig. 2). Often, these buildings are quoted as impetus for renewed interest in CABS. A comprehensive overview that summarizes research, design and development efforts is not yet available in literature.

The aim of this paper is to provide a review and analysis of CABS that goes beyond the classic examples, by exploring the current state of the field in terms of (i) built examples, (ii) subsystems and components, (iii) full-scale prototypes and (iv) reduced-scale prototypes. Section 2 starts with establishing a proper definition of CABS to set the boundaries of the present work. By borrowing terminology from the field of flexible systems engineering, the need for more adaptability in the built environment is then advocated in Section 3. This is followed by providing an overview of the state-of-the-art in the field to point out some particularities of individual examples, but mainly to extract the overall trends and observations of CABS in general. Section 4 discusses the main findings of the literature review along five themes: (i) sources of inspiration, (ii) relevant physics, (iii) time-scales, (iv) scales of adaptation and (v) control types. The results are then synthesized in the form of a table. Section 5 concludes the article with setting a research agenda, by indicating some of the barriers and impediments that need to be overcome before the concept of CABS can become a success on a larger scale.

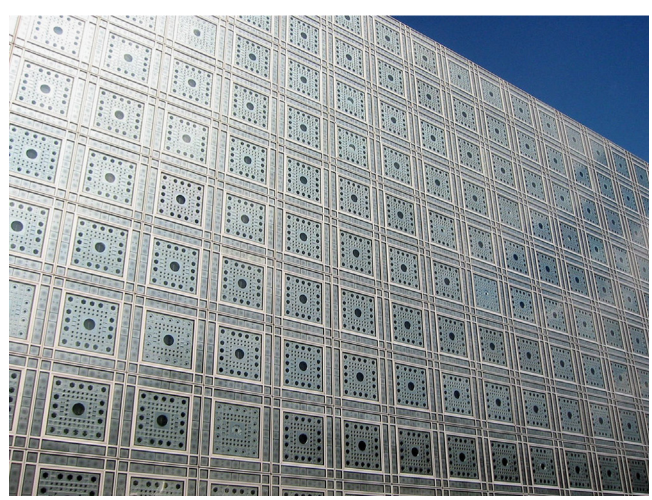

Fig. 1. Arab World Institute, Paris.