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Tall Buildings and Renewable Energy

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Biography

Lukia Fais holds a Diploma in Architecture, a postgraduate MArch in “Bio-ecological Architecture and Sustainable Technologies for the Environment” and since June 2011, a Ph.D. degree in Environmental Design in Rome, DATA Department - Design, Architectural Technology, Territory and Environment, Faculty of Architecture, University of Rome “La Sapienza”.

She is an Adjunct Professor in Design Studio and Construction Technology at the 2nd year of BArch and Design Tutor of postgraduate MArch in “Bio-ecological Architecture and Sustainable Technologies for the Environment”.

Her research areas currently include topics on tall buildings, energy from renewable sources and the promotion of sustainability in the design of the built environment by going into teaching and taking part at the Action funded by the European Commission (Intelligent Energy-Europe, IEE/08/635/SI2.528419) called EDUCATE (Environmental Design in University Curricula and Architectural Training in Europe) as member of the research group for DATA Department in Rome (www.educate-sustainability.eu).

She works freelance, individually and in groups, in residential and commercial building sectors. She has a wide experience of working in multidisciplinary teams on the design and supervision of building projects in Italy and Greece and recently in Latin America with the preliminary design for a marina in Cartagena de Indias in Colombia.
Abstract

Achieving the dramatic emission cuts needed to avoid climate change will require a massive uptake of renewable energy. Within this goal, decentralized energy based on renewable sources is now widely recognized as one of the key strategies. The tall building could play a key role in the future scenario, where the current obsolete electricity grid work will be replaced by an intelligent energy web, hosting a vast community of renewable energy producers and consumers. Thanks to its typological and morphological characteristics, it could include the majority of renewable energy systems and in remarkable quantities, as well as microgenerators and combined heat and power systems.

This paper summarizes the results of the research intended for a PhD degree in Environmental Design at the University of Rome “La Sapienza”. The research is focused on the potential capability of tall buildings to be energy-plus buildings in order to contribute to the energy needs of their surrounding context. Consequently, it addresses the energy issue for tall buildings in terms of energy consumption and the production of energy from renewable sources.

From the scientific point of view, this research focuses on the complex of relationships between the requirements of tall building design in terms of energy needs, the specifics of the various systems for the production of energy from renewable sources and the requirements for their integration into buildings.

The research results need to be configured as a critical framework of information that may help assess the strengths and weaknesses of the different systems of energy production from renewable sources for tall buildings.

Keywords: Renewable Energy, Positive Energy Tall Buildings.

Introduction

Tall buildings (TBs), because of their morphological features, offer a significant potential in terms of urban energy balance. From the ground up to the top, if properly designed they could be better than low- and mid-rise buildings at exploiting the particular climatic conditions of the urban environment to produce energy from renewable sources. This sort of architectural experimentation is still in its infancy.

At present the number of net zero energy tall buildings is extremely limited and, in the absence of operational data, the term net zero energy (NZE) is likely to remain no more than the aspiration of a client sensitive to environmental issues that wishes to associate its image with a commitment to greater sustainability. Some visionary designs aspire to go beyond the NZE level, by the massive deployment of a single system and the integrated application of more than one system. In the context of this research, an analysis of technologies for the production of energy from renewable sources that looked at consolidated, emerging and innovative systems, highlighted the potential of the tall building as a positive energy structure, in that a significant gap was found between the products available and those used.

In addition, the potential of the TB has emerged as a device for shifting the balance of urban density, in terms of its quantitative and qualitative values, where the latter derives from the variety of density and diversity of intended use (Reale, 2008). In essence, the tall building has the potential to concentrate a large amount of resources and human activity into a small space and, if rapidly included in urban planning policies and properly contextualized, it can become an effective solution.

Research structure and methodology

The research was divided into three areas. The first aimed to outline the potential key roles of the TB within the changing urban fabric. The second, designed to track the configuration of the tall building in terms of energy demand, investigated the highly controversial topics of embodied energy of the TB and the energy consumed during operation. The third and core area of the research, is the analysis of technologies for the production of energy from renewable sources.

Studying the most up-to-date literature, renewable energy sources (RES) systems are analyzed on the basis of the fundamentals of the individual technologies, selected according to their integration criteria, investigated in terms of the details of the systems design and finally, evaluated in relation to their applicability...
to TBs. The assessment phase takes into account the technical maturity and producibility of the systems, maintenance and safety features, and local and external impacts. It concludes with a summary, which supports the selection of specific products for further investigation. During the further study of these in the section devoted to the technical and morphological characteristics of the systems, the components exposed are evaluated in terms of their morphological qualities, their level of integration with building components and their level of integration with energy saving devices. Components for the processing and storage of energy are evaluated in terms of their applicability in tall buildings. Finally, the compatibility of the systems with HVAC systems is considered along with the specific benefits resulting from their application in TBs.

The critical analysis of twenty case studies forms an integral part of the research: ten buildings (completed, under construction, or in an advanced stage of design) were chosen to represent the state of the art in the implementation of RES technologies in the context of TBs. The other ten projects, strongly marked by the presence of these technologies and by dimensional and functional freedom, represent the future scenario. The case studies use state of the art research into the sustainability of TBs. Also, the research focuses on the one hand on data about the urban context (socio-economic and infrastructure for the production and distribution of energy), and on the other hand on a morphological-functional study of the building and its technological and plant engineering systems.

Embodied energy in TB
The embodied energy issues are addressed in the light of a possible assessment of height as their variable. The most significant fact to emerge from studies and research concerns the role of density for assessment of embodied energy in TBs (Norman and MacLean, 2006). Density could be a parameter to be considered in this assessment because, inserting into the calculation of embodied energy the part concerning the infrastructure needed for the two different types of development (horizontal and vertical) and then relating the result to the number of people who use the settlement, embodied energy for a vertically developed settlement, is less than that for an horizontally developed. Therefore, it is clear that this area requires further investigation. Design strategies have also been developed for the reduction of embodied energy in TBs (Yeang, 1999; Yeang, 2006).

TBs and energy requirements during operation
The study aimed to define, by looking at research and analyzing case studies, the main morphological and functional features of a tall building with reduced energy requirements (Goncalves, 2010; Yeang, 2006). In summary, the latest generation of high-rise buildings is modeled according to climate zone, taking account of natural light for their planimetrics and altimetrics, using techno-morphological devices (passive systems) for a large part of the heating and cooling and almost all the air renewal. They have a sophisticated and automated envelope, which may be configured in various ways and have some components of decentralized mechanical air conditioning systems, working in tandem with passive systems. Finally, they are characterized by sectoral design, which contributes to the efficiency of techno-morphological devices and the active envelope and by a mix of functions to create a balance in terms of thermal energy consumption and recycling.

TB and Renewable Energy
The research aimed to counter the weakness of renewable sources, that is, the discontinuity of the source, with the strengths resulting from their implementation in tall buildings and their integrated application.

The continuity of the geothermal source. The geothermal source is the only RES available on an ongoing basis capable of ensuring, via the use of geothermal heat pumps (which boast a very high level of technological consolidation), thermal energy for the heating and cooling of confined spaces throughout the year, whatever the external weather conditions. Tall buildings are well suited to the application of this technology, because their foundation piles can be transformed into devices for energy production, simply by including geothermal probes. The thermal energy produced is distributed inside via low temperature systems, which are actually the same used for the distribution of thermal energy produced from solar source.

The potential of solar thermal energy. Combined systems for air conditioning and the production of domestic hot water use vacuum solar collectors whose structure enables them to fit into a variety of locations in the TBs, via the ample transparent and opaque wall space and, at the same time, absorb all components of radiation thus ensuring a significant yield. A storage system, if properly sized, can cope with moderate breaks in the solar energy source.

The advantages of solar photovoltaics. The primary feature of photovoltaic technology is its level of consolidation. The latest products also ensure a high aesthetic and morphological quality. The most innovative products using photovoltaic Concentrated Solar systems (CSPV) would also reduce costs and
optimize performance. Suitable conditions for the implementation of the latter, which basically just transform direct radiation into electricity, are to be found above the boundary level of the urban canopy layer (UCL).

The idiosyncrasies of wind power. Both types of rotor – horizontal and vertical axes of rotation – use the shear rate and wind conditions above the UCL. In addition, the vertical axis rotors exploit winds from every direction and turbulence created by the confluence of the horizontal flow of the wind with the vertical flow that develops along the facades of the building. This reaches a considerable speed in the case of TBs, resulting in one of several configurations of concentrated wind power (Mertens, 2006) that can be achieved by the combination of a tall building and rotor, in which the element that performs the multiplication of the source is the TB itself. In contrast, wind power has limits in the morphological sense and with respect to the conditions necessary for its application, both of which are particularly important for horizontal axis rotors.

The investigation in the field of concentrated solar power. The vertical development of TBs opens the option of the thermodynamic process, which uses CSP (concentrated solar power) technology as an alternative to photovoltaic and wind power systems for electricity generation in the built environment. The advantages that this technology would bring from its application in TBs are substantially the same as those offered by solar photovoltaic concentration. Thus CSP may find in tall buildings a suitable infrastructure for its application in the urban environment.

The limits of biomass energy. It would seem that the systems of energy production from biomass cannot be profitably applied to tall buildings, with the exception of two scenarios. The first is for vertical farm buildings, with which the production chain criterion could be easily satisfied, and second, the ability to produce algae for biomass, via bioreactors in the facades of tall buildings. In the latter, the tall building could be configured as a system for removing carbon dioxide from the urban environment, if we managed to overcome the difficulties of capturing carbon dioxide from moving and scattered sources and in terms of storage.

The importance of fuel cells. At the state of the art, polymer electrolyte cells are the type best suited for stationary applications powered by hydrogen. The advantage of their use in tall buildings is that the TB could produce electricity from renewable sources, necessary for the water electrolysis process that produces hydrogen for the operation of the cells. The system as a whole works as a storage system for electricity produced from renewable sources.

Conclusions

The analysis of case studies of the current scenario shows that an energy mix, or integrated application of above technologies is still in its infancy and would seem to be mainly focused on the production of electricity. Solar thermal energy (STE) for air conditioning or also just for heating and even the production of hot water, is currently an exception in tall buildings. This is also the case for geothermal energy production. And as for PV, this seems to be the most popular technology, but emerging products have not been taken into consideration. On the contrary, the wind system is used in its most innovative form, "concentrated" wind power. Finally, we can observe the appearance of fuel cells for the storage of electricity produced from renewable sources.

This visionary scenario leads to a desire to investigate possible applications of solar thermal and CSP, to further explore the "concentrated" wind power and to measure the potential of the building in terms of growing algae.

The analysis of RES systems has led to the conclusion that with the exception of geothermal energy, the barriers that exist in their application are mainly morphological in nature. The state of the art research aims to reduce this limit to encourage their integration into buildings.

The current trend in the field of CSP (concentrated photovoltaics) is towards miniaturization. This is achieved on the one hand by reducing the size of the parabolic tracking concentrators, as they can be incorporated and protected within a panel, and secondly, through the manipulation of the optical surfaces, in order to reduce the thickness of the panel and the number of cells needed, while at the same time absorbing the widest light beam possible.

Research into solar thermal collectors has focused on selective flat collectors, following two approaches: the first is to color the absorber plate and the second to color the glass that covers the collector (Munari Probst and Roecker, 2010). The goal is to minimize the loss of efficiency of the collector, offering a product that potentially could cover large opaque surfaces of tall buildings, without depriving them of their architectural qualities. Such a development in technology paves the way towards the possibility of large-scale production of thermal energy via TBs.

With regard to CSP, we saw that the configuration of the experimental linear Fresnel collector system could potentially be adapted for a vertical application.
Finally, fuel cells, as a system for storing electricity from renewable sources, are of very great value: this is a single emission-free and high efficiency storage system, compatible with all electricity production technologies, which plays a very important role in experimentation and in the commitment to achieving the goal of net zero and plus energy TB, to the point when it will be normal to sell energy produced from a building to the grid.

Case Studies: Current Scenario

Conde Nast (Fox & Fowel, 1999) / The Solair (Pelli Clark Pelli, 2008) / Co-operative insurance tower (2006) / Bahrain World Trade Center (Atkins, 2008) / Manitoba Hydro Place (Kuwabara Payne McKenna Blumberg Architects, 2008) / Pearl River Tower (SOM, 2011) / Lighthouse Tower (Atkins) / Blue Crystal Tower (Schivo) / The Energy Tower (Gerber Architekten) / Moscow CityTower (Foster and Partners)

Case studies: Future Scenario
Concentrated solar collecting tower (Design studio-IIT) / Interconnected towers (Design studio-IIT) / Solar thermal tower (Design studio-IIT) / Thermal collector cradle (Design studio-TUM) / Bio-city (e-volo) / RAK Spire Building (Castillo and Beyers) / Eco-skin (e-volo) / Freedom Tower (Libeskind and Childs) / Rotating Tower (Fischer) / Clean Technology Tower (Smith and Gill)

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