Recent trends in shaping bioclimatic skyscrapers in Europe

Joanna PIETRZAK

Keywords: bioclimatic building; European high-rise buildings; skyscrapers

Abstract: There is a growing interest in bioclimatic buildings that fit in the local microclimate. Bioclimatic design aims to be energy efficient and to provide users comfort. The premise of a bioclimatic building becomes important in the design of high-rise buildings, where the difficulties associated with changes in microclimate increase with height. Bioclimatic building design should be based on the analysis of many aspects of the microclimate and their diurnal and seasonal changes. The form, interior and enclosure of a skyscraper are shaped according to the collected data. Thanks to the development of digital tools every element of a skyscraper can be adapted to the conditions prevailing in its location. Original spatial forms are the result thereof.

1. Introduction

Local environmental conditions are probably the most endemic factors among the many architectural design criteria (Ryńska, 2001). Because of their objectivity and relative immutability they determine the logical direction of the design process. Currently, though, most of the human population resides in cities, where contact with the natural environment and its impact on buildings is very limited. In highly urbanized areas the share of biologically active areas, water, fauna and flora is small. Therefore, the elements of the natural environment with the strongest impact on the buildings are climatic factors (air temperature, humidity, sunlight, wind, and rain) (Zielonko-Jung, 2013). Climatic factors within the city are prone to change. Hence, considering the environmental impact on the building, we refer to the microclimate that relates to the building’s neighborhood, the extent of which is estimated at 1000 m (Zielonko-Jung, 2013).

2. Bioclimatic design

Research on the state of the environment has its beginning in the 1970s. The 80s were the beginning of the computerization era and the period of designing spaces (especially

*Warsaw University of Technology, Faculty of Architecture, Department of Structural Design, Construction and Technical Infrastructure.
office buildings) in which the user comfort was strictly dependent on the efficiency of different technical systems. Studies carried out in subsequent years showed the need for building designs to be more focused on the quality of the internal environment (Pietrzak, 2013). After a period of dominance of technical solutions, more attention was paid to ecological design whose aim is, inter alia, creating a healthy and comfortable microclimate conditions in interiors of buildings (Zielonko-Jung, 2013).

Since the 1990s one of the main architectural movements was a return to design compatibly with the local climate i.e. the bioclimatic design. According to its assumptions buildings should be designed according to the local conditions in order to operate with the advantage of the local climate. In addition, energy efficiency and increased user comfort would also be considered as basic principles. Bioclimatic design is a characteristic feature of vernacular architecture, but historically it has never been applied to large-scale facilities built in the urban environment. Implementation of bioclimatic design in universal practices may be the biggest change shaping architecture since the modern movement (Ryńska, 2001).

2.1. Bioclimatic design - consideration of microclimate

Currently, a variety of terms relating to design focuses on respecting the natural environment. Let us clarify then what bioclimatic design actually means. According to one of the most noted theorists of this trend, Ken Yeang, „bioclimatic design is the passive low-energy design approach that makes use of the ambient energies of the climate of the locality that create conditions of comfort for the users of the building” (Yeang, 1999). Note, however, that bioclimatic design is only one component of a much more complex ecological design, which ultimately should lead to taking into account all the ecosystem relationships.

Designing a bioclimatic building is limited to relying on the analysis of all aspects of the local microclimate and their diurnal and seasonal changes. However, due to the environmental parameters inside the building and its energy demand, the most significant are solar radiation, temperature, air circulation and water balance (Zielonko-Jung, 2013).

It should be noted that every project is affected by different physical and climatic factors unique to each location. Knowing the character of the place is the key issue of bioclimatic design, which has no other universal determinants. According to the bioclimatic design philosophy: „there will never be a standard ‘one size fits all’ solution” (Hart, 2011).

2.2. Bioclimatic design - consideration of users’ comfort

Bioclimatic premises can be used to design energy efficient buildings. This, however, is not the sole and perhaps not the most important criterion of the quality of this type of buildings. By providing contact with the external environmental conditions, bioclimatic buildings improve the quality of user comfort. Users are able to see and feel the weather conditions and their changes. This prevents them from spending the better part of the day in an artificial, constant environment (Yeang, 1994).

In order to obtain a high user comfort, both biological and psychological requirements should be taken into account. The appropriate physical conditions are: acceptable indoor air quality and thermal comfort. Ensuring satisfactory interior microclimate parameters for all users can be difficult. But undoubtedly users’ satisfaction
increases when they can manually control the microclimate in their workplace. For example, one may introduce operable windows and manually controlled blinds. Other solutions that improve the well-being of users are atria and sky gardens. Open spaces allow for the establishment of visual and social contact with other users of the building, and the implementation of nature into these elements creates a human-friendly environment of social interaction and recreation (Wood and Salib, 2013).

2.3. Not only passive low-energy design

A high utility standard in a bioclimatic building is conditioned by a harmonious cooperation between the use of local climatic phenomena and mechanical systems (Ryńska, 2001). Supporters of vernacular architecture promote the use of traditional materials and techniques, the so-called low-tech (Daniels, 1998), coupled with the use of passive processes. Representatives of the high-tech philosophy promote innovative technologies and active control of processes occurring within the building. Both approaches started to be combined in the 1990s (Jaworska-Michałowska, 2010). Currently, in order to maximize the efficiency of bioclimatic projects, active systems complement passive solutions and low- and high-tech elements can be found within a single building.

3. Bioclimatic skyscrapers in Europe

In addition to defining the concept of bioclimatic architecture, Ken Yeang also contributed to the redefinition of the skyscraper as a building, which may be ecological, instead of being merely a symbol of aggressive consumption (Hart, 2011). Bioclimatic solutions started to be applied in high-rise buildings around twenty years ago, so the possibilities of generating new types of bioclimatic structures are still to be unveiled. In addition, the elements of a high-rise building are influenced by the changing microclimatic parameters of a given object’s altitude - this also shows how the design of bioclimatic skyscrapers is an extremely complex and interesting issue (Ryńska, 2001).

The bioclimatic design methods are used in European high-rise buildings as well. European skyscrapers do not compete in the global race of height. But it is the high quality that is the main determinant of the prestige of high-rise buildings, and bioclimatic solutions, inter alia, define this quality.

Buildings located in European temperate climate appear not to be exposed to extreme weather conditions; therefore, the spectrum of changes in atmospheric conditions requires a specific design approach. In the winter a high thermal insulation of external walls and passive heating is required, while during the summer higher ventilation rates and protection from overheating. Shading should protect against solar radiation during summer and provide its access to interiors in the winter (Wood and Salib, 2013). It is also necessary to protect against occasional or frequent precipitation (Zielonko-Jung, 2013).

4. Shaping of bioclimatic high-rise office buildings

The desired goals in the design of bioclimatic high-rise buildings are inter alia: maximum use of daylight, natural ventilation, cooling and heating, optimal exposure to sun rays, protection against solar heat gain and glare, control of heat gain and loss,
energy saving, and load limitation. Solutions used to achieve these goals have been divided into three groups depending on whether they relate to: the building’s form, interior or enclosure.

In the design process of the European bioclimatic skyscrapers all the available technologies are used: both low- and high-tech solutions, passive and active, dynamic and static elements. The recent leading trends in shaping bioclimatic buildings will be discussed, namely the design of static elements which allow some passive processes to take place. When it comes to the philosophy of the processes, the described solutions are low-tech, however, their material solutions are often related to the recent technological developments and belong entirely to the high-tech. The material solutions, however, are not the subject of this analysis.

4.1. Form shaping

The fundamental issue in the design of a bioclimatic building is the shaping of its form. Efficiently designed enclosure and/or interiors should complement the appropriately shaped: floor plan and cross-section of a skyscraper.

One of the fundamental premises of the European projects is striving for compact skyscraper forms, the most effective of which are based on round or elliptical floor plans (Fig. 1a, 1b, 2). They obtain the largest possible ratio of floor area to perimeter length, minimize the area of the enclosure, and reduce heat gain and loss (Wood and Salib, 2013).

Fig. 1. a) Westhafen Tower, Frankfurt, built: 2003, arch.: Schneider + Schumacher

The factors taken into account when designing a bioclimatic skyscraper are the geographical directions (Rokicki and Pietrzak, 2013) and the shaping of the form in accordance with building orientation. This approach allows, among other things, maximal access to daylight and optimal room exposure to sunrays (Fig. 6a). What is more, the need for additional protection against overheating may also be limited (Fig. 3b).

Streamlined and bionic forms, which have been formed as a result of aerodynamic analyses, appear in the high-rise building design on regular basis. The aerodynamic form has less resistance to the wind and, as a result, it reduces the load on the
building construction and its enclosure (Fig. 6b). In addition, an adequate shaping of
the building improves the wind conditions at the surrounding ground level (Fig. 4b).
Designing buildings with elongated floor plans aligned parallel to prevailing wind
directions (Fig. 3a) is among one of the observed trends (Johnson, 2014). Besides
this rule, each building has a unique environment and a different form. The standard
procedure is to define the characteristics of the wind phenomena occurring around the
skyscraper through the wind tunnel testing (Johnson, 2014). Conducting precise wind
tunnel tests of the impact of the surrounding on a new object is essential, especially
in a dense neighborhood and a complex urban fabric (Irwin et al., 2013).

The use of natural ventilation is an important feature of a bioclimatic building.
This type of ventilation occurs due to the pressure difference generated across the
ventilation openings, which may be generated for example by the effects of wind
(Fig. 1b, 2b, 3a). When the aerodynamic phenomena result in the difference in
pressure around the building, the air in the windward side of the enclosure is drawn
into the building, and the leeward side air is being drawn out. Appropriately shaped
forms of bioclimatic buildings ensure the desired pressure distribution around a high-
rise building, while taking different wind directions into consideration (Wood and
Salib, 2013).

Significant heights of skyscrapers give the possibility of their efficient integration
with wind turbines. Descriptions of such technology in use occur regularly in the
literature (Johnson, 2014), however, in the case of the European skyscrapers these
appear only in experimental projects, and are conducted on a small scale.

4.2. Interior shaping

Shaping the bioclimatic building structure is usually associated with an appropriate
design of its interior. Limited plan depths and sufficiently large height facilitate an
efficient use of daylight and natural ventilation (Fig. 1a). Interior room divisions
are important as well. Open space offices should be located on the perimeter of the
building (Fig. 4b), cellular offices and other enclosed rooms in its central part (Wood
Converse spatial designs are also common; however, the described system seems to use naturally occurring phenomena most effectively.

The natural ventilation process, essential for bioclimatic designs, can occur not only due to adequate pressure distribution around the building, but also due to buoyancy forces caused by the differences in the density of air at different temperatures (Fig. 2b, 5b). This phenomenon is also known as a stack or chimney effect and is mainly dependent upon the height of the chimney it occurs in. In order to incorporate this type of natural ventilation, it is crucial to provide the interior with a chimney, atrium, sky garden, or another type of a vertical shaft. However, the designed shaft cannot be too high, because then naturally occurring phenomena can be difficult to control (Wood and Salib, 2013).

Atria and sky gardens are a popular solution used in bioclimatic buildings. In addition to creating natural ventilation chimneys, such solutions bring daylight deeper into the building plan (Fig. 1b, 2b). They can also act as a solar and thermal buffer between the exterior and the office space, as well as protection against undesirable weather conditions. Plants and water (Fig. 5b) that both positively affect air quality and thermal comfort can also be introduced inside the atria (Pietrzak, 2013).

Although widely discussed in the literature, atria are not a common solution in high-rise European buildings. The potential loss of a floor space is too high for many developers. Instead of multi-storey atriums perforating the entire high-rise building (Fig. 1b, 2b), sky gardens are placed point-wise. Sky gardens are usually relatively narrow spaces extending along the façade (Fig. 1a) or occupying one of the first or top floors (Fig. 5a).

![Fig. 3. a) KfW Westarkade, Frankfurt, built: 2010, arch.: Sauberbruch Huttonb) Heron Tower, London, built: 2011, arch.: KPF.](image)

### 4.3. Enclosure shaping

Analogous to its purpose of exchanging energy between the interior of the building and its surroundings, the contemporary enclosure of a bioclimatic building is called the skin (Zielonko-Jung, 2013). The bioclimatic skyscraper façade is also an essential element of adapting the building to the changing climate conditions. The skin
may be structurally independent of the body of the building, but the most effective solutions arise when the enclosure is inherent to the building’s structure. The shape, construction and functionality of the enclosure should be dependent on the form and the interior of the building.

The project of the elevation project can rely on a relatively simple solution (Fig. 1a, 2a). The more effective solutions, however, rely on a different elevation shaping, depending on the orientation and combined with a suitable shaping of the form of the skyscraper (Fig. 2b, 3b, 5a).

Double-skin façades are commonly introduced in high-rise European buildings. The double-skin façade (Fig. 3a, 5a) consists of two layers of glass separated by an air space (Johnson, 2014). Such solution requires a partial reduction of internal space; but, it is usually accepted for its efficiency. In addition, a double-skin façade functions on a similar basis to the atrium, occupying significantly less floor space.

A number of benefits come from the use of double façades because of their insulating, acoustic and thermal properties. One of the most important factors is, however, the use of natural ventilation. This process takes place in the cavity of the façade, and may be of dual nature depending on the structure of the enclosure. The cavity without horizontal divisions allows buoyancy-induced ventilation (Fig. 5a). ‘Corridor’ double-skin façade (without vertical divisions) allows wind-induced ventilation (Fig. 3a). The inflow and outflow of air into the cavity occurs through the holes in the outer layer of the façade, while the ventilation of the room is possible via operable windows in the inner layer. Simultaneously windows are shielded from undesirable weather conditions, especially strong winds.

The void in the double façade also acts as a thermal buffer against heat loss and gain. In addition, external sun shadings can be safely installed in its cavity. Thanks to reflection and absorption of solar radiation before it reaches the interior, the efficiency of shading is increased.

The selection of materials for single-skin façades plays a key role. These materials should feature high-performance properties so as to effectively protect the interior of the building (Fig. 1a). The characteristics of the materials may dominate the shaping
of the enclosure. However, some single-skin façades are also equipped with specially designed external components (Fig. 4a, 4b) that perform a variety of functions: reduce glare, limit solar heat gain when necessary, allow solar gain when beneficial (Wood and Salib, 2013), are a visual barrier, and limit gusts of wind (Johnson, 2014).

Layered walls are also worth mentioning as they serve as an indirect solution between the single- and the double-skin façades. This solution constitutes in designing the inner wall as a continuous envelope, which is then protected with a perforated layer (Fig. 2a, 6a). The outer layer usually consists of lamella, brise-soleil or other similar items that give shade and protect the users from glare, allowing a person to maintain visual contact with the environment and the daylight. Simultaneously, since the air can circulate freely between the layers of the façade, the risk of overheating is limited.

Material solutions in European high-rise building vary, but usually the dominant part of the outer enclosure is made of a glass curtain wall (Fig. 1a, 1b, 5b) accompanied with variously shaped sets of shadings, usually made of metal (Fig. 4a, 6a) or glass (Fig. 2b, 6b). Photovoltaic cells start to be incorporated into elevations (Fig. 3b, 5a). Despite the scepticism of introducing the cells in temperate climates, one can find information to actually support their application: “light levels in the UK and Northern Europe are generally sufficient to make PVCs viable, with photovoltaic cells generating power even on cloudy days” (Johnson, 2014).

5. Increasing complexity of bioclimatic skyscrapers

The implementation of bioclimatic parameters allowed architects to create a new aesthetic in construction (Ryńska, 2001). The first bioclimatic skyscrapers were characterized by a strong geometry, modularity and a simplification of spatial solutions, technical and architectural details (Rokicki and Pietrzak, 2013). Then the development of computer techniques contributed to the further evolution of this type of buildings (Fig. 1-6 in chronological order).

![Fig. 5. a) Intesa Sanpaolo Tower, Turin, topped out, arch. Renzo Piano Building Workshop; b) Skytower, Frankfurt, topped out, arch.: Coop Himmelblau.]
Fig. 6. a) Phare Tower, Puteaux, proposed, arch.: Morphosis; b) Bishopsgate Tower, London, on hold, arch: KPF.

The technological evolution also influenced the design of high-rise buildings of the twenty-first century. The development of CAD software and analytical methods allowed the design of increasingly complex forms and spatial distributions. Some buildings constructed according to this method can be defined simply as sculpture; but it has to be noted that the complex forms in the bioclimatic trend are based on objective premises.

The implementation of digital tools both simplified and complicated the process of bioclimatic design. The use of increasing computational capabilities of computers, parametric design and optimization algorithms allows architects to design buildings more accurately fitting in the environment. The forms, interiors and enclosures of emerging skyscrapers are adapted to the microclimate parameters. Each element of the building can be adapted to the conditions prevailing in its location as a result of multi-criteria optimization. All possible environmental parameters that will affect the skyscraper are taken into account in the process of generating the form. Buildings varied both in plan and cross-section, with curved, original forms whose complexity goes beyond traditional design are the result of the revolution in the design techniques. On the other hand, their complexity also creates difficulties associated with the production process and erection of these buildings.

6. Conclusions

Nowadays, designing high-rise European buildings based on bioclimatic architecture premises seems to be increasing. Such projects are a return to the traditional construction methods, the premise of which has been used in an unprecedented scale. The erected skyscrapers are a demonstration of the new approach to the design of high-rise buildings, which shifted from being consumers of the environmental resources into objects that function in accordance with the laws of nature and premises of a sustainable development.

At the current level of construction industry development, an introduction of bioclimatic premises into the design process maximizes access to daylight, enables natural ventilation, heating and cooling, minimizes heat gain or loss, prevents glare
on the employees. The use of these techniques can increase the efficiency of the construction process, as well as provide a healthier and more comfortable indoor environment.

When designing a bioclimatic object, shaping the form of the building, its interiors and enclosures is conducted in detail. The more efficient solutions rely on a simultaneous and comprehensive adaptation to the prevailing local environmental conditions. Most of the buildings designed according to this approach have a strong geometry and repeatability of spatial solutions and details. Some of the latest designed skyscrapers have, however, a curvilinear geometry and variability in both the floor plan and the cross-section. This new generation of bioclimatic buildings is a result of the introduction of the multi-criteria optimization to the design process, meaning that every part of the building is being adapted to the conditions prevailing in its location.

A bioclimatic building is not only an example of a project based on rational and unchanging conditions, i.e. local microclimate parameters. The process of designing a bioclimatic skyscraper serves as a justification for the use and development of advanced computer techniques. In addition, the original and varied forms of bioclimatic high-rise buildings are attractive because of the reasonable climate analysis underlying their design, rather than purely artistic reasons. Emerging skyscrapers are examples of projects both very rational and original.

References

Daniels, Klaus (1998), Low-Tech Light-Tech High-Tech: Bauen in der Informationsgesellschaft, Birkhäuser, Basel; Boston; Berlin.
Jaworska-Michałowska, Maria (2010), Inteligentna wrażliwość współczesnych ścian: struktura-organizacja-funkcjonowanie, Wydawnictwo Politechniki Krakowskiej, Kraków.