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PASSIVE DESIGN APPLICATIONS - INDUSTRIAL ARCHITECTURE PERSPECTIVE

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Abstract. *This paper deals with the process of design in the context of the idea of energy conservation. We used analytical instruments in order to extract the principles and methods the architects used in their design as the solutions for passive design concepts. We narrowed down our research focus to the industrial architecture as a paradigm of the contemporary designs that is very much into the idea of green technology and energy conservation. As great energy consumers by their function, investors of the industrial buildings are justifiably interested in building a more energy effective building. There is a characteristic difference in the design of industrial architecture and the other types that also make passive design applications specific. Using the case study method and invert method of translation, we have examined the selected design projects. We tend to make some progress in the field of architectural design methodology, as a main area of application of our findings. The idea was to make the proposition of methodological principles extracted from the successful architectural practice for more rational and less time-consuming design method that has passive design component.*

Key words: *energy efficiency, passive design, industrial architecture, solar architecture, case study, design principles*

1. INTRODUCTION

Energy preservation is an important agenda of contemporary society. Knowing that the buildings are one of the great energy consumers, the art and science of making buildings has to be orientated towards energy conservation. One on the basic concept that has been developed for a quite long time is passive design. This is concept has roots in logic of traditional building that tend to use natural resources to achieve optimal and healthy living conditions. Avoiding the use of mechanical and electrical appliances and therefore

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additional usage of energy is an agenda of passive design that rejects the achievements of technical revolution in a way to construct energy independent buildings. The engineering theory and some more or less experimental architectural practice, that is usually connected with high level of investment, is now focusing on green and energy efficient buildings that are also known as zero-energy buildings or similar. However, there is an impression that such concept is not so widely spread and it is reserved for elite projects. Also, there is an overall impression that such projects are "over-engineered" involving so many engineering teams that are employed to provide the energy-efficient (or passive) standards, usually through the system of certificates (LEED, BREEM, etc.)

In this context, there is a visible need to simplify such procedure, to translate the desirable energy efficient principle (and/or passive) into architectural design principle. To narrow down this research, we were focused on applications of passive solutions that have been recognized as a base for further improvement towards sustainability and energy efficiency. Therefore, we have focused the research toward three elementary components of passive design of buildings: solar gains for heating, delighting and natural ventilation. (*Hegger, 2003*) Furthermore, we chose to investigate the possibilities of applications of passive design principles in designing industrial buildings, recognizing them as a vulnerable category of buildings that have lower architectural status, and usually are not in the focus of architectural research. Similarly, passive design principles are usually discussed and elaborated within residential buildings (*Passive Solar Design Strategies*) or even office buildings, while the industrial buildings has to be proven on the possibility of using such benefits. To discuss the application of existing passive principles to industrial buildings should first determine specificities of the industrial buildings in this context.

The passive use of solar radiation for heating functions without the need for technical systems. The buildings should itself make direct use of solar energy by virtue of its placement, geometry, buildings components and materials. This is the simplest and the same time the most effective form of passive solar architecture… The clever selection of the site, placement, shape and orientation, deliberate window arrangement, considered selection of materials and wall structures – these are the factors that make it possible to absorb and store solar heat, to maintain comfortable temperatures in a climate-conscious envelope and to utilize light to the best effect. *(Hegger, 2003)* The form should be simple and compact, but as well the depth of the building should not exceed the two of its height in order to be considered for passive design. The zones of the building that does not belong to this area cannot be considered passive zones, except those that are near the atrium (if they exist) that is referred as a buffer zone, semi-passive, in the size of one or one and the half of the height. *(Baker & Steemers, 2005)* This is connected with essential, timeless principles of solar architecture: minimizing of the surface (advantageous A/V ratio), open towards to the sun, solar zoning – cool rooms on the north side, warm rooms on the south side, selective shading, protection against high solar altitude on the south side, utilization of storage masses for temperature compensation. It is said, that building and living with the sun also means more comfort: bright interiors flooded with light have measurable positive physiological effects on human beings. *(Hegger, 2003)* While all these guidelines sound quite logic for residential architecture, the industrial buildings follow different logic: the usage of day-lighting in the industry is usually connected with northern light. Because of diffuse light with relatively constant intensity during a day, the window openings orientated towards the north is for all working facilities is recommended.

Passive design, on the other hand, recommends no openings from the north. Also, in theory, it is said to be difficult to introduce in deep-plan and large scale buildings *(Baker & Steemers, 2005)* and industrial buildings definitely can be considered as such.

In order to examine the applicability of the general passive architecture guidelines and recommendations in designing industrial buildings, we used the case study analysis to extract possible adopted passive design principles useful for industrial architecture.

2. Materials and Methods

We have analyzed four contemporary industrial complexes that were built between 2006 and 2011. They are chosen among other contemporary projects due to the clarity of the passive design principles showed in particular works. Three of those analyzed buildings designed Guillermo Hevia, Chile based architect and those ones, Olive Oil factory, Glass bottling plant Cristalchile and Ferreteria O'Higgins warehouse are situated in Chile, while the remaining one is the RS+Yellow Distribution Centre in Germany. In this way we covered for analysis and discussion different climate zones, but as well different industrial facilities, both plant and warehouses. Analysis of these case studies is systematized by main design considerations: location, orientation, form and building envelope.

3. Results

3.1. Case Study 1 - Olisur: Olive Oil factory, Chile by Guillermo Hevia

3.1.1. Location and topography.

Situated low on a south-facing sloped site this industrial complex is skilfully designed so that the building is protected from the northern winds by thick vegetation. (Figure 1-a.) On the other side, placing a water pond directly in front of the south façade, provides an additional cooling effect of the inlet air. (Figure 2-a.)

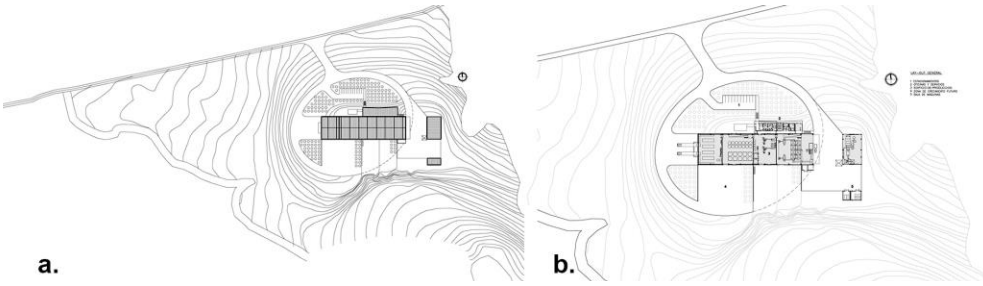

Fig. 1 Olive Oil factory - (a) Site plan and (b) General floor plan

3.1.2. Orientation

The building is positioned perpendicular to the slope, thus facing South with its longer façade. Such a position favored the natural transverse ventilation of buildings. Shaded by long cantilever on the south façade, the interior is additionally protected from overheating by direct sun.

3.1.3. Form

The building form is simple and compact and clearly follows the idea of an optimal A/V ratio. Elongated form also suggests the use of transversal natural ventilation.

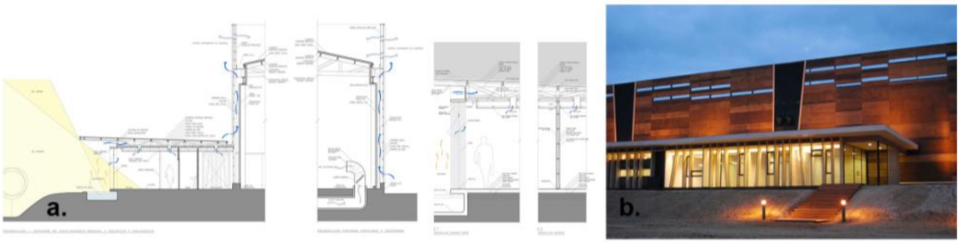

Fig. 2 Olive Oil factory - (a) Partial cross sections (b) Photo of the exterior of the building

3.1.4. Building skin

There are no large openings in the buildings. The opaque panels are composed with the translucent ones for selective day lighting. The façade is constructed as ventilated with two separated walls (layers), the outside wooden panel are used as shading, perforated to enable natural flow of air in inter-medium. The inside panels serve as insulation as well as a massive storage component.

Roofing panel is also ventilated, following the same logic as façade solution. Perforated wooden facade panels are mounted to over-top the roof, thus making the shade and protecting the roofing panel of overheating in the summertime at the same time allowing transverse air flow above the building.

3.2. Case Study 2 - RS+Yellow Distribution Centre, Germany by Bolles + Wilson

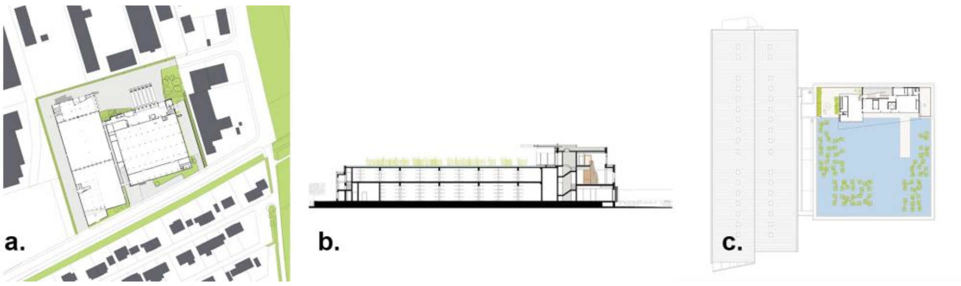

Fig. 3 RS+Yellow Distribution Centre - (a) Site plan and (b) Cross section of the main building (c) Layout of the top floor

3.2.1. Location and topography

Tightly built on the flat modest-sized industrial site, this complex uses the vicinity of its neighboring buildings to shelter from excessive winds.

3.2.2. Form

The compact form of the building follows the rule of optimal A/V ratio. The square layout of the building does not favor any of orientation. With the floor topped northern part of the building work as a barrier against northern winds for a shallow pond and the roof garden formed on the top of the rest of the building.

3.2.3. Building skin

In this case the transparent openings are not obvious. The façade skin is formed by a single layer lightweight concrete system.

The pond and bamboo vegetation on the top of the building is additional thermal insulation that also contributes to a favorable micro-climate, by evaporation, especially in the south facing glazing façade of the top floor. Deep eaves at this façade shade the window structure from overheating and direct sun lighting.

3.3. Case Study 3 - Glass bottling Plant Cristalchile, Chile by Guillermo Hevia

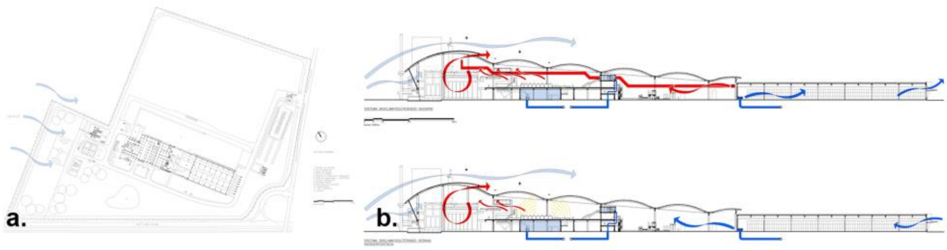

Fig. 4 Glass bottling Plant Crtistalchile - (a) Site plan and (b) Cross sections of the main building

3.3.1. Location and orientation

The typically flat industrial site is chosen for this industry. The building is positioned parallel to the strongest northern wind direction. This cold wind is additionally slowed by dense vegetation in the direction of the wind. A small water lagoon that is designed on the site is also used for adjusting the micro-climate of the site.

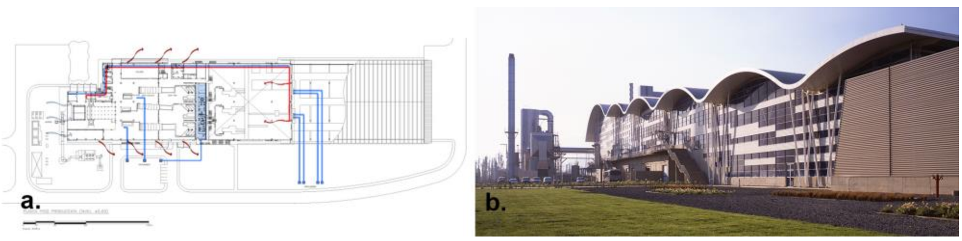

Fig. 5 Glass bottling Plant Crtistalchile - (a) Layout of the ground floor and (b) Photo of the building exterior

3.3.2. Form

Compact but longitudinal form is rationally designed to make optimal A/V ration. Building height gradually increases in the opposite direction of the wind, and serves as a natural barrier. At the same time, internal, natural ventilation (transverse as well as longitudinal), carefully planned, is allowed by the openings in the façade and roof. Here, are also used the buried ducts for air cooling, requiring usage of mechanical pumps.

3.3.3. Building skin

Unlike the previous design, large window screens are extensively used in this plant providing quality natural light in the working zone. Deep roof overhang protects the transparent wall from overheating and direct sun during high summer zenith position. The southwest façade is largely opened to solar insolation, while the northeast is less transparent.

3.4. Case Study 4 - Ferreteria O´Higgins, Chile by GH+A

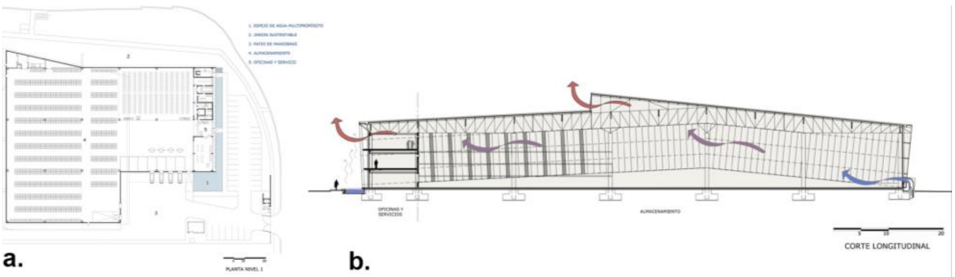

Fig. 6 Ferreteria O´Higgins - (a) Site plan and (b) The cross section of the main building

3.4.1. Location and orientation

Flat but tight site is optimized for such industrial function. The building has filled almost the whole site, so there was not room for additional landscaping.

3.4.2. Form

Following the size and the form of the site, the building is designed from two volumes, slightly leaned against each other, but intersecting each other. The compact form contributes to the reduction of the energy losses.

Fig. 7 Ferreteria O´Higgins - (a) Partial cross section of the building (b) & (c) Photo of the exterior

3.4.3. Building skin

The eastern façade is a large curtain wall screen additionally protected from the direct morning sun by the translucent veil made out of perforated Corten steel sheets. These sheets move slightly and constantly with of the wind, which combined with the effect of the multipurpose water mirror located in their base, give the building a dynamic dimension. Besides having an aesthetic value, this pond is a water reservoir in case of fire, and through the evaporation of water keeps the facade of the building cold during the summer months, improving the inside living environment. The rest of the building is designed so that weight supporting structure is surrounded by a Corten steel double skin, reinforcing the idea of two solid bodies, and at the same time protecting the inside of exterior temperature and direct solar radiation. An air chamber is created between the exterior Corten steel skin and the interior insulated panel facade, which helps create a very efficient thermal barrier. The air flow between panels is reinforced by additional temperature difference by burying ducts.

Controlled sunlight comes in through translucent stripes in the ceiling (7%), completely eliminating the need for artificial lighting during daytime operations, with great energy savings.

4. DISCUSSION

The presented cases have shown us that there are differences between the passive housing design and industrial buildings, so that, the existing guidelines for passive design cannot be literally used. There is a big difference between a sunlit house and the cloistered industrial facility. However, there are some similarities and principles that are easy to follow no matter the type of building.

As each architectural project starts from the location analysis, we start our discussion with location aspects. Our cases show that there it is very important to take into account possibilities of improving the overall ambience and the micro-climate of the site. The site must not be considered just from the functional aspects of an industrial complex, they are inevitable, but the site must be carefully landscaped in order to take benefits from passive design. Vegetation is recommended for use as a natural wind protection. A good wind protection can be also existing, neighboring buildings. This is especially important for industrial buildings built within an industrial zone, without sufficient free and open space where vegetation can be planted.

A favorable micro-climate can also be achieved by adding artificial water surfaces (pools, ponds, lagoons, etc.). This content on an industrial site is very much acceptable taking into account the size of a site and the function. Small-sized water containers are useful if placed directly to the façade, to cool down the inlet air. Sky reflection on the water mirror also contributes to overall day-lighting, but also, such water can be used in fire protection, which is a very important aspect in designing industrial buildings. If there is sufficient place, larger water containers can be designed within an industrial site, but also a creative solution can be used of rooftop for placing a water pond for the same reasons. It also in this case can serve as a thermal insulation.

Further aspects of design that should be discussed is the form. In order to be rational and to avoid any unnecessary thermal losses, there is an absolute law of creating a compact form for buildings. None of our case studies has shown deviation from this principle. Unlike the contemporary trend in architectural design, where forms have trend of being complex, unusual, irregular; the passive design concept needs a rule of creating compact, rational and regular form. Here we recognize two types of general forms: compact, approximately quadratic and elongated form. First one has an optimum A/V ratio, but those quadratic forms in proportion of an industrial building fail to fulfil the requirement of the optimal depth of the building. Elongated form is therefore one of possible passive solutions due to the better performance in this context. Narrow sides of the building allow transversal natural ventilation as well as natural lateral lighting. As we analyzed cases showed, in situations where natural lighting, but also ventilation, is needed for working process more logical form is elongated (provided that this is not limited by the site), while warehouses and similar spaces in the industry where the lighting is not valuable category, the compact, quadratic form is preferred.

However, we recognized the construction of the building envelope as the most important aspect of designing passive buildings. This is the final element of design that has the role of correcting all the mistakes and unfavorable conditions that could not be avoided or corrected. The building envelope has an aim to allow natural sunlight to enter the building, to enable proper thermal insulation and disable excessive thermal losses. Natural ventilation of the building is also to be enabled by design of the building skin. As for the usage of daylight as a part passive design concept in industrial buildings, our cases showed two solutions. Unlike traditional design of industrial buildings where the northern light was favored, passive solar design solutions favor the south (or southeast or southwest) orientated windows, but inevitably equipped by some sort of shading – deep overhangs as fixed solutions or vertical shading panels that are usually movable. In this way the amount of penetrating sunlight can be controlled. The industrial buildings are maintained and controlled buildings, so the façade that is created as the active and transformable system is acceptable. Still, there are situations where introducing sunlight inside the building via south façade is not suitable. If industrial process is too sensitive to direct sunlight (e.g. Oil production), the solution to block any kind of natural light in the building is highly more reasonable.

Solar radiation for heating industrial buildings is also used aspect of passive design. But all modes of gaining solar energy for heating, are not possible to introduce in industrial buildings. As we concluded that direct sunlight into the building must be carefully controlled, so the thermal gains of such radiation are also limited. Double skin façade our cased showed are the most suitable solution. First layer is sun-diffuse while the inner layer (wall) serves as a thermal mass. The interspace between those layers are usually ventilated (controllable) serving to protect overheating during the summer period. Such construction is applicable due to the rational design; it does not mean needs for additional space.

Natural ventilation of the building interior is also vastly used concept. This is an easy principle known also in traditional industrial building construction. An important aspect of this process is possible to form inlet and outlet openings on facades and to position them on opposite walls. Inlet opening is usually low positioned on the wall while the outlet has to be high on the wall or even on the roof, which is suitable for wide buildings. By placing water surface near to inlet opening, it is possible to additionally reduce the inlet air temperature. The materialization also should be as much as uniform (constant) as possible in order to avoid any unnecessary thermal bridges. The architectural aesthetic is then “reduced” or preferably focused on façade design through color and texture, but as well by designing a useful solution for windows shading.

5. CONCLUSION

From the presented cases and our discussion, we were able to conclude that it is possible to introduce the passive design in designing industrial buildings. Although there are circumstances that are not in favor of it, primarily the problem of introducing natural lighting into the building, there is the other that is easy to follow. Our concluding remarks are: in order to protect the building from excessive thermal losses, the building should be positioned on the site so that it is protected from strong wind flows. The protection can consist of vegetation but as well of the neighboring buildings. Beside the excessive vegetation, improvement of micro-climate on industrial site is easy to perform by designing a water surface. They are especially useful in summer for creating a cooler breeze, but they also reflect a sunlight that can be directed towards and inside the building, and as well it is an additional water pond that contributes to the fire protection.

Also the A/V ratio must be kept rational, in the form of the buildings should be kept compact. Quadratic shapes are the most recommended, but they exclude the lateral natural lighting and transversal ventilation, so the elongated shapes in such cases are more logical to use. Additional thermal gains from the direct sun radiation should be used by creating south orientated walls capable of collecting sun radiation. There is a double way to achieve this goal, and both of them do not exclude each other, so it is possible to combine them. The industrial building is suggested to be designed with a transparent southern wall (but the shades are obligatory) or as an opaque wall that is used as a thermal mass wall. Overheating in summer period may be regulated via double skin facades, with ventilated interspace and as well deep overhangs and vertical shades for transparent walls (windows). The vertical shades are suggested to be mobile, transformable and used depending on external conditions. An important aspect of this analysis is that it showed that the passive design concept is also adaptable for the industrial architecture, and it does not disturb any of the basic characteristic of industrial architecture: to be rational, easy to be built and rebuilt, meaning the usage of prefabricated structures and at the same time to have significant architectural qualities.

Further improvement of passive design concept would be adopting the strategies of sustainable design such as recycling (e.g. Atmospheric water) and usage the renewable energy sources, e.g. the energy of sun or wind but as well the geothermal energy. The industrial sites are absolutely compatible for such facilities, because of the size of the rooftops, suitable for photo-voltaic panels, but as well the position and the size of the industrial site that are usually flat and spacious which recommends them for installing windmills.

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PRINCIPI I PRIMENA PASIVNOG PROJEKTOVANJA IZ PERSPEKTIVE INUSTRIJSKE ARHITEKTURE

Ovaj rad se bavi procesom arhitektonskog projektovanja u kontekstu ideje o očuvanju energije. Kroz analizu postojećih primer aindustrisjke arhitekture koji imaju izražene elemente pasivnog dizajna, izdvojeni su principi i metode kojima se služe projektanti kroz koncepte pasivnog projektovanja. Istraživački fokus je sužen na industrijsku arhitekturu kao paradigmu savremene arhitekture i projektovanja koja dosta ulaže u ideju zelene tehnologije i očuvanja energije. Kao veliki potrošač energije, industrija i investitori industrijskih objekata su opravdano zainteresovani za izgradnju energetski efikasnijih objekata. Sa druge strane, postoji karakteristična razlika u projektovanju industrijskih objekata u odnosu na druge objekte, što čini primenu principa pasivnog projektovanja specifičnim u ovom slučaju. Koristeći metod studije slučaja i inverzni metod translacije karakteristični primeri su analiirani, iz kojih su dalje izvedeni zaključci koji imaju primenu i unapređuju metodologiju arhitektonskog projektovanja.

Ključne reči: *energetska efikasnost, pasivno projektovanje, industrijska arhitektura, solarna arhitektura, studija slučaja, principi projketovanja*