ENERGY EFFICIENT ATRIUM DESIGN FOR DIFFERENT CLIMATE ZONES

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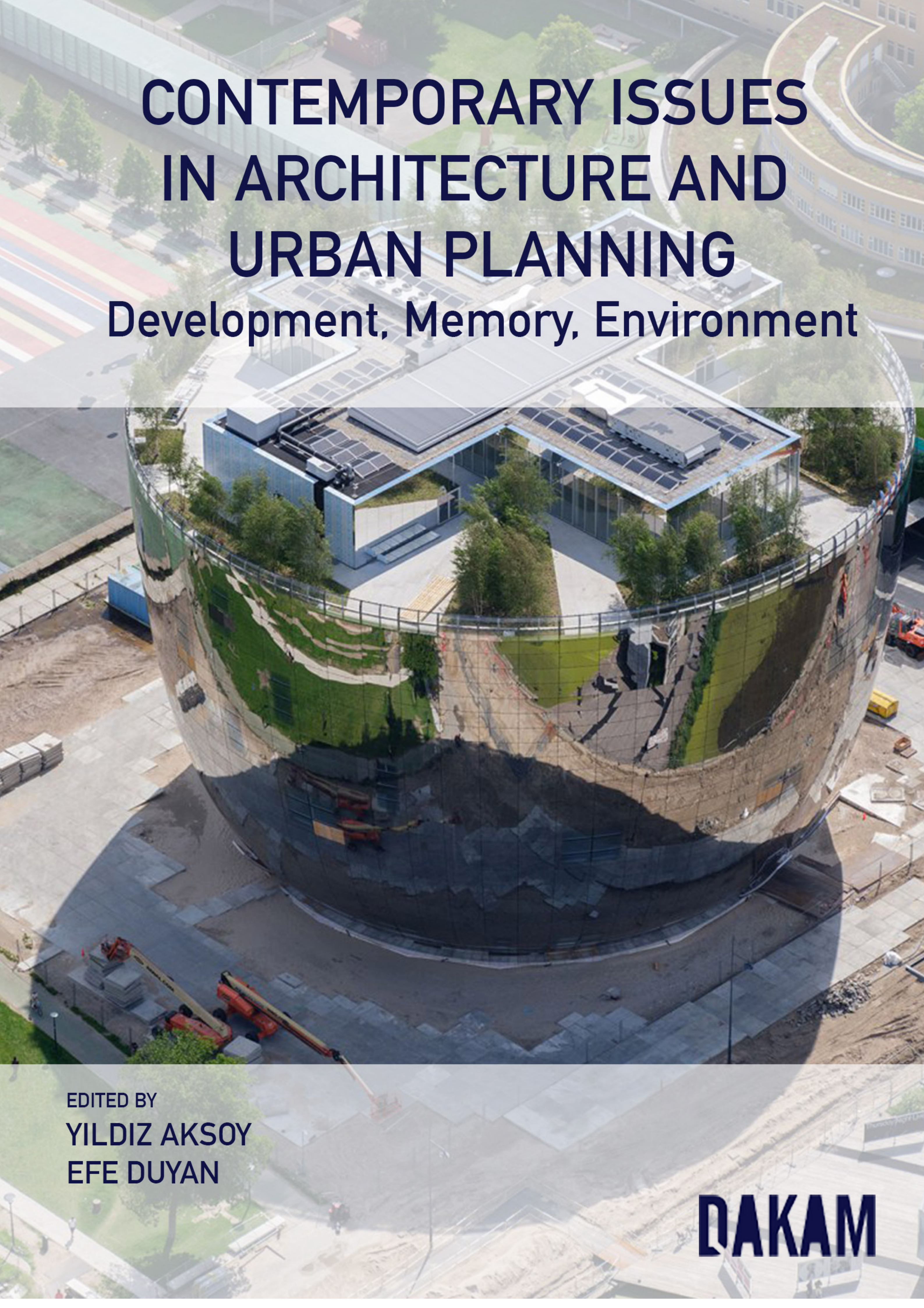
CONTEMPORARY ISSUES IN ARCHITECTURE AND URBAN PLANNING

Development, Memory, Environment



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EDITOR'S NOTE

Contemporary Issues in Architecture Development, Memory, Environment is an edited (multi-authored) book focusing on the new trends and frontiers in architecture.

Development in terms of urban and technical aspects has always been one of the frontiers of architecture. Today, it is possible to observe that technical innovation go hand in hand with urban visions. Memory has played an important role in historiography and humanities recently and architectural perception as well as historical perspectives have acquired a new edge in the form of memory. Environment continues to be one of the hot-topics in the center of global warming and sustainability.

Within that scope, the concepts of development, memory, and environment had been brought into focus.

YILDIZ AKSOY AND EFE DUYAN

ENERGY EFFICIENT ATRIUM DESIGN FOR DIFFERENT CLIMATE ZONES

İDİL AYÇAM[1], AYŞE ŞEYMA ARSLANTAŞ[2]

ABSTRACT

Atriums are places that should have different energy-efficient strategies depending on climatic charecteristics. With in the scope of energy efficient building parameters in atrium design; air movements, heat gain-loss ratio, relationship with adjacent spaces, natural light and glass facade/roof relationship and orientation factors should be considered together with the whole building. Buildings having a specific plan type or form of general properties, it is seen that atrium typology bears a resemblance.D esigning the atrium space as in proportion to the building, significantly affects the annual energy consumption of the building. Despite the fact that natural ventilation and cooling strategies are effective in the period requiring cooling scenarios due to the difference in climate characteristics, energy efficient strategies through natural lighting and with passive design solutions it is possible to optimise of building thermal performance (heating-cooling). Height has desicive impact on the control strategies in atriums. While energy efficiency can be controlled more easily in low-rise buildings, the negative effects of climate on comfort in high-rise buildings. It's necessary be addressed together with automation-based sensitive control strategies. When the examples of buildings with atrium are examined in modern architecture, it is seen that the centered atrium is more prevalent, but the greenhouse type and more complex types are configured with different control techniques in warm and humid areas.

KEYWORDS: Atrium Design, Atrium Types, Energy Efficiency, Energy Efficient Strategies, Passive Design.

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1. INTRODUCTION

Designing the physical environment by human since the past has been determined by the climate conditions. When we examine our building history, the courtyard was used in Traditional Turkish Architecture for the same purposes as the atrium. In our civil architecture, there are residences with inner courtyards and outer courtyards, inns and caravanserais with centered and open courtyards. In traditional Turkish architecture, while design of the courtyard, the orientation, the choice of the open and closed courtyard type are determined according to the climate of the region where the building is located (Bozkurt and Altınçekiç, 2013).

The first use of the atrium is encountered in Roman houses as a spacious entrance space. This area serving as a semi-social space is on the centre of entry and exit without being covered by a canopy. As a semi-open space, one feature is that it has a relationship with the outdoor space. However, by the century 19th, variations has began in courtyard spaces with enhancement of steel and glass technology (Göçer, 2006; Hung, 2003).

In 1986, Bednar (1986) and Saxon (1986) investigated the pros and cons of the first atrium buildings formed by covering the courtyard owing to development of various covering systems on the aspect of influencing building performance as an energy strategy.

In his book Saxon (1986), in which he examines the atriums standing as a milestone chronologically, he states that the high-tech and nature-sensitive atrium was designed with the effects of greenhouse development, the conservation of building and energy.

It is a positive feature of the atrium that can be used in all climates to provide a more livable environment in the building against the extreme adverse impact of climate. Moreover, it also has a positive effect on the energy efficiency of the atrium in lighting which is useful in many climates, except for its use in directions or situations leading glare. Yet, in terms of heating, cooling and ventilation loads, several parameters should be taken into consideration simultaneously during design of the atrium.

2. THE RELATIONSHIP BETWEEN CLIMATE AND ATRIUM

The physical events (greenhouse effect and air stratification) occurring in the interior of buildings with atrium complicate the energy consumption control, determining energy performance in these buildings and providing convenient air-conditioning on the basis of the purpose of usage. In addition to these physical events, the type of atrium and the climate zones also play a crucial role to determine the proper heating and cooling strategies in buildings. The climate data affect the choosing of atrium type in accordance with balance of the loads heating and cooling.

In areas where the heating load of building is more, depending on the dimentions, aspect ratio, and height of the place, etc. all change the energy performance.

On the contrary, atriums having a wide transparent surface causes over-heating and increases in heat loss affects negatively to energy efficiency. Although glazing system of the atrium enhance the solar heat gain, the main factor for energy efficiency is increasing the nightime heat loss during heating period. Providing the air tightness in envelope is a considerable stage in the design and construction of buildings. Moreover, winter night time and summer day time control strategies can increase the total energy performance of atriums significantly.

Atrium design for temperate climates, cooling and heating loads must be considered in year based solutions, it is also approved that cooling strategies takes a considering the cooling loads are more important in total energy consumption (Göçer, 2006). The automation system ensuring the heating strategies to work in the heating period, passive-active cooling and heating strategies also affects the performance in cooling periods.

The cooling is priotity in warm climates. The precautions taken against high air temperature, humidity, and solar radiations coming directly gain importance in terms of the reduction in energy consumption. These types of precations in cooling aimed atriums are the exact opposite of the heating aimed atriums. In cooling aimed atriums, avoiding the solar effect as much as possible is intended (Göçer, 2006).

In energy efficient building design atriums are one of the key components which can alter the total energy performance, so choosing the proper type and control strategy regarding the climate zone has vital importance, especially buildings with high internal gains. Depending on the function in the interior, it is necessary to maintain a specific ambient temperature. The heating loads in atriums for long-term use is quite more than for short-term use in general.

The research on the performance of the atrium in terms of climate characteristics has started 2004, in Turkey. The pioneering study of Yaşa (2004) was an experimental study which evaluates natural air conditioning with different 17 aperture design on a yard. In the real model with a 2-story courtyard made by Yaşa (2004) made of transparent plexiglass, 17 different courtyards were formed by emptying the axes. In this model, horizontally 36 points and vertically 32 points tested in a wind tunnel. Consequently, it is observed that the wind speed exceeds the comfort levels in models containing openning on the windward but not on the leeward (Yaşa, 2004).

According to Göçer (2006), in his study of appropriate glass choice for atriums is Comfort Low-E glass as the least heating loads option for adjacent areas in Istanbul's climate. In addition, Low-E glass material is the least energy-consuming option in heating performance, the flat couple glass material is the least energy consuming option in lighting performance (Göçer,2006).

Farhoudi (2016) introduces 20-storey atriums as the most energy consuming type in various climates in his study of investigation on annual energy consumption under the climate conditions of Calgary, Paris, Singapore, and Phoenix. In this study, central atriums are stimulating as 5,10 and 20-storey and in the shape of square and rectangle. Besides, the least consumption of energy occurred in less storey and centered square type of atriums. It is put forward that the volume of atriums is directly proportionate to the energy consumption.

Tabesh and Sertyeşilışık (2016) tested a two-stage simulation of integrated usage of yard and atrium with Design Builder and Energy Plus in Turkey's province of Istanbul, Ankara, Antalya, Erzurum, and Diyarbakır. They studied merely on the basis of thermal performance evaluation and concluded that the courtyard design in summer and atrium design in winter provides energy efficiency. Moreover, the transformation courtyard into an atrium made sensitive in İstanbul, Antalya and Diyarbakır in hot-temparete climates but not in Ankara and Erzurum, cold-continental climates.

When experimental studies were being conducted in the worldwide literature, in 1996, Said et al. measured the air stratification in a wide single place thanks to the enhancement of measurement tools (Said et al., 1996). In the 2000s, as studies have taken advantage of computer technology, the energy performance measuring became study of simulation method.

Since the energy performance of atrium depends on various parameters, the researches conducted on the basis of the material, shape, location, and size of the components that compose the place provides researchers with the opportunity to compare outcomes more elaborately. Aldawoud and Clark (2008) worked on the advantageous usage of courtyard and atrium regarding different climate zones, different types of glazing, and story height. It is found out, atrium at higher floors, using the atrium after the second floor in cold zones, and using courtyard in warm climates are more effective energy solutions in atrium design.

Mohsenin and Hu (2015) investigated atrium within the context of their types by making experimental measurement different atrium types (centered, linear and single-sided atriums). Roof lighting levels were also measured for different heights. Moreover, it is experienced that centered atrium is inadequate in terms of lighting in their case and when the roof lights horizontal height is 1/7 of the atrium depth, the level of daylight improves (Mohsenin, 2015).

Moosavi and Hu (2015) evaluated air conditioning performance by measuring temperature, humidity, and air exchange in different points of an atrium containing a water wall and a chimney outlet in a subtropical climate. The decrease in humidity and temperature by means of stack effect in chimney, during working times is observed and they suggested more comfortable space to be used in interior arrangemet by determining the comfort level of measurement points.

In some studies, acoustic performance is taken into consideration too regarding indoor comfort. Li et al. (2015) evaluated thermal, indoor air quality, acoustic, and satisfaction of occupants all together by means of a quartered compass in order to evaluate user satisfaction. Comparisons between conventional building type and green building type is analyzed in both simulation and post occupancy evaluation. According to this study, bridge-type atrium in a high-rise green building delivers the best performance. Relying on the post occupancy evaluation, linear type in high-rise building and relying on the building performance, one-sided atrium in low-rise resulted in the worst case comparing to other referance buildings (Li et al, 2015).

3. ENERGY EFFICIENCY IN ATRIUMS

Atrium desing must be considered in different aspects, which have both advantages and disadvantages for energy efficiency. Complex air movements occur inside of the atrium, unlike other spaces due to the fact that it is a space interconnecting the volume of all stories of buildings and the pressure difference arised from the bottom to the top. The size of its volume and the width of the total area of the envelope exposed to outdoor climatic conditions differentiate it from other spaces in terms of energy efficiency. These properties have two main effects on energy efficiency:

To provide solar heat gain; the atrium provides heat gain through the solar radiation from the transparent facade and/or roof. Whereas it is an effect that is studied to be reduced in warm climates, it should be aimed to increase in cold climates.

To take advantage of the stack effect; these are air flows originated from the rise of heated air in the volume. Air flows accumulated on the top parts of the volume is the effect of stratification. It affects indoor air quality at upper elevations in both warm and cold climate zones (Gemi, 2006; Göçer, 2006).

These effects constitute an advantage on the behalf of different parameters regarding energy gain. Advantages for energy efficiency are the increase in the level of light in the lower floors, serving as a buffer zone between main spaces and outdoor weather conditions, making use of the stack effect to provide adjacent areas with natural ventilation, reinforcing cooling by generating cross-ventilation, working as an air gathering space by both collecting air from adjacent areas and releasing the air outside, benefiting from the orientation owing to have a large building envelope exposed to outdoor air conditions.

In cold climate zones, to reduce heating loads in atriums, increasing heat gain and preventing heat losses are primary energy efficient targets. To achieve these goals, utilization the orientation with solar heat gain in space organization, heat gain with thermal mass, the design as a pre-heating fresh air source for adjacent areas, the design as a buffer zone to prevent from heat loss by infiltration in adjacent areas, glazing ratio and material selection for ensuring sufficient light level in adjacent areas are priorities.

In warm and warm-humid climate zones, in order to reduce the cooling and ventilation loads in the atriums, cooling through increasing the air movement and preventing excessive heat gains are the primary energy efficient targets. To achieve these goals; utilization the orientation to prevent excessive heat gain in space organization, increasing cooling by air movement, night cooling with using thermal mass, design as a pre-cooled fresh air source, buffer zone for adjacent areas, indirect lighting and shading design to prevent excessive heat gain, glazing ratio and material selection to supply adequate light levels to adjacent areas are priorities.

While during the warm period of mild climate zones, the strategies for warm climate are valid, during the heating period the effect of cold climate conditions on the performance should be taken into consideration. In mild climate zones, controls and advantageous strategies depending on outdoor weather conditions should be determined and controlled by the automation system during mild periods.

Thermal performance measurements; the factors such as temperature level, main radiant temperature which measures the average temperature of the surfaces around a certain point, air flow rates (due to its effect on cooling) are evaluated.

In warm and humid climate zones, wet bulb globe temperature, indoor air quality, wind speed, air flow rates, relative humidity values are used to calculate cooling loads in measurements and simulations. In the calculation of cooling loads, measurements and simulations are conducted in hot periods when the cooling systems operate with the highest performance.

In the literature, CFD, Fluent, TRNSYS, Design Builder, Energy Plus, EDSL TAS 3D, DIVA for Rhino, DOE2.1E, Dynamic Therma Model, Ecotect software are used as simulation tools. In most of the studies, instead of annual energy consumption, loads in the short term is determined and compared by making measurements and simulations together (Mohsenin, 2015; Mohsenin & Hu, 2015; Gemi, 2006; Littlefair, 2002; Alraddadi, 2004;

Ghasemi et al, 2015; Shafiei & Moosavi, 2016; Yaşa, 2004; Chow et al, 2013; Hussein & Ousthuizen, 2021). Various energy efficient strategies are simulated in different climates, compared with each other that under the circumstances of no strategy has been implemented, and the state in which the systems bring the least load is determined.

In order to measure the level of daylighting in atrium spaces, daylight factor, average daylight factor, spatial daylight capacity, well index, balcony well index values are used in academic studies. These values have been experimentally measured in studies evaluating the lighting level with various sensors or simulation tools (Mohsenin, 2015; Littlefair, 2002; Alraddadi, 2004; Ghasemi et al; 2015; Chow et al, 2013; Saxon, 1994).

When evaluating user comfort, there are studies that take an account Predicted Percentage Dissatisfied (PPD) value, which is what percentage of the people satisfied with the thermal environment in the building, the Predicted Mean Vote (PMV) value, which is a parameter related to how people in an environment perceive the environment (Fanger, 1970; Ekici, 2013). The PMW / PPD index is the mathematical expression of the thermal physiology as of the human being adjusted to the temperature perceptions recorded by people in conditioned spaces (Fanger, 1970). ASHRAE Standard 55 states that in order for an environment to be considered as comfortable, if the environment is thermally homogeneously distributed, 90% of the people in that environment must be satisfied with the thermal environment. However, if there is an asymmetrical thermal environment, 80% is considered as an acceptable value (Ekici, 2013; Fanger, 1970).

4. ATRIUM TYPES IN ENERGY EFFICIENCY

In order to achieve energy gain strategies, the atrium is primarily affected by the factor of orientation when climate data is taken into consideration. The orientation is the choise requires altering control systems, thermal state in atrium, air quality and lighting in both warm and cold climate zones. Regarding the building envelope area and heat gain/ loss, the location and the size of the atrium in the building is important. Types of the atrium are analyzed in accordance with the location in the building to evaluate energy efficient strategies. In addition to the formerly specified type of atriums in the literature, various types of the atrium are also figured by taking account of the new building examples that are compatible with energy efficiency. In this context, types of the atrium are listed as follows:

4.1. One-sided atrium:

This is the most common type of atrium with a centered atrium. If it is in the south direction, prevents against the excessive heat gain and air stratification should be taken (Hastings, 1994;Atria Systems, 2016; Gemi,2006).

4.2. Two-sided atrium:

Because of the irritative effects on eyesight low angel radiation from east and west sunlight, linear type is emplaced on the direction of north-south, and solar control system is design at the south facade of the atrium (Hastings, 1994; Atria Systems, 2016; Gemi, 2006).

4.3. Three-sided atrium:

The energy efficiency is attained by emplacing in the utility direction with balancing solar heat loss and heat gain (Hastings, 1994; Atria Systems, 2016; Gemi, 2006).

4.5. Centered Atrium:

It is the type of atrium that glass surface is only at the roof. That's why the properties of the glazing system have various impacts on performance. I this type, providing more luminous ambient with ceiling glazing, but horizontal glazing above roof floor with opaque ceiling diminishes lighting level and thereby the view of the sky is restricted. It is easier to control air monement in the atrium. Adjacent areas constitute a buffer zone between outdoor air conditions and atrium (Hastings, 1994; Atria Systems, 2016; Gemi, 2006; Bednar, 1986).

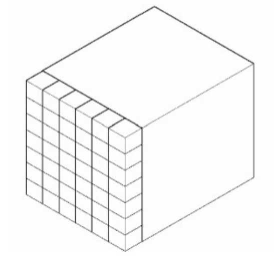
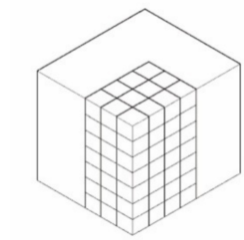
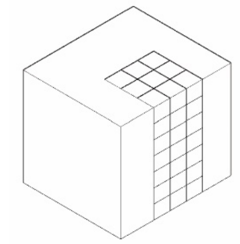
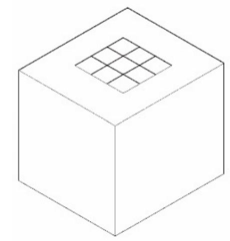
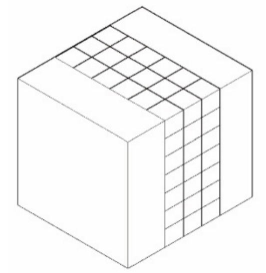
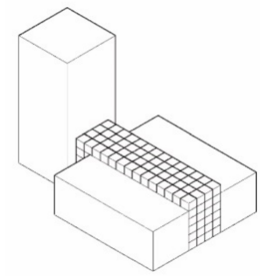
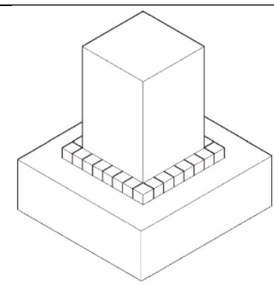
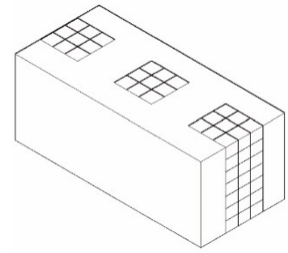
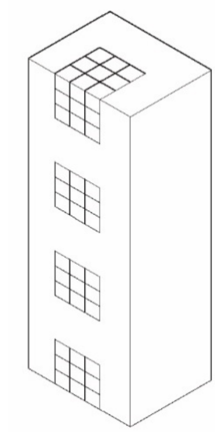
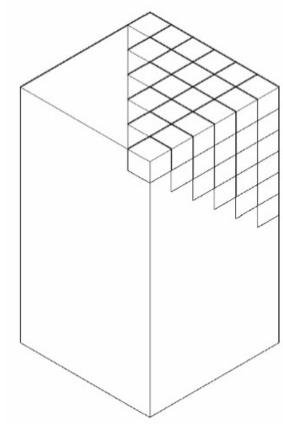
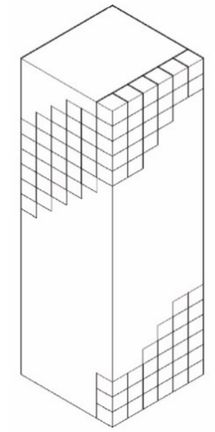
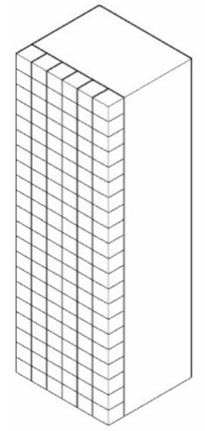
4.6. Opposite sided atrium:

It can be utilized to take advantage of the benefits from each of two sides opposite direction as north-south causing different heat gain/loss in winter and summer. Yet, attention needs to be paid to the airflow on the junction points (Hastings, 1994; Atria Systems, 2016; Gemi, 2006; Bednar, 1986).

4.7. Bridge atrium:

In the atrium connecting different higher blocks from each other, the air stratification at high levels with buoyancy effects should regard as an impact on the energy performance of the higher block (Atria Systems, 2016; Gemi, 2006; Saxon, 1989).

Chart 1. *Types of Atrium (Hastings, 1994; Atria Systems, 2016; Gemi,2006; Saxon, 1989; Bednar, 1986).*

 a. One sided	 b. Two sided	 c. Three sided	 d. Centered
 e. Opposite sided	 f. Bridge type	 g. Podium	 h. Multiple horizontal arrangement
 ı. Multiple vertical arrangement	 j. Arcade (terraced)	 k. Spiral	 l. Greenhouse type

4.7. Podium atrium:

The effect of shading in the direction of north depending on the direction is needed to be planned especially with respect to comfort priority of different climates in atriums emplaced between high rise building and low-rise adjacent areas (Atria Systems, 2016; Gemi, 2006; Saxon, 1989).

4.8. Multiple horizontal arrangement:

It is the atrium emplaced in the way that horizontal regular repetetion through building width. It is preferred in a wide-planned building in order to satisfy the need for natural light and generates air movement in volume as such in centered atrium (Atria Systems, 2016; Gemi, 2006; Saxon, 1989; Bednar, 1986).

4.9. Multiple vertical arrangements:

It is the partial atrium scattered specific stories of high-rise buildings. It provides different air-condition opportunities in building owing to these places are not connected to each other. Moreover, air stratification level decreases at upstairs compared to the atriums continued throughout the building. In this way, the comfort level increases (Atria Systems, 2016; Gemi, 2006; Saxon, 1989).

4.10. Arcade atrium (terraced):

It is the atrium constituted by gradual shifting in the one side of volume of the atrium at downstairs or upstairs. Separating the adjacent areas from the atrium volume can provide a different kind of stack effect. The air stratification level slides to the bottom or top elevations due to pressure and volume.

4.11. Spiral atrium:

It offers an opportunity for the utilization of the single atrium volume in different facades of the building. Yet, attention should be paid to the air stratification at upstairs and up-downstairs pressure difference due to the wind effect. The negative impact of stack effect on comfort conditions should refrain with pressurization.

4.12. Greenhouse type atrium:

Serving as a double facade at tower sides, it creates a buffer zone between adjacent places and outdoor air conditions. As in atriums continued throughout the tower, the negative effect of stack effect and air stratification are refrained. Plaza type of atriums is considered in this category.

All factors need to be taken into consideration simultaneously in the choice of atrium type to balancing of gain and loss of energy. Volume sizing also should be configured up to annual energy consumption balance aim.

5. PARAMETERS IN BUILDINGS WITH ATRIUM FOR ENERGY PERFORMANCE

5.1. Heating Strategies

In cold climates, thanks to the atrium, the passive heating is feasible to take a great amount of sunlight in and store this energy in thermal mass in times of winter days. Likewise, this self-sufficient heating capacity may contribute to heat adjacent places too. Being a buffer zone between adjacent place and outdoor air conditions, it reduces the heat loss in places.

Under climate conditions when heating period is more dominant, it is necessary to take into account the orientation, slope of roof, thermal performance of the outdoor glazing and the properties of materials used in the interior, to be compatible with air conditioning, cooling, and heating systems.

Heat losses emerging from natural ventilating can be reduced by mixing the interior and exterior air in the atrium volume. In the prevention from heat losses derived from infiltration and natural air conditioning, it is possible to retain the heat in preconditioning in atrium but it is also essential to pay attention in the stage of underconstruction the junction point of materials to avoid air leakage. To ensure airtightness, a special gasket, metal panels filled with foam insulation can be used in curtain walls and glazing systems.

In winter period, the control on heat loss is important, especially where the night service is available as in hospitals and hotels. The expected thermal comfort under the circumstance of night should be known in advance and then required precautions are taken according to it. Night louvers may be utilized inside of the glazing in terms of control and usage convenience (Gemi, 2006).

If an atrium is generated with giving priority to heating strategies, shadings can be used to prevent excessive solar heat gains when cooling is needed. Incoming long-wave infrared light have to obstruct before passing it to the surface of glazing. Otherwise, condensation occurs between glass and interior shading so may result in an increase in the consumption costs by causing harm to building materials.

5.2. Cooling Strategies

Passive cooling depends on the outdoor air, the difference between indoor and outdoor temperature, the thermal condition of the building, the conducting between thermal mass and ventilation, the rate of night ventilating, and the control strategy. In summer period, the active system is required to cooling in the atriums that designed according to the winter conditions with great solar heat gain. That is why the fundamental priority in cooling should be given to constrain overheat gain.

Mechanical cooling can be altered into an energy-efficient system by utilization of natural resource such as the wind, the sun (solar radiation), and the soil (via ground-coupled heat exchanger). The cooling system should be reinforced with the ventilation system because the air movement at the appropriate speed for building occupants is between 0,5 m/s and 3 m/s for this reason it creates physiological cooling. This thermal comfort mechanism should be at the exact level with the human comfort (Yaşa, 2004).

Depending on the location, the north direction should be preferred in warm climates in compliance with the orientation. In mild and cold climate, the atrium should be placed in the direction of the south but shading elements should be used in times of cooling need is raised.

Cross ventilation should be used in the cooling of the atrium and adjacent places. It also creates a more favorable interior place comfort for adjacent places. If the outdoor temperature is fewer than the interior temperature stemmed from the usage or absence of air movement, cross ventilation becomes an effective method. Yet, when the outdoor temperature and humidity is high, it even can cause interior places' temperature to rise more. Therefore, in the final situation, the average temperature is to be considered not the maximum temperature. The cross ventilation also avoids air stratification so heated air volume can no longer escalate and push down the mild air. In warm climates, it is necessary for atrium to boost the cooling system comparing to the case of absence of it by gathering heated air. Cross ventilation would be more efficient in both warm and cold climates if the control of air inlet and outlet is ensured automatically. Moreover, It is needed to pay regard to airflow to not exceed the comfort levels in the cross ventilation. The atrium should not give rise to turbulence or venturi effect like in the narrowing corridor.

In both the cross ventilation and the stack effect ventilation, the ambient temperature is needed to be stabilized by carrying out the temperature measurement at the point of air inlet and outlet and by reinforcing with the active systems if it is needed. Considering the thermal mass usage along with the stack effect, delaying heating by night-cooled thermal mass may be used as a cooling strategy.

Shading prevents interior place from solar heating and user from glare and direct sunlight. Being a wide range of lighting at the sky, shading systems should be motorized to provide sufficient lights and avoid over-heating when needed. It is required to have shading as much as needed in summer period and to control heat loss and leakage in winter period.

5.3. Ventilation Strategies

Since the very past, increasing the place volume and creating adequate air movement within the comfort levels are methods of passive ventilation in a natural design for crowded places. Atrium is the aesthetic and functional solution for places that fulfills this method exactly. Evaluating the size of the volume and inputs concerning climate and orientation simultaneously contributes to ventilation positively.

There are various parameters in supplying indoor comfort regarding intended usage. The amount of clean air required per person, depending on the function of the atrium space, increases the energy consumption, especially in the air conditioning units of atriums that do not have natural ventilation. In atriums where natural ventilation is used, an air change is required that will not create turbulence and maintain the comfort conditions.

In wind force studies, Beaufort determined that wind velocity greater than 9 m/s hinders the walking (Vipikedia, 2021). Yet, according to ISO 7730, the wind velocity of 0,10 m/s in winters and 0,12 m/s in summers are allowed for interior places such as an office. Also, the percentage of forming turbulence is required to be between 30% and 60% (EN ISO 7730, 2005).

The air stratifications taking place in the atrium is a considerable disadvantage affecting the interior air quality. The humidity above the comfort level that occurs depending on the size of the volume and adversely affects the user in adjacent spaces close to the atrium roof level causes the formation of CO^2 and temperature layer.

The air stratification is specially confronted in high-rise buildings where active ventilation is utilized fully. The absence of aperture in building envelope due to extreme weather conditions pose problems of increasing stratification at upper elevations where it is above the neutral pressure level in high-raise buildings. In their study investigating the pressure differences in high-rise buildings, Mijorski and Cambelli (2016) stated that atriums designed throughout a high-rise building impairs the inlet and outlet elements at the building envelope such as doors, windows, vents. This pressure differences causes undesirable air flows in immense volumes like atriums, leads unwelcomed gas such as smoke, odor to spread all over the building. Additionally, it deteriorates heating and cooling systems due to in large quantities air leakage and makes the active systems perform excessively (Mijorski,& Cambelli, 2016).

Relative humidity influencing the building materials' lifecycle negatively increases the sensible temperature in hot-humid climates and damages the comfort conditions. Therefore, the relative humidity level should be maintained at 30-40% in winters and 45-55% in summers (Comfort conditions for space, 2016). If the measured humidity level exceeds the comfort levels, several passive strategies are determined to decrease relative humidity level or temperature. As support to decrease the cooling load of the building, the fresh air taken from the ground level of the atrium and release out from the roof of the atrium by cross-ventilation in the way that heated to rise up owing to buoyancy forces. In this way, the humidity and heat are removed. With the shading elements on the exterior side of the glazing system, solar radiation are prevented before it enter inside of the volume and so excessive humidity should be restrained.

The wind ventilation could be provided in the shape of the cross-ventilation, the oneway ventilation, and the wind turbulence (Laskari, 2008; Sev, 2009; Yaşa, 2004). Prior to benefit from the wind energy with the intention of ventilation, It is required to be sure that the predominant wind direction is not blocked by other buildings and topographic characteristics and atrium is needed to have aperture or side at the windward. Based on the velocity of the predominant wind, several passive methods can be used. Utilization of the stack effect derived from the wind direction and pressure difference inside of the volume as a supporter to ventilation depends on the climate, wind direction, orientation, height of the atrium, the directions of the air inlet and outlet.

The ventilation with rising air effect (buoyancy effect) occurs through air exchange among different air density layers. Concurrently, this passive method which also can decrease the cooling load removes the heated air from the volume. Allowing the heated rising air to its natural draft to exhaust at the high elevations could be carried out without the energy consumption. Having a small difference in interior and exterior temperature in summer period, the buoyancy effect decreases. For this reason, thermal masses or fans making the air exhaust to outdoor could be use. However, thermal mass should be avoided to heat adjacent places in summer period.

5.4. Lighting Strategies

The configuration of the atrium, the glazing system, and the reflectivity of the interior surfaces determine the interior lighting, as well as the light of the local sky and the sunbeams' angel of incidence as the main source of lighting. The atrium section should be wide enough to allow sunlight to spread to the lower floors. Narrow and long atriums in horizontal or vertical dimensions reduce the lighting degree of adjacent spaces. In order to provide maximum benefit in the minimum area, especially in narrow-sectioned atriums, in order to increase the luminous value, reflective interior surfaces can be used to spread daylight to the lower floors.

Daylight factor, average daylight factor, spatial daylight capacity values are used to measure the level of ligting in spaces. These values can be measured experimentally with various sensors or simulation tools such as Dialux, Relux, Radiance, Velux and Daysim.

In order to prevent horizontal beams coming from the east and west directions of the building, sunshades controlled according to the position of the sun should be used in a such way that not to cause glare in all climate conditions. The glare problem is an issue that designers have been aware of since the first years when atriums were designed. In the early years of industrialization, the horizontal structural elements of the glazing system were used for this purpose. Lighting can be limited with different glass options by means of developing technology (Saxon, 1989).

5.6. Shading Systems

The increasing need for cooling requires to prevent heat gain in hot climates or hot period. Having a large area of glazing envelope of atriums, shading has a great impact on energy performance. By the enhancement of the solar heat gain system, shading is needed to prevent the system from working in times of need for cooling or to make it work as a cooling system.

The elements of shading should be designed regarding the weather data as fitting the intended purpose. The glazing system could be provided by the shading elements such as curtains, louvers, or blinds and by the innovative glasses (froste glazing, smart glazing, electrochromic glazing, configuring the different level of transparency, etc.) creating various transmissivity levels at the glazing system. It is also designed by splitting it with a nontransparent element from different angles (Göçer, 2006; Dickie, 2006; Eşsiz, 2004).

The external shading elements are used for controlling glare and when the sunlight is not wanted to heat the inside air volume via conduction and convection. While it is used effectively in times that requires cooling to prevent heat gain as the first step of providing passive cooling, if it is integrated with photovoltaic panels, it provides additional energy gain in times that requires heating. (Altın, 2014; Murray, 2013; Skylight & Atrium Window Coverings, 2021; Tavil, 2006).

As the purpose is to avoid glare, shading could be used on the internal side of the glazing system. The internal shading elements can sustain cooling to some extent because of blocking heating of the volume via radiation. Located in the internal side of the glazing system, curtain, louver, and blinds lead to an increase in interior temperature and condensation between the glass surface and shading element owing to solar radiation that already have entered the place (Dickie, 20016).

In shading between the double-glass, the continuum of the heat transmission to interior place via solar radiation should be considered in the absence of the shading. Not being compatible with the interventions, changes and correctability are the disadvantages of shading in the glazing system.

Electrochromic glasses, low emissivity (Low-E) glasses, solar control glasses, ETFE systems, semi-opaque materials, aerogel glases, and translucent facades are the options of glasses to control solar radiation with materials. It should be paid attention to these materials' heat transfer coefficients must be accordant with the U values for energy conservation in the atrium envelope in standars (Ulusoy, 2012; Eşsiz, 2004; Tavil,2006).

5.7. Renewable Energy Strategies In Atriums

The wide building envelope of atriums creates a convenient surface for photovoltaic panels integrated with the building. When it is used on the transparent facade, it can also function as a shading element to a certain extent depending on the shading rate of the used system. When it is used on the vertical transparent facade, it can be designed intermittently that prevents glare. The PV utilization in the atrium is more prevalent in the glass roof systems. Generally, stable panels are used. The cellular density of it is determined at a level that does not diminish the interior lighting. PV panels rotatable according to angle of sunlight also serve as a sunshade to prevent the atrium from directly incoming sunlight and from solar heat gain.

5.8. Operation Strategies

In establishing the control strategies, climatic factors and user characteristics should be regarded simultaneously. Which activities taking place at the ground of the atrium and which functions situated at the adjacent place of the atrium are needed to be known. The design of control systems on the building not serving at night will be different. Whereas a control system is adequate to ensure comfort condition during the working times, the comfort condition should be sustained during the nights at the buildings used also at night such as hospital and hotel. The temperature comfort level should be determined with regard to use frequency to thermal comfort conditions. The heating of atriums serving as a transition area differs from the heating of atriums that user frequency is short and peak.

The disadvantageous aspect of the lighting for comfort condition is glaring. The automatic control of shading elements with respect to the angle of daylight is needed to be applied at the glass facades in the direction of east and west that may cause glitter. In all climates, but especially in hot climates, it is make sure that excessive lighting above the comfort level depending on the skylight does not occur at the atrium and adjacent places. That is why, the lighting controls should be based on the outdoor daylight value and data of sun lights' angle (Göçer, 2006; Chow et al, 2013).

Though photoelectric light control may reduce the energy cost in the atrium, it also may cause greenhouse gas generation and pollution. The light control on the basis of daylight is a more efficient option for atriums (Chow et al, 2013).

The control of heating, cooling, and ventilation levels vary from each other by climate. The priority is given to cooling and shading in hot climates and to lighting and heat control in cold climates.

In cold climates, the night cooling control to enhance the heat gain capacity of thermal mass, heating system on-off control, ventilation system control should be done. In warm and hot climates, shading system control, ventilation system control, cooling system control, and humidity balance control should be done. In mild climates, depending on the outdoor measurement, the on-off control of unwanted systems should be done. Control of avoiding air stratification and glare should be done under all climate conditions.

6. ATRIUM EXAMPLES FROM ENERGY EFFICIENT BUILDINGS

In this study, the energy efficient strategies in various types of atriums from different climates all over the world are investigated. Considering the local climate characteristics, the properties of heating, cooling, lighting, ventilation, renewable energy and control systems are listed for the examined atriums of buildings if they are accessible. In addition to atriums of building, the properties of green, sustainable and smart building are also analyzed.

Buildings and their locations are evaluated on climate, general properties of the building, energy-efficient features, heating, cooling, ventilation, lighting, the renewable energy role of the atrium, and operational strategies through the template chart from Figure 16. The north direction is taken at the top of the page.

<table>
<tr><td colspan="2">*Structure, Location</td><td>temperature</td><td>humidity</td><td rowspan="2">wind direction</td><td rowspan="2">* avg.</td><td>aim</td><td>atrium type</td></tr>
<tr><td>climate zone</td><td>* ASHRAE and Köppen Griger climate class</td><td>*avarage</td><td>* avg.</td><td></td><td></td></tr>
<tr><td colspan="2" rowspan="2">* image</td><td colspan="4">* plan</td><td colspan="2" rowspan="2">* energy efficient properties, rewards, sustainable properties</td></tr>
<tr><td colspan="4">* general properties</td></tr>
<tr><td>HEATING</td><td colspan="7">* strategies implemented in the structure</td></tr>
<tr><td>COOLING</td><td colspan="7">* strategies implemented in the structure</td></tr>
<tr><td>VENTILATION</td><td colspan="7">* strategies implemented in the structure</td></tr>
<tr><td>LIGHTING</td><td colspan="7">* strategies implemented in the structure</td></tr>
<tr><td>ENERGY GAIN</td><td colspan="7">* strategies implemented in the structure</td></tr>
<tr><td>OPERATION</td><td colspan="7">* strategies implemented in the structure</td></tr>
</table>

Figure 1. Building and Atrium evaluation template chart.

Chart 2. *Genzyme Center (Genzyme Center, 2004; Genzyme Center Gets Natural Air Flow, 2010; Genzyme Section, 2010).*

Genzyme Center , Massachusetts, USA		temperature	humidity	wind	aim	type
climate zone	5B dry, warm continental climate	10,5	67%		lighting	centered

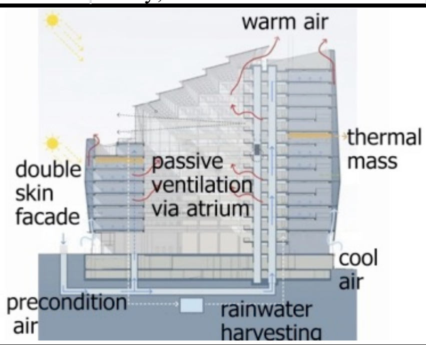
Construction date: 2003
Building area: 31.958 m2
Number of Storey: 12
Office building
42% less energy, %34 less water comparing to traditional buildings

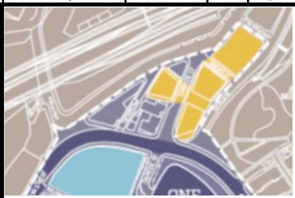
LEED platinum rating
U shaped roller blinds, Reflacting surfaces, Heliostat, Green Roof, Pv, Rain water recycling, Low voltage armature, Operable windows, Low solvent content materials (interior air quality), Thermostat at the offices.

HEATING	Double facade space creates a buffer zone around the building
COOLING	
VENTILATION	air stratification is prevented by air release via atrium roof. Atrium provides adjacent places with both fresh air inlet and exhaust air outlet.
LIGHTING	Heliostats used at the roof for increase the lighting level inside. Artifical lighting load is reduced by using reflactor at interior atrium and surfaces.
RENEVABLE ENERGY	It have PV utilisation at the roof
OPERATION	Sensors at the windows diminish heat loss.

Chart 3. *One Angel Square (Most 'Outstanding' BREEAM One Angel Square Officially Opens in Manchester, 2013; The Co-operative Group's new HQ will produce 80 percent less carbon and halve its energy use, 2021).*

One Angel Square, London		temperature	humidity	wind	aim	type
climate zone	5B dry, warm continental climate	10,1	73%		lighting, ventilation	arcade





Construction date:2012
Building area: 30430 m2
Office structre
962 m2 atrium
14-storey

Highest scoring BREEAM Outstanding (in United Knigdom) Orientation atrium roof to south. No facade to only facing north direction by triangular plan schema provides benefit from daylight further.

HEATING	Heat is stored by termal mass at the mid-stairs. Passive heating and cooling is provided by jeothermal energy. Adjacent places are not seperated by glass to maximize solar heating at the middle and bottom stairs.
COOLING	In the atrium, supporting to cooling is with natural ventilation. Over-heating at the wall of adjacent place in south direction exposed to much daylight is prevented by covering with glass .
VENTILATION	It is ventilated with natural air inlet to both spaces adjacent to the atrium and atrium. Outlet is at roof level for exhausting that raised air by buoyancy forces.
LIGHTING	With the reflectivity of interior atrium surface and the south terraced atrium roof, provides more utility lighing with daylight.
RENEVABLE ENERGY	
OPERATION	The heating systems is supported with double skin facade and precondition system.

Chart 4. *Kelley Engineering Center (Oregon State University, School of Electrical Engineering and Computer Science (From "The Ecological Engineer: Glumac" Kelley Engineering Center, 2011; Oregon State University, 2021).*

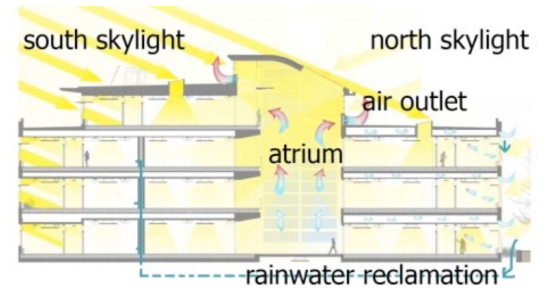
Kelley Engineering Center, Oregon,USA		temperature	humidit	wind	↓	aim	type
climate zone	4A cold continental climate	12,0	73%			ventilation	opposite sided
 		 Continental climate Year of commissioning: 2005 153,000 sf				LEED Gold certificate. 35% less energy than referenced in certificate is consumed. At atrium roof, partial glazing is used at sloping part. These windows can be closed by movable elements The priority is given to natural ventilation.	
HEATING	Atrium balances the overall temperature in warm weathers. Even if the windows at the roof face the north direction, internal shading system combined with it is controlled with automation system.						
COOLING	The night cooling with thermal mass is used.						
VENTILATION	atrium serves as a volume that exhaust air is gathered and evacuated. The night cooling system opens the air outlet and provides fresh air with direction from neighboring places to atrium roof. Carbon monoxide monitoring system is used.						
LIGHTING	By making use of the daylight passed from vertical and sloping south windows. Indirect and restricted lighting is created with semi-opaque atrium roof material.						
RENEVABLE ENERGY							
OPERATION	Active energy usage only is needed with light and heat sensors only. Operable windows that are capable of manage heating and cooling runs seperately at every single space. It is based on energy gaining maximization by regulating the operation of the HVAC system according to detecting the openness of each windows. The system closes the every windows under the condition of bad weathers and opens all of the window for night exhausting (night flushing)						

Chart 5. *Ravensbourne College (Ravensbourne College by Foreign Office Architects, 2010; Foa, 2011).*

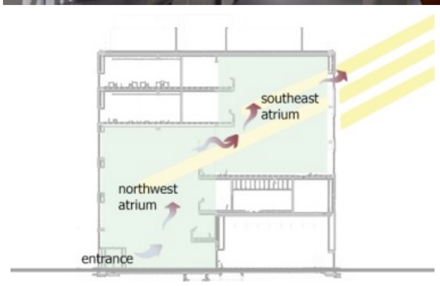
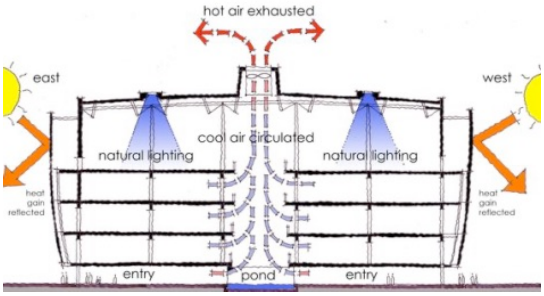
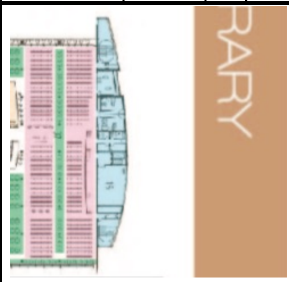
Ravensbourne College, Peninsula in London, UK		temperature	humidit	wind	↗	aim	type
climate zone	5B dry, warm continental climate	10,1	73%			thermal comfort	centered
  		 Construction date:2010 5-storey Atrium provides visual and physical connecting between sections.				It has BREEAM certificate. atrium involving the entrence is located on the middle of the plan scheme oriented on the northwest-southeast direction. The building won a British Construction Industry Award in 2011.	
HEATING							
COOLING	atrium volume determines performance of all structure. During warm and cold seasons, both north and south facades' advantages are benefited because of atrium facing north and south						
VENTILATION	Atrium located on the two different facade an interconnected provides natural ventilation via cross ventilation						
LIGHTING	The entrance at the northwest receives direct daylight from southeast atrium. All facades reduced glazing are designed to prevent glitter on the direction of east and west.						

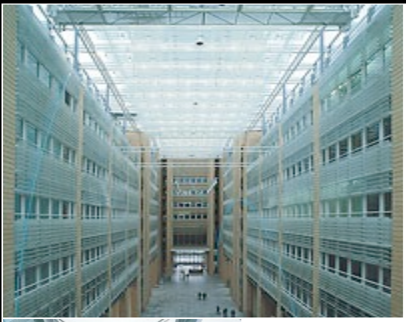
Chart 6. *Phoenix Central Library (Inside Phoenix' Burton Barr Central Public Library,2008; [Precedent Reearch,2010](); Phoenix Central Library, 2004).*

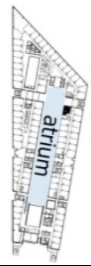
Phoenix Central Library, Arizona,US		temperature	humidit	wind	←	aim	type
climate zone	2B hot-dry climate region	19,5	38%			ventilation	centered
		 library building. Year of commissioning: 1995 6-storey.				The structre located on the north-south direction has opaque east and west facades.	

HEATING	
COOLING	To provide cooling at night, louvres are used at the north facade consisting of glass system to prevent solar heat gain. High-ceiled is implemented to ensure user not to be affected by dirty and warm air on the top storey. Horizontal moving shadings prevent over heat gainig at the south facade.
VENTILATION	High capacity chimney structure is used for warm and dirty air outlet at atrium roof.
LIGHTING	Natural lighting is provided through the minimized windows at the roof. In order to prevent east and west glaring, the interior side of opaque east and west facade is detailed to provide indirect lighting by reflecting the light received from the ceiling. On the north facade, louvres in the shape of sailcloth are designed to avoid direct sunlight and maximize natural lighting for reading rooms. On the south facade, the solution of horizontal moving shadings in accordance with the angle of the sunbeams is designed.
RENEVABLE ENERGY	
OPERATION	The sunblinds on the south facade are adjusted according to the angle of the sunbeams.

Chart 7. *Debis Tower (Debis Tower, 2021; Debis Tower, 2016).*

Debis Tower, Berlin, Germany		temperature	humidit	wind	aim	type
climate zone	5, warm continental climate	8,5	69%		lighting	centered





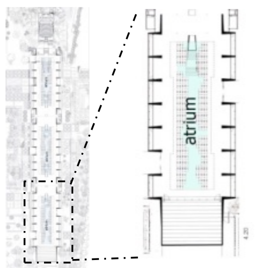
Construction date: 1998
Building area: 44779 m2
7 storey atrium and 21 storey tower
Office structre

The roof of the atrium located on the middle of the complex is covered by moving frosted glass louvre so the sunlight control is provided.
Movable glass panels is used in double facade.

HEATING	Outdoor layer of double-facade movable provides heat gain and reduces heat loss in cold
COOLING	
VENTILATION	Ventilation is performed by natural air taken from outdoor to between double facade. The outer glass panels pivot open up to 70 degrees for warm-weather ventilation
LIGHTING	At the roof of the atrium, inner frosted glass louvre system moving according to the location of the sun ensures better spreading of daylight.
RENEVABLE ENERGY	
OPERATION	Double facade elements controlled by users depending on the winter and summer conditions are designed. There is automatically controllable glass louvre system at the roof of atrium.

Chart 8. *Vasconcelos Library (Vasconcelos Library / Alberto Kalach, 2010).*

Vasconcelos Library, Mexico		temperature	humidit	wind	aim	type
climate zone	1, semitropical high altitude climate	18,0	80%		lighting	horizontol multiple



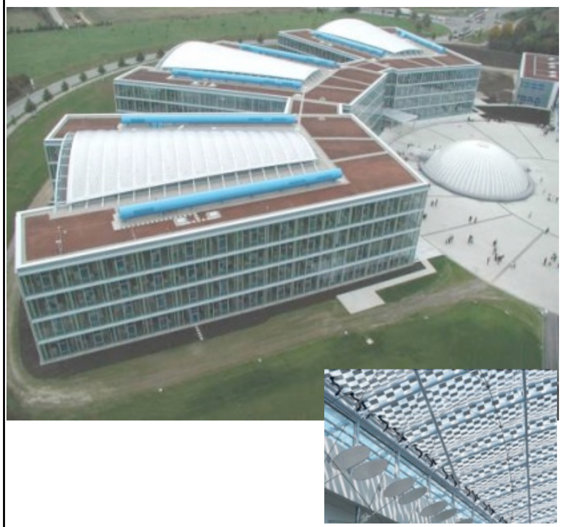
Construction date:2007
Area: 38091 m2
horizontal multiple centered atrium throughout the long rectangular plan scheme.
Plan located on the direction of north-south

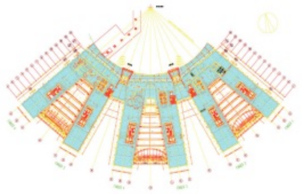
Natural light required for library buildig is provided by indirect lighting from the roof.
In the spaces where the bookshelves are, the semi-transpared floor is made, for allowing daylight to reach the lower stories.

HEATING	
COOLING	
VENTILATION	
LIGHTING	Natural lighting is provided by increasing the level of lighting with vertical windows on the ceiling of the entire building.The level of lighting can be reached to the lower stories by choosing semi-opaque floor materials. The long east and west facades of the building are glass and direct sunlight is prevented by shadings.

Chart 9. *Festo Tecnology Center (Gemi, 2006).*

Festo Technology Center, Stuttgart, Germany.		temperature	humidit	wind	aim	type
climate zone	5, warm and mild climate, Cfb	10,5	77%		thermal comfort	three sided



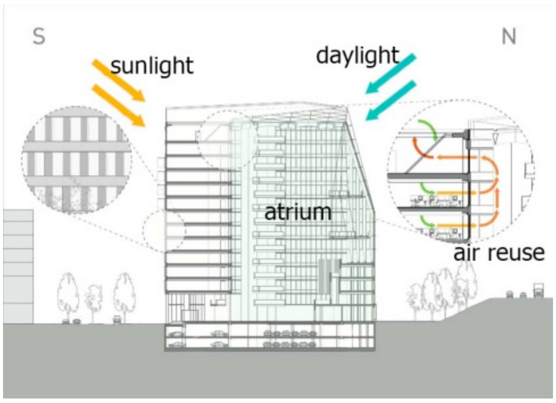
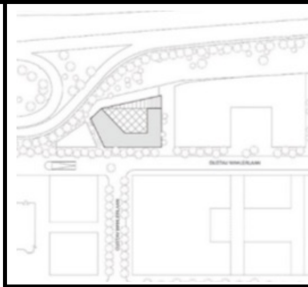


Construction date: 2001
Office building.
Atrium area: 1028 m2
4-storey.

Utilisation of pneumatic ETFE in atrium roof .
Vertical side windows with U: 1.4 W/m2K characteristic.
By shading and thermal mass cooling at night, reached the temperature that 25 degrees on the 4th storey during the summer season.
The highest temperature is recorded as 20 degrees in winter on the 1st storey with shading, thermal mass, low-e glass and heat recovery system.

HEATING	With the use of ETFE in the atrium ceiling, heat loss is reduced.
COOLING	Night cooling is provided by the thermal mass. ETFE provides shading to prevent excessive solar heating.
VENTILATION	
LIGHTING	ETFE also ensures that the daylight is shaded by 50%.
RENEVABLE ENERGY	
OPERATION	ETFE material especially when an air-inflation system is already a intirinsic automated material.

Chart 10. *The EDGE, Amsterdam (The Edge: Amsterdam office building with highest BREEAM score to date, 2017).*

<table>
<tr><td colspan="2">The EDGE, Amsterdam, Holanda</td><td>temperature</td><td>MOIUST</td><td rowspan="2">wind</td><td rowspan="2">↗</td><td>aim</td><td>type</td></tr>
<tr><td>climate zone</td><td>5, Warm and mild climate, Cwb</td><td>8,5</td><td>84%</td><td>lighting, ventilation</td><td>three sided</td></tr>
<tr><td colspan="2" rowspan="2">
</td><td colspan="4"></td><td colspan="2" rowspan="2">Atrium can be used as a working area. Intense daylight is obtained with the large atrium volume. The atrium faces the north direction. PV panel is utilized on the south facade. It produces up to 102% energy of its use. Aquifer thermal energy storage generates energy for heating and cooling. There is a rainwater collection system. An ecological corridor was designed between the building and the motorway in site. It won BREEAM Outstanding %98,4 Highest Score.</td></tr>
<tr><td colspan="4">Construction date :2014
15-storey office building,
Total Usable Floor Area:
39,910 m2</td></tr>
</table>

HEATING	In the atrium, energy efficient heating is provided by raydant heating as locally.
COOLING	
VENTILATION	Atrium serves as a buffer zone between indoor and outdoor weather conditions.
LIGHTING	There is no glare problem emerging from the atrium faces the north. The size of the atrium volume also positively affected the lighting.
RENEVABLE ENERGY	There is a PV 720 m2 on the south facade of the building, which is not an atrium.
OPERATION	There are 30000 sensors in the building detecting daylight, occupancy, motion, humidity, temperature and CO2.

Chat 11. *LEO Office, Malezya (Moosavi et al. 2015; Low Energy Office, 2010; Purtajaya Perdana Berhad, 2020).*

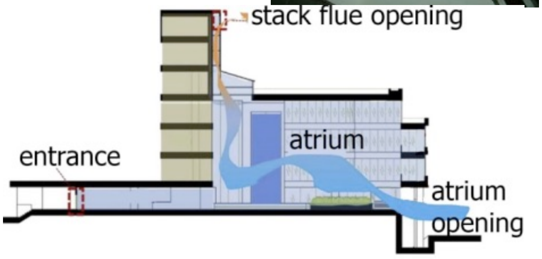
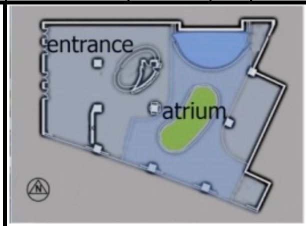
Low Energy Offise, Putrajaya, Malezya		temperature	humidit	wind		aim	type
climate zone	1, tropical climate	27,0	80%		↑	lighting, ventilation	centered
 		 Climate: Tropic Construction Date: 2004				The glazing of atrium is 1cm single glass and steel frame. Glass heat and light transmittance provides 51% solar radiating and 65% daylight.	
HEATING							
COOLING	In atrium temperature are prevented suddenly to peak by the water wall system. The atrium and adjacent spaces are divided by glazing for air-conditioning seperately. In this way, office local cooling can work more effectively.						
VENTILATION	The rising air by buoyancy effect is thrown out with the roof chimney system. Cross ventilation is provided by the lobby entrance.						
LIGHTING	Lighting is restricted by minimizing atrium glazing.						
RENEVABLE ENERGY							
OPERATION	the temperature of roof chimney outlet is used for controlling air-condition system.						

Chart 12. *The Bow Tower (Griffiths, 2013; The Bow Also Rises,2013).*

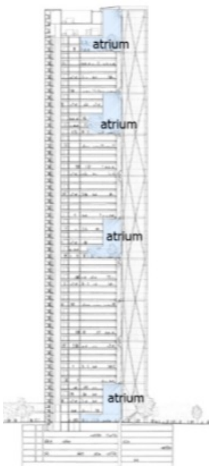
The Bow Tower, Calgary, Canada		temperature	humidit	wind		aim	type
climate zone	7, cold climate	13,0	50%		↘	lighting, thermal comfort	vertical multiple
 		 construction date :2013 6-storey atriums in a vertical repeating building within the 58-storey tower. 199.781 m2 building area.				The concave facade provides heat gain in the south, the convex facade disables the effect of the wind in the north. The natural ground feeling is given with the plants used on the stories of atriums connected with stairway. It is also protected from extreme winter conditions due to the high-rise building around the building.	
HEATING	Atriums located on the concave south facade of the tower provide passive heat gain by solar ra						
COOLING							
VENTILATION	It is provided that fresh air to the upstories of the tower building, free from the effect of wind as recirculation volume at that level. Hence, it serves as a buffer zone between the storey where it is located and extreme outdoor weather conditions.						
LIGHTING	The wide glazing facade reduces the artificial lighting need of the building.						

Chart 13. *Harbin Tower (Harbin Twin Towers Proposal / spatial practice, 2013; Harbin Twin Towers in Harbin, China by spatial practice, 2013)*

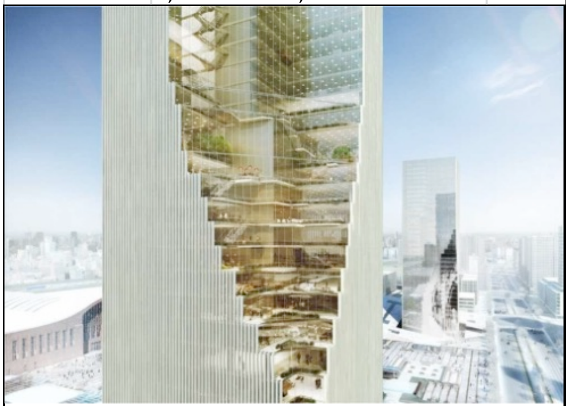
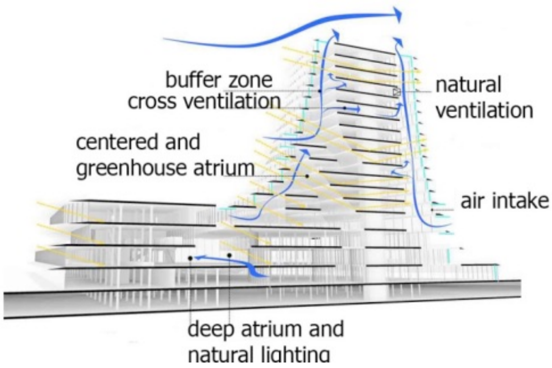
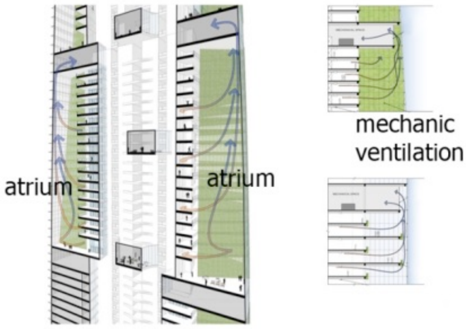
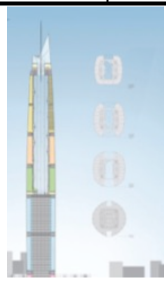
Harbin Twin Tower, Harbin China		temperature	humidit	wind		aim	type
climate zone	3, cold climate,	3,5	63%			lighting	two sided
		 Date: under construction Atrium created by emptying one corner of the square plan schema. Building area: 75.000 m2				The atrium is designed as a volume between double facade layers. It is an opposite sided atrium located on the southeast and north west facades in different stories. The atrium creates microclimate effect in high storey.	
HEATING	Atriums in the south direction provide passive heat gain during the cold season						
COOLING	The atrium in the upper half of the tower in the northwest direction provides passive cooling during the warm season.						
VENTILATION	It serves as a buffer zone between the storey where it is located and extreme outdoor weather conditions.						
LIGHTING	Natural lighting is provided throughout the building with atriums on opposite sides of the building and on different stories.						

Chart 14. *Keelung Terminal (Keelung Terminal, Taiwan : New Building Complex, 2012).*

Keelung terminal, Taiwan		temperature	humidit			aim	type
climate zone	2, semitropical climate	23,0	76%	wind		lighting, ventilation	centered greenho use
 		 Date: under construction. The building has an aerodynamic model considering the northern winds. The tower, which is on a 4-storey wide base, has 14 stories.				The greenhouse type atrium is in the northeast and southweast, the centered atrium is in the southwest direction. Centered atrium figured on section diagonally has a positive effect on exhauisting of polluted air and its drive up from lower stories.	

HEATING	
COOLING	The cool air in the lower stories of the centered atriums intersects a greenhouse type atrium at the upper level and provides cooling with natural air flow. Horizontal structural elements work as a sunshade.
VENTILATION	Two different types of atirum offer cross ventilation. Centered atrium figured on section diagonally that provide ventilation to the wide ground storey also reduces cooling loads by providing natural air flow.
LIGHTING	The light taken from the facade provides direct lighting to the centered atriums. Due to the plan scheme geting narrower as it rises, natural light is penetrated to the wide ground stories through the center atriums.
RENEVABLE ENERGY	
OPERATION	CO2 sensors control in storey parapets. Office temperature is 24 degree, greenhouse type peripheral atrium temperature is 26 degree. Radiant effective floor cooling is planned with dry air. Windows is operable.

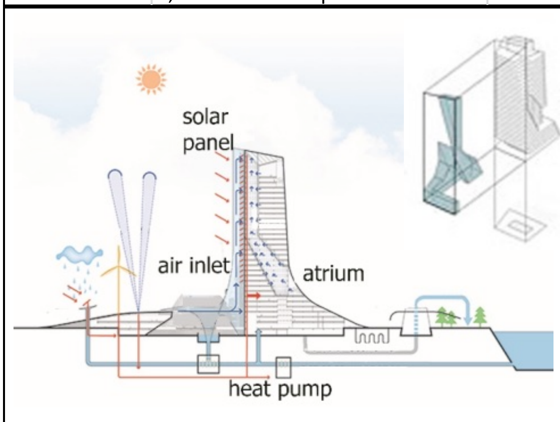
Chart 15. *Seoul Light DMC Tower (Digital Media City Landmark Tower in Seoul, 2009; Seoul Light DMC Tower, 2011).*

Seoul Light DMC Tower, Seoul, Korea		temperature	humidity	wind	aim	type
climate zone	4, humid continental climate	10,5	68%		lighting, ventilating	centered green house
		 Date: under construction The 133-storey tower has two atriums that centered and greenhouse. The centered atrium is the vertical circulation area.			The central atrium space allows air to be drawn into the wind tunnel passively on the tower. The effect of air stratification is prevented by placing the peripheral atrium in the form of a greenhouse and vertical divided. The centered atrium is used on the upper stories of tower and a greenhouse type atrium is used on throughout of tower.	

HEATING	In the central atrium used on the upper stories, heat is gained from the rising air.
COOLING	Air handling unit located on every 20 stories are also used for cooling purposes.
VENTILATION	Air handling unit are placed in vertical greenhouse atrium as a divide allowing the polluted air to be drawn with its natural flow.
LIGHTING	Heliostats are considered on the roof to increase the lighting in the lower stories. The dimensions of the central atrium are designed in accordance with the penetration of sunlight to the entire building.
RENEVABLE ENERGY	It is planned to obtain energy from the wind turbine on the roof.

Chart 16. *The Korea Electric Power Corporation Headquarters (KEPCO Office Complex : H Associates, 2021; Korea Electrıc Power Corporatıon Headquarters, 2010).*

The Korea Electric Power Corporation hq., Korea		temperature	humidit	wind		aim	type
climate zone	4, humid semitropical climate	14,0	70%			ventilation	spiral

	 Date: under consturction. 120.000 m2 office area.	Thanks to the large area of the building, geothermal energy is used. Rainwater collection system and gray water treatment system are used. With the spiral form of the atrium, it starts with the south direction on the ground and settles on the west, north, east and again south facades, respectively. Green roof is used throuhout site.

HEATING	Water of heating system is preheated underground with geothermal energy. The atrium will be utilized from the south at ground level that will been cold.
COOLING	Geothermal heat will also be used in cooling. It is thought that the hot and humid air will rise and be exhaust with its natural flow in the atrium.
VENTILATION	The spiral atrium will provide natural air flow. Cross ventilation will be provided by intaking with the entrance area at the atrium ground level.
LIGHTING	It is planned to obtain energy from the wind turbine and the collectors in the recreation area.
RENEVABLE ENERGY	In site, wind turbine an PV in recreation area obtain additional energy.

The examined atriums focus on a specific energy-efficient system based on the its'climate zone conditions. As the lighting and heating strategies are developed mostly in cold climates, the cooling and ventilation intended strategies are developed especially in warm climates. In chart 17, annual average temperature, average humidity, and predominant wind direction of building location are demonstrated with aimed strategies in atriums.

The implementation of the lighting strategies, which are the starting point of the atrium, as an energy-efficient strategy, is seen in the buildings that were built in previous years. Owing to innovation in construction technology over time, energy efficiency from not only one system but also several systems is aimed at high-rise buildings that have not been constructed yet. Energy-efficient designs have been developed for more than one system in the One Angel Square, Seoul light DMC Tower and Keulung Terminal buildings of these buildings. Only One Angel Square has been constructed and it owns the highest certificate of Bream.

Chart 17. *The prior aimed strategies of cases, with values annual average temperature, humidity and predominant wind direction of its region (Weather Data, 2021; Forecast Weather Data, 2021; Wind Roses,2021).*

	Climate Annual Average			Aimed Strategies in Atriums			TAG		
	temper	humidity	wind	natural lighting	natural ventilation	termal comfort	FUNCTION	TYPE OF ATRIUM	CONSTRUCTION DATE
Genzyme Center , Massachusetts, US	10,5	67%					office	centered	2003
One Angel Square, London	10,1	73%					office	arcade	2012
Kelley Engeneering Center, Oregon,USA	12	73%					education	opposite sided	2005
Ravensbourne Collage, Peninsula in London, UK	10,1	73%					education	centered	2010
Phoenix Central Library, Arizona,USA	19,5	38%					library	centered	1995
Debis Tower, Berlin, Germany	8,5	69%					office	centered	1998
Vasconcelos Library, Mexico	18	80%					library	multiple horizontal	2007
FESTO Technology Center , Sttutgart Germany	10,5	77%					shopping	three sided	2001
The EDGE , Amsterdam	8,5	84%					shopping	three sided	2014
LEO Office, Malaysia	27	80%					office	centered	2004
The Bow, Calgary, CANADA	13	50%					office	multiple vertical	2013
The Harbin Towers, Harbin, China	3,5	63%					multifunctional	two sided	_
Keelung terminal, Taiwan	23	76%					transportation	centered, greenhouse	_
Seoul Light DMC Tower in Seoul, Korea	10,5	68%					hotel	centered, multiple vertical	_
The Korea Electric Power Corporation hq.	14	70%					multifunctional	spiral	_

7. CONCLUSION

In this study, energy-efficient construction strategies in atriums, could be advantageous at night and disadvantageous at days at the same time and warm-season these advantages could turn into a disadvantage when there is a need for heating. When existing buildings and designs are examined, centered atriums are widely used. In recent years, spiral, arcade, greenhouse type, and vertical multiple arrangement atriums are also confronted. The reason why centered atriums are prevalent demonstrates the intention to increase the natural lighting. Whereas, atriums are also energy-efficient strategies for heating, cooling, and ventilation.

In the next studies, the energy efficiency should be examined in atriums in which the above-ground level of the building consists of merely the atrium volume. Atrium is a space containing complicated heat transfer mechanisms caused by the movement the immense amount of air volume. This complexity is needed to be turned into a benefit on energy efficiency by simulations. These simulation tools must be capable to calculate the impact of heating, cooling, lighting, and ventilation loads on the annual energy consumption of the building and also to make a comparison between stated comfort conditions and for each trial of designs during the stage of design and taking decision.

While it is known that, there is a discrepancy between simulation results and the energy consumption realization of the building after built due to unpredictable behaviors of users, they should be utilized to attain energy efficiency as the fastest and least costly tool in the design stage. In terms of wholistic design, a simulation calculating the energy efficiency and safety in the event of fire simultaneously and adapting the contradictory solution of each of two disciplines according to each other should be configured.

Different energy efficiency systems should be designed by both optimizing the the gain among themselves and not contradicting with the other construction systems. Ensuring the entegrated design strategy as a result of different coherent systems providing the user comfort creates the ideal building notion in terms of environmental building control. When this ideal's energy efficiency and energy-efficient system at building is designed by calculating advantageous and disadvantageous consumption in different climates, the total energy consumption will reduce and so the natural resources will conservated. Hence, the current living conditions will be sustained for the next generations and the building will attain this superior feature in line with this purpose.

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