OPTIMUM ATRIA TYPE IN TERMS OF THERMAL COMFORT FOR HIGH RISE OFFICE BUILDINGS IN THE SEMI-ARID CLIMATE OF MIDDLE EAST

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ABSTRACT

Building sector is responsible for at least 40% of energy use in most countries worldwide around 33% of its energy is known to be used by HVAC systems in buildings. Tall buildings tend to have an increasing appetite for energy due to deep plans and provision of HVAC to maintain comfort levels especially in the Middle East with its hostile environmental conditions. However, the region has a tradition of successful climatic conscious design solutions; therefore, the paper aims to investigate the impacts of applying the traditional layout of courtyards to contemporary tall buildings in the form of atria. It also examines through a simulation technique the comparative energy consumption in relation to a number of different atria layouts. Moreover, it provides insight of the differences in energy consumption to maintain comfort levels of different layouts in tall office buildings. Dynamic Thermal Simulation (DTS) tool called Design Builder is used to achieve the aim. The software provides results of the prototypes over an annual period of time. By using Design Builder DTS tool the optimum form of atria type has been verified in semi- arid climate for rectangular and square plan shapes. It is concluded that rectangular shape buildings aligned on the east-west axis with atria orientated towards south seem to be the best option in using less energy to provide thermal comfort annually.

INTRODUCTION

Because of the rapid speed of population growth in urban areas and limited land in it, high-rise buildings have emerged as solution. They allow more people by square meter of a land compared to low rise buildings (Sauerbruch et al., 2011). Among other advantages is that high-rise structures compared to low-rise structures create less carbon footprint (Sauerbruch et al., 2011) as well as use less material needed for usable floor space and can reduce energy loads (Sobek, 2011) via the share of natural energy between floors (Salib and Wood, 2013).

However, Tall buildings tend to have an energivore due to deep plans and especially provision of Heating ventilating and air conditioning (HVAC), to maintain comfort levels (Holford and Hunt, 2003). Using HVAC as a mean to assist thermal comfort has resulted in 33% of energy usage in commercial and office blocks around the world (Salib and Wood, 2013). So the amount of energy used to provide thermal comfort mechanically is considerable. Not designing buildings according to climate conditions results in consuming a lot of energy and money (Wahid, 2012). Thermal comfort is one of the most important parameters when designing buildings (Douvlou (2003) and when buildings are designed poorly it leaves no choice but to reply on mechanical means, HVAC, for providing one of the basic needs of human beings: thermal comfort for occupants (Wahid, 2012).

Therefore it is of much importance to try to achieve the thermal comfort via natural means as much as possible and to lower the energy usage in buildings via incorporating energy efficient strategies into designs (Aldawoud, 2013). There are other advantages in providing heating and cooling via natural means (Douvlou, 2003, Abdullah, 2007, Health and Saftey Executive, 2014):

1. Reducing resource depletion
2. Reducing harmful impacts to environment because of pollutions caused by energy production
3. Reducing costs

1. Reducing Sick Building Syndromes (SBS)
2. Improvement of human productivity because of healthier environment

This paper explores the performance of tall offices in Tehran. The climate in Tehran is semi-arid climate, which has hot summers and cold winters. Achieving thermal comfort range naturally for the occupant of a building throughout the year is a challenge in the semi-arid climate which has hot summers and snowy winters. The semi-arid climate of Tehran is one example which has this characteristic.

However it is not an impossible task as vernacular architecture of the semi-arid climate of the region in

middle-east, has successful designs which used passive ways to provide inhabitants with a comfort temperature inside houses.
One interesting passive strategy used is that of including courtyards. Courtyards have been used in different climate zones because they are actually energy efficient in all climates (Aldawoud and Clark, 2008).

ATRIA

Atrium is derived from the Latin word "āter" which means "Dark" and refers to a central space open to the sky and surrounded by rooms that used to be covered with dark black smoked walls in traditional houses of Rome (Moosavi et al., 2014) (Fig 1). The idea of atrium was partially inspired by courtyards, an old tactic for climate control (Abel, 2000, Medi, 2010). Bednar (1986) believes that the history of atria is known to have begun with the archaeological remains of Ur.Mesopotamia, a Malaysian courtyard house, in 3000 BC and that later on the central uncovered roof houses were found in ancient Greek and Roman cities, where the open space allowed fire smokes to escape and allow daylight in. It is then believed that this form was extended in the middle-east forming a larger courtyard space (Sharples and R.Bensalem, 2001) (Fig 2). During the late 19th century and the beginning of 20th century the traditional forms of courtyards gave its place to the atrium enclosures in buildings (Abel, 2010). Gradually atrium was introduced into office spaces in early 20th century (Abel, 2010) and by late 1950's and early 1960's modern atria were gradually becoming common (Atif, 1994) .

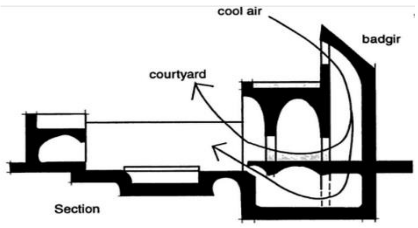

Figure 1: Section of a typical Persian house with courtyard and wind catcher in middle-east

Atria are mostly popular with large office headquarters as well as commercial buildings and shopping malls (Reid et al., 1994). The popularity of atria in office towers became even more since SOM (Skidmore, Ownings and Merrill LLP) architects, Norman Foster and Ken Yeang led the way (Abel, 2010). However, many large office blocks were using atria as a central open courts or light wells in the 19th century when there was actually more advantages to it (Salib and Wood (2013). In fact buildings are still using atria mainly as means for circulation purposes (Sharples and R.Bensalem, 2001).
It can be argued that atria with or without a roof in high-rise buildings are somehow the extrusion of courtyards in low rise buildings and can also be a potential strategy for providing thermal comfort in buildings with less energy consumption that one without an atrium. Hence, atria do have the potential to provide occupants comfort through solar radiation and natural heating and cooling in order to minimize lighting, heating and cooling energy requirements (Abdullah, 2007).

Some of the potential advantages of Atria are:

- Providing Natural Ventilation: Moosavi et al. (2014) strongly states that "Natural ventilation is the main potential environmental advantage of atria".
- Providing Natural light: Atrificial lighting is known to be the major element that contribuets a great deal in increasing heating loads (Aldawoud, 2013) and so atrium would be huge bonus in this aspect especially in deep plan public buildings.
- Providing solar gain: The sun rays can provide heat in this space (Assadi et al., 2011, Abdullah and Wang, 2012) and the heat can be captured
- Provide better air quality: By using plant-filled atrium, air could be filtered and particulates removed when it enters the hollow space (Barkkume, 2007).
- Provides Shelter: A buffer zone sheltering the space form wind , snow rain and other outdoor environmental factors while retaining the outdoor effects such as fresh air, natural light and sunshine (Göçer et al., 2006)
- Provides great visual space: (A.Lauouadi et al., 2003)
- Provide social gathering and circulation area as well as green space (bryn1993;bednar,1986; saxon 1986) and (Gocer, Tavil, 2006) and (Moosavi et al., 2014) also consider atrium having significant impact on increasing inhabitants socialization and interaction.

PROJECT STATMENT

Even though HVAC, supposes 33% of usage in tall commercial and office blocks, at times it could be the only remaining solution in constructions especially commercial towers where there is a greater size of floor area, higher population density and internal heat gains through equipment (Salib and Wood, 2013). However, noticing that atrium is becoming a very popular feature of large buildings (Assadi et al., 2011) because of its various advantages, it is of importance to optimize the atria design and to ensure it is not poorly used, in order to maximize using

passive heating and cooling as much as possible before using HVAC.
Some examples of office buildings having atria to assist bringing down energy consumptions of HVAC are Commerzbank Tower in a temperate climate of Frankfort, Torre Cube in humid climate of Guadalajara and St.Mary Axe building in temperate climate of London which they have 80%, 100% and 40% naturally ventilation throughout the year respectively (Salib and Wood, 2013, Jenkins, 2009, Wells, 2005).
However, this paper presents preliminary results of Dynamic thermal simulation in semi-arid climate and compare the influence of different atria types on office heating and cooling hours in a typical high-rise building and to compare it also with a base study of office high-rise building with no atria. This paper also identifies which types of atria and which orientation are beneficial in this climate.

BASIC ATRIA CONFIGURATION

The placement of the atria is the main factor determining the advantages that an atria could potentially have in a building (Moosavi et al., 2014). Out of nine classified generic types of atria (Saxon,…), five types have been recognized as the simpler forms suitable for buildings whether it be small or complex (Fig 2):

- Single sided (ex: Law Courts, Vancouver)
- Two sided atrium (ex: Ford Foundation, New York)
- Three sided atrium (ex: Hercules plaza, Wilmington)
- Four sided or central atrium (ex: *IMF headquarters)*
- Linear atrium (ex: Hennepin County)

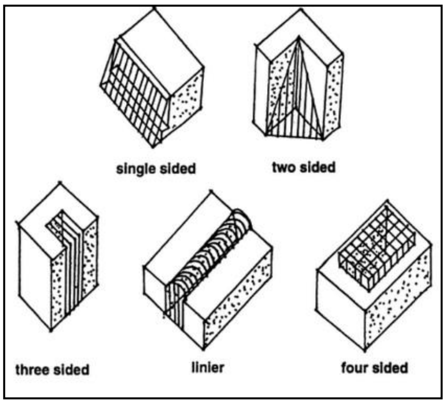

Figure 2: Five basic configurations of atria in buildings (Onyenobi, 2008)

Central atria, similar to central courtyard in plan, is the most common form of atria and used normally in deep plan office buildings to allow natural light into the centre. Linear atria also allows air and light deep into the plans of a deep plan building. Moreover, single sided atria have been used usually in temperate climate as a *glazed façade* in order to have more solar heat gains in winter time as well as great views during the rest of the year, while linear and central atria seem to be used mostly in hot and humid climate (Moosavi et al., 2014)

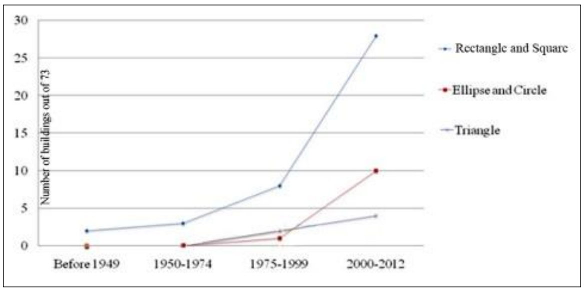

Figure 3: plan shapes of 73 tallest buildings in the world (Onyenobi, 2008)

Architectural shapes of most high-rise in the world have been derived from basic forms which are square/rectangular, triangle and circle(Onyenobi, 2008) (Onyenobi, 2008) .Figure 3 and 4 compares plan shapes of 73 tallest buildings in the world; it could be seen that rectangular and square shape buildings have been and still are amongst the most used building shapes (Alaghmandan et al., 2014). Thus this study only focuses on the square and rectangular shape high-rise office buildings with the previous 5 different types of atria.

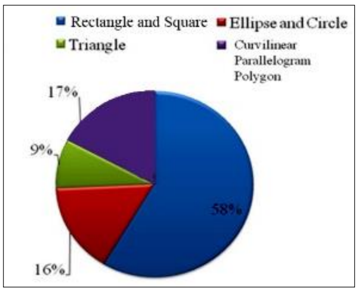

Figure 4: plan shapes of 73 tallest buildings in the world (Onyenobi, 2008)

Computer simulation is used to predict the (thermal) performance of buildings at sketch stage design (Clarke, 2001). Predicting early results of projects that could inform future action or research in the real world (Wang and Groat, 2002) is very important as it prevents problems early in the production process rather than later finding and fixing them which causes other problems in itself ie. cost (McLead, 2001). It also allows a great number of possibilities to be tried in a short space of time (Malama, 1997). Computer simulation is also used for the development of this prototype.

PRELIMINARIES

This research is conducted in the city of Tehran with average low and high daily temperatures ranging from -5 to 40 during a year (figure 5).

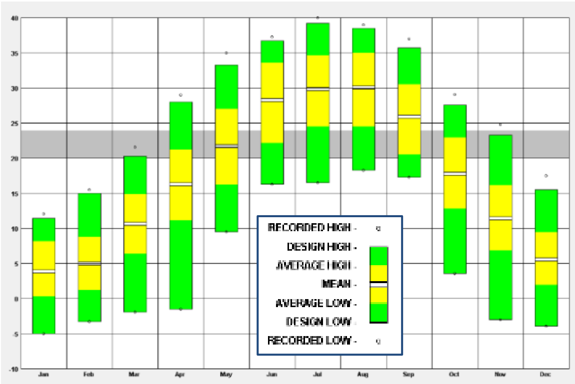

Figure 5: Tehran temperatures graph produced by climate consultant software

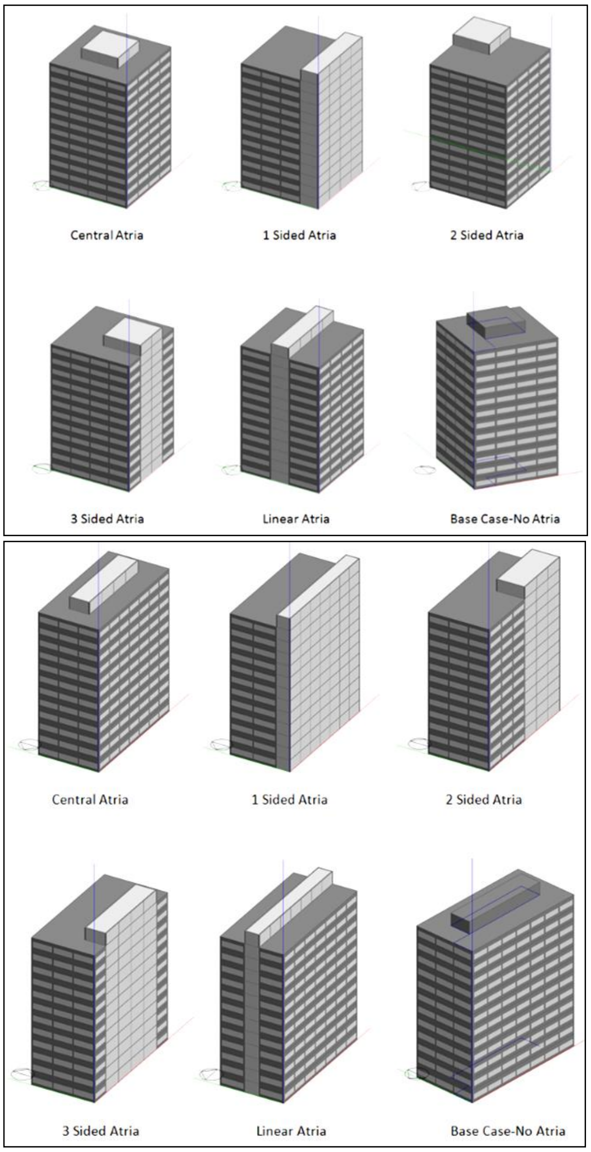

Figure 6: main prototype cases

According to literature review and Tehran regulations of high-rise buildings, the typical high-rise prototypes is a minimum of 12 story height with 500 m^2 office area on each floor and 150 m^2 of atria plan area, 40% external window to façade ratio, 60% of internal window to façade ratio, with atria roof opened in hot days and closed in cold days (Göçer et al., 2006, BHRC, 2014, TMPD, 2012).

Thermal simulation has been carried out in Design-builder software which uses Energy Plus. The prototypes are run on office hour times and Natural ventilation mode is set to “ON” which means that the external and internal windows to open if set point temperatures are met.

The minimum set point temperatures that closes the external windows is 21 °C, which is within the comfort temperature in cold seasons and because outdoor temperature of hot seasons does not reach 21 during working hours of the day therefore it is a reasonable figure.

It is also important to know that the thermal comfort range in Tehran climate according to Heidari (2009) survey in Tehran and his produced formula, ranges from around 18 °C to 26.5°C in cool season and from around 23.5°C to 31.5°C in warm season. Thus any temperature outside these ranges in cool and warm seasons is classified as cold or hot uncomfortable temperatures and therefore the hours are counted as hours which are need of mechanical heating or cooling.

DISCUSSION

Five types of atria (figure 6) have been designed into square and rectangular plan shape prototype buildings, all with the same fixed floor atria plan area. The rectangular prototypes plan is designed with the width being half of the length which is recommended by Yeang (1948) as the optimized plan shape in buildings in the arid climate.

The prototypes have gone under simulation with the consideration of four main orientations of atria, So for example if the atria was 3-sided and faced towards the south it is called a 3-sided-south atria. In the rectangular cases if the building is being situated in the north south axis letter V is in the prototype name and if its along east west axis Letter H is in the prototype name. so for example if a building plan is along east- west axis and has a three sided type atria which is towards the south it is called a 3-sided-(H)-S building (see for example figure 7). Moreover, two sets of simulation of warm season and cold season are conducted on all the prototypes. October to March is treated as cold season when the atria roof is closed and April to September is treated as warm season when the atria roof is fully opened up.

The results of hot hours (hours above 31°C) are shown in figure 7 and for cold hours (hours below 18°C) are shown in figure 8. As it can be seen, the least hot hours annually in the square prototypes, is the base case with 4537 hours and in rectangular porotypes is the base case-(H)-EW with 4341 hot hours annually. In both forms, having no atrium in hot days performs better as there is least amount of overheating hour. This is possible as Bednar (1986) and Zhang (2009) explain that the atrium can be a direct heat gain space which might be of advantage in winter but can be a disadvantage in summer. Apart from central atria, other prototypes do have a 100% atria glazed façade towards outside meaning that their external glazing to façade ratio increases which adds to the heat gains via external windows.

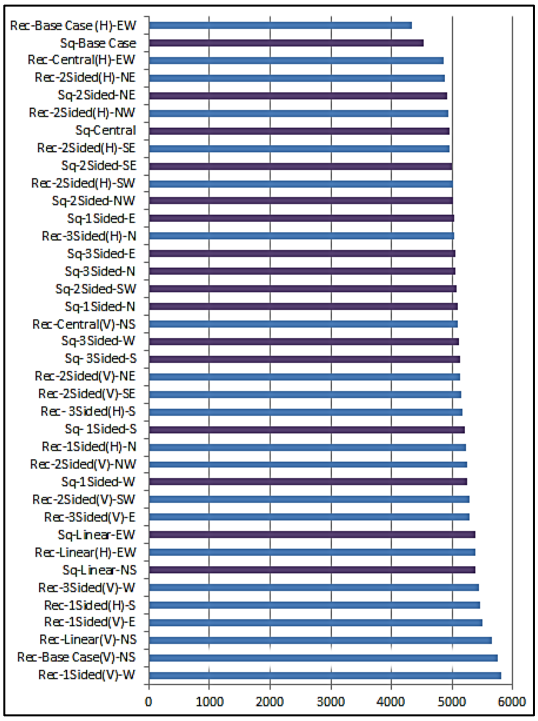

Figure 7: Rectangular and square prototypes annual hot hours in increasing order

In addition, the rectangular form aligning on the east-west axis has least overheating hours compared to the square base case. The reason could be that since the width of rectangular is less than square therefore better cross ventilation appears which helps towards getting rid of the inner hot air, which is above outside temperature.

However, the situation is very different in cold days because in fact the base case is the worst-case scenario (figure 8). In winter the atria cases which are the coolest, result in more cold uncomfortable hours for occupants in offices, and the greenhouse effect of atria are favourable in this situation. Again apart from central atria, other prototypes do have a 100% atria glazed façade towards outside meaning that their external glazing to façade ratio increases which adds to the heat gains via external windows. This explains why the atria types are better than the central type atria and the building with no atria at all as they absorb the solar radiation through external windows and the atria's perform the greenhouse effect. Moreover, Hawkes and Baker (1983) states that in cold climates using closed top glazed atria are obviously beneficial as they can act as a buffer zone between indoor environment and harsh external climate condition and be used as means to reserve heat during sunny days of cold climates and helping with the heating load. Bednar (1986) and Zhang (2009) also explain that the atrium can be a direct heat gain space because of its greenhouse effect which is the effect when short waves enters the atrium, hits the face of objects, transforms into long waves and ultimately gets trap in a closed atria

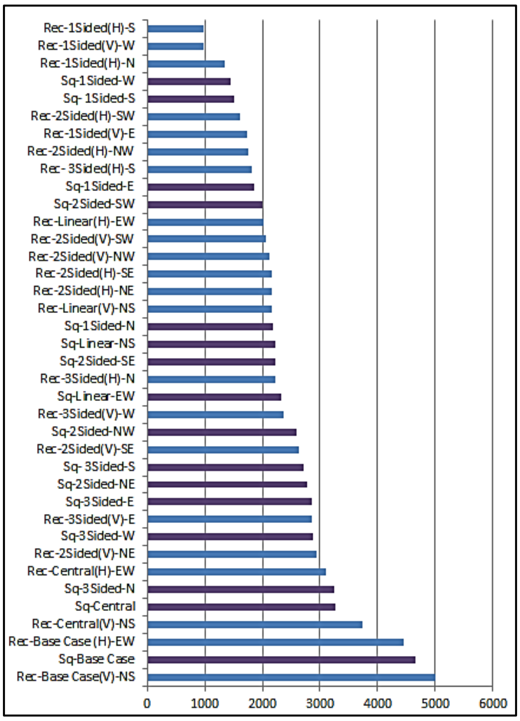

Figure 8: Rectangular and square prototypes annual cold hours in increasing order

In the rectangular prototypes, 1-sided-(H) building with South atrium provides less uncomfortable hours in winter, 975 cold hours annually, due to absorbing the south and partially the east and west sun rays in the atria during the day. Since the orientation of this prototype building in along east west axis meaning that the long façade is towards the north and south therefore maximum south solar rays can enter the atria and help towards heating up the offices and is an advantage compared to the warmest square type atria in cold season. Also the south atria in the 1 sided-(H) building acts as an extra insulation partially blocking the prevailing wind of SWW in Tehran.

In the rectangular prototypes, it can also be seen that the 8 buildings with the least cold hours are mostly those along the east-west axis (H) in Tehran semi-arid climate which is on the northern hemisphere. It seems that east-west axis buildings are a better orientation than most of the buildings alongside north-south axis (V) in this region. The reason is that in winter when the sun has a low angle, solar radiations are appreciated along the longer façade to heat up the building naturally, however in summer the sun has a very high angle in city of Tehran and therefore, the building can benefit from having the long side towards the prevailing winds coming from SWW in summer and natural ventilation can help more in cooling the building.

In the square prototypes 1-sided-S is the second best choice in cold days having 1516 cold hours annually. However, the least cold hours is 1452 annually which the 1 sided W provides. The atria on the west heats up when the sun is at its lowest angle on the west while blocking most of the prevailing winds coming from SWW. Since the south and west do have the same façade area therefore it seems that the balance of blocking wind and solar gains is better on having the atria on west for the square prototypes.

Comparing the square and rectangular prototypes with each other, the difference of cold hours annually is noticeable. The 1-sided-(H)-S rectangular prototype has far less cold hours annually compared square 1-sided-W prototype and the reason as mentioned before could be that; the rectangular building with its alignment along east west axis has more south façade therefore maximum south solar rays can enter the atria and help towards heating up the offices and is an advantage compared to the warmest square type atria in cold season where it has less south façade area.

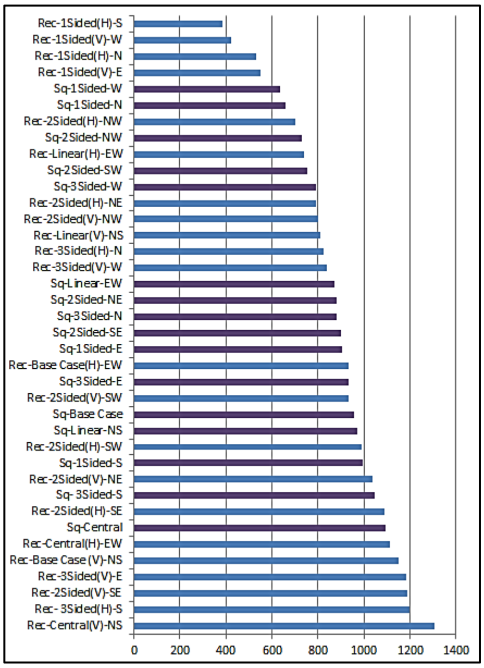

Figure 9: Rectangular and Square prototypes total annual heating and cooling loads (MWh)

To summarise the description on annual hour graphs, the annual uncomfortable hours in square 1-sided atria facing west and rectangular 1-sided (H)-S is less than other types and orientations. The east-west axis for the rectangular building proves to be better than north-south axis. In addition, having the right atria type is better than the option of not having atria at all in semi- arid climate for cold days. Last but not least, among all prototypes the rectangular prototype with 1 sided atria type facing the south orientation has the least uncomfortable hours and is suggested to be the best option amongst all other prototypes.

In addition, the sum of annual cooling and heating loads in rectangular and square prototypes have been calculated and are shown in figure 9. Between rectangular prototypes the 1-sided-(H)-S has least cooling and heating loads and thus needs less energy to provide comfort temperature annually. Between square porotypes the 1-sided-W have the least cooling and heating loads and thus needs less energy to provide comfort temperature annually. Hence, it seems that the options which are best in cold days are actually best annually as well and therefore it is important to provide heat via natural means in cold days as much as possible in semi-arid climate of middle east. Overall, rectangular 1 sided prototype along east west axis with atria towards its south is the best option amongst all other prototypes.

CONCLUSION

It is of much importance to minimize the energy consumption in buildings via providing better passive strategies to use natural heating and cooling. This paper compares high-rise office buildings without atria with those high-rise buildings with 5 types of atria with rectangular and square plan shapes and seeks to see if any atria type can provide better thermal comfort naturally in a year and use less energy to reach comfort temperature. The results confirm that the best option amongst all prototypes is the rectangular plan building orientated along the east-west axis with 1-sided atria towards south. It contributes best towards lowering the possible annual energy loads for office hours in a semi-arid climate by improving the annual comfort hours, which in return lowers the energy consumption to provide thermal comfort temperature in office buildings of semi-arid climate.

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