

Influence of different atria types on energy efficiency and thermal comfort of square plan high-rise buildings in semi-arid climate

Marveh Jaberansari^{*a}, Hisham Elkadi^b

^{a,b} School of Built Environment, UK

^{a,b} University of Salford, UK

*Corresponding author's mail: marveh594@yahoo.com, m.jaberansari@edu.salford.ac.uk

Abstract

Building sector is responsible for at least 40% of energy use globally in both developed or developing countries such as the middle east region (UNEP, 2009) (Francesca Cappelletta et al., 2015) and almost 33% of its energy is known to be used by HVAC systems in buildings (Salib and Wood, 2013). Iran is one of the developing countries. Even though buildings in Iran also are accounted of 40% of all energy used in the region (Mahdavejad, ...) but compared to European countries the building sector consumes six times more energy (Asgar, 2014). Amongst all building types, tall buildings use more energy due to deep plans and provision of HVAC to maintain comfort levels (Holford and Hunt, 2003). This building looks into tall buildings and specifically in office types where more people are allocated in limited space and hence demand more energy. However, the region has a tradition of successful climatic conscious design solutions such as courtyards hence the paper aims to investigate the impacts of applying the traditional layout of courtyards to contemporary tall buildings in the form of atria in the semi- arid climate of Middle East. Cubic shapes are the most common used building forms amongst high-rise buildings in the world (Alaghmandan et al., 2014), therefore, this paper looks into the square plan shape tall office buildings with no HVAC. Moreover, it provides insight of the differences in energy consumption to maintain comfort levels of different atria layouts in tall office buildings with a square plan shape. Dynamic Thermal Simulation (DTS) tool called Design Builder has been used to achieve the target. The software provides results of the prototypes over an annual period of time and compares then with non-atria building.

Keywords: Atrium; office; high-rise; heating and cooling load; energy consumption; thermal comfort

1. 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 (Douvrou (2003) and when buildings are designed poorly it leaves no choice but to rely 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 (Douvrou, 2003, Abdullah, 2007, Health and Safety Executive, 2014):

- Reducing resource depletion
- Reducing harmful impacts to environment because of pollutions caused by energy production
- Reducing costs
- Reducing Sick Building Syndromes (SBS)

- 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).

2. 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) .

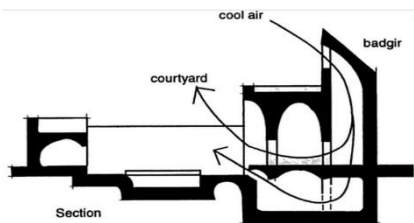


Fig 1: Section of typical Persian house with courtyard and wind catcher in the Middle-East.

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, Owings 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: Artificial lighting is known to be the major element that contributes 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, Tavit, 2006) and (Moosavi et al., 2014) also consider atrium having significant impact on increasing inhabitants socialization and interaction.

3. Project statement

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 Frankfurt, 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.

4. 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*)

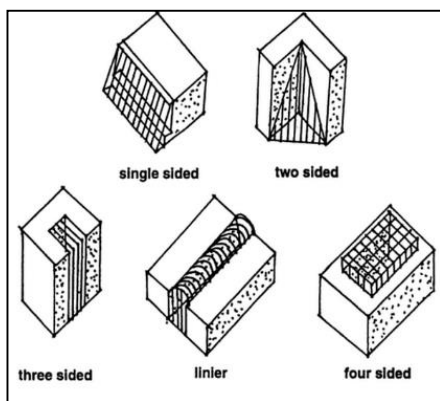


Fig 2: Five basic configurations of atria in buildings (Onyenobi, 2008)

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 (REF?). 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)

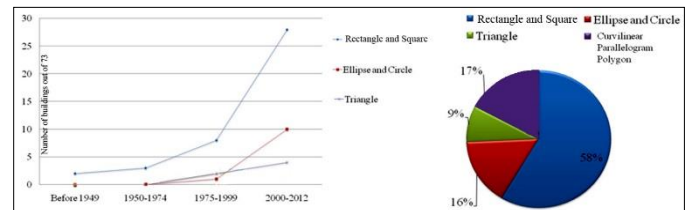


Fig. 3: plan shapes of 73 tallest buildings in the world (Onyenobi, 2008)

Architectural shapes of most high-rise in the world have been derived from basic forms which are square, triangle and circle (Onyenobi, 2008). Figure 3 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 shape high-rise office buildings with the previous 5 different types of atria.

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 i.e. 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.

5. 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 (fig 4).

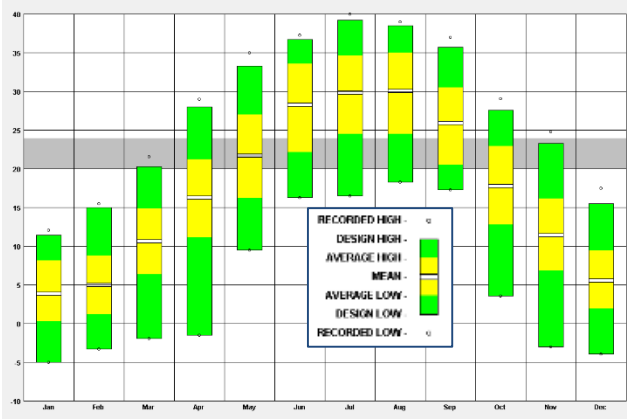


Fig. 4 Tehran temperatures graph produced by climate consultant software

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 m² office area on each floor and 500 m² 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 (BHRC, 2007)(Göçer et al., 2006, BHRC, 2014, TMPD, 2012).

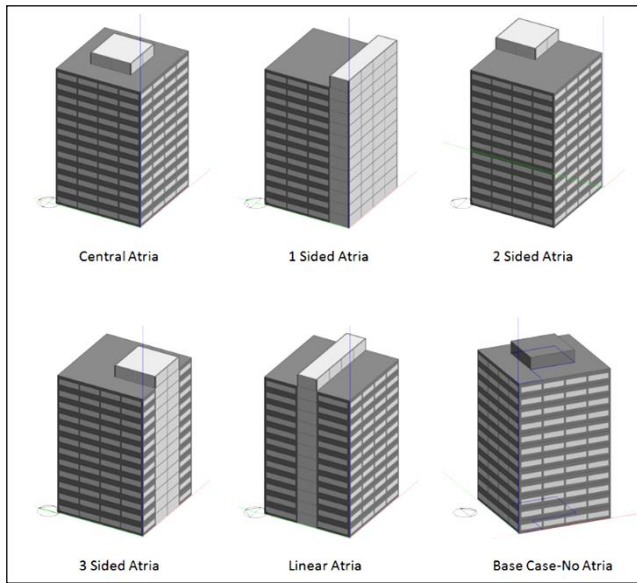


Fig. 5: main prototype cases

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. (have to rephrase the last 2 paragraphs)

6. Results and discussions

Five types of atria (Fig 5), have been designed into square plan shape prototype buildings, all with the same fixed floor atria plan area. The prototypes have gone under simulation with the consideration of four main orientations in two sets of simulation of warm season and cold season. So for example if the atria was 1 sided and faced towards the south it is called a 1 sided south atria. Overall a number of 64 simulations were run on prototypes.

The results of cold hours (hours below 18°C) are in fig 7 and hot hours (hours above 31°C) are in fig 6.

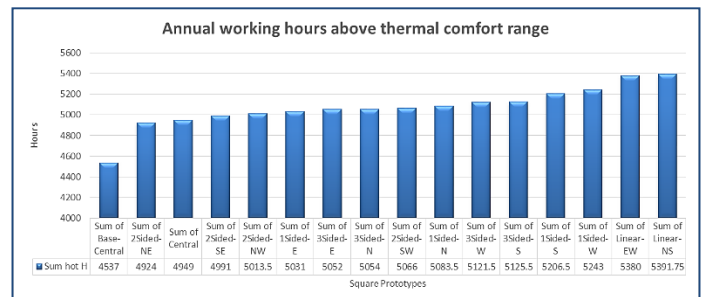


Fig. 6

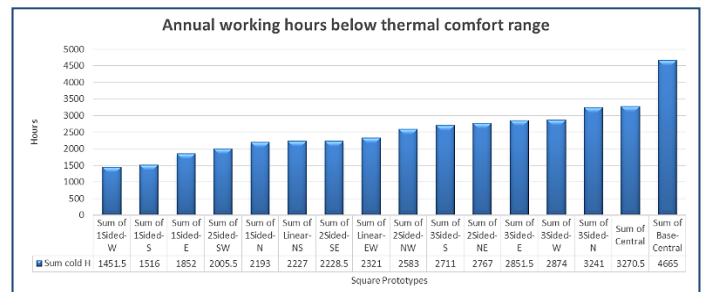


Fig. 7

As it can be seen in summer base case scenario which has no atria performs better. Because the amount of hours above comfort range in a building with no atria is 4537 which

compared to all other options in atria is the least amount. 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 as well. Fig 8 below also shows that the base case has the least amount of heat gains via windows compared to other prototypes. 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 (included in the solar gain exterior window graph in figure 8) which explains why the heat gains are more.

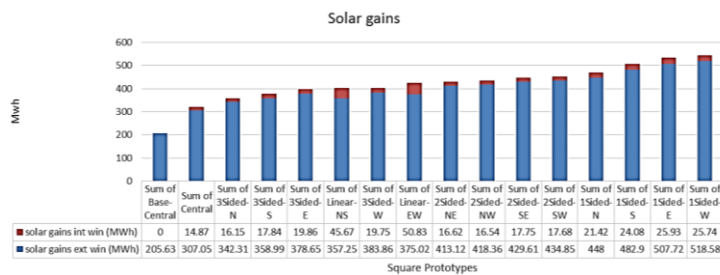


Fig 8 solar gains warm season

Never the less, there are other sources of heat gains in offices such as computer and equipment heats, occupants, windows and heat from light bulbs (fig 9). Which explains even though the heat loss in base case with no atrium is the least (fig 10), however, since the heat gain is also small compared to other prototypes, thus it still remains the best option in summer hot days, having the least amount of uncomfortable hours.

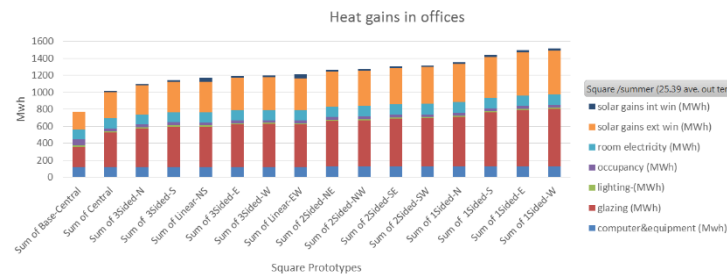


Fig 9 heat gains in warm season

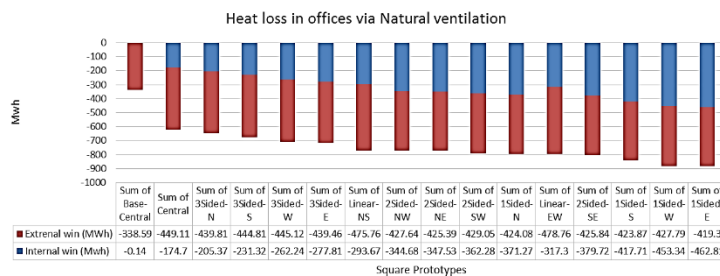


fig 10: heat loss warm season

However, the situation is very different is cold days. Because the solar gains are more in 1 sided atria compared to other atria and in fact the base case is the worst case scenario. 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 (included in the solar gain exterior window graph 11) which explains why the heat gains are more some atria rather than others and the base case.

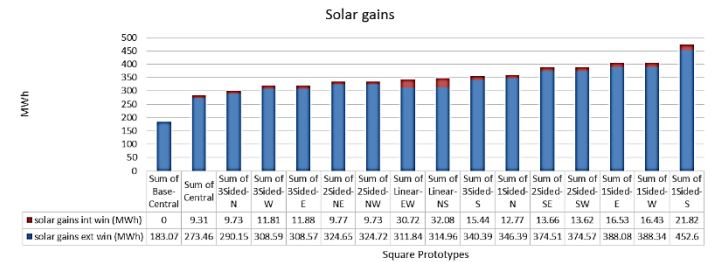


Fig 11 solar gains cold season

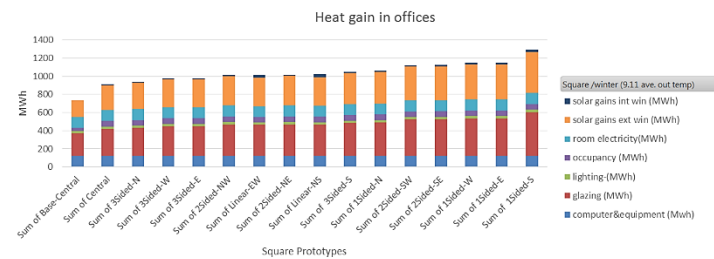


Fig 12 Heat gains cold season

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. 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

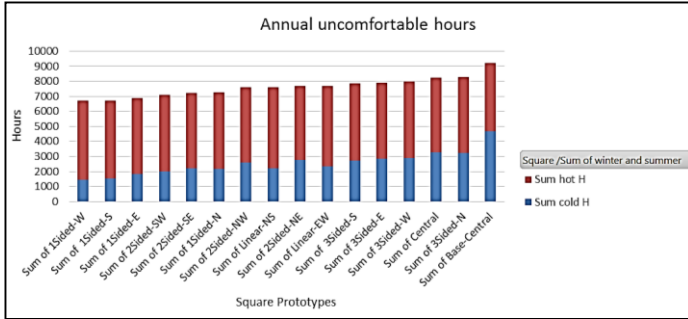


Fig 13

Overall, the annual uncomfortable hours in a 1 sided atria facing west is less than other types and orientations of atria and most certainly is the better option than not having atria at all in semi- arid climate (fig 13).

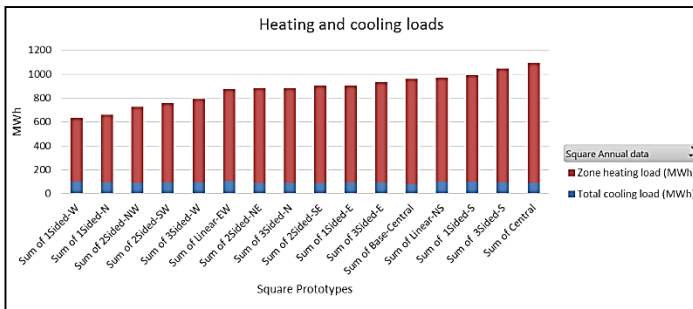


Fig 14: annual heating and cooling loads

Also from fig 14 above it can be seen that the heat load is considerably more than cooling load and so it is important to provide heat via natural means in cold days as much as possible.

7. Conclusions

It is of much importance to minimize the energy consumption in buildings. This paper shows the consumption between high-rise office buildings without atria and those high-rise buildings with other different types of atria. The results confirm that using atria and one which faces the west, for office hours in a semi-arid climate can contribute towards lowering the annual energy loads which in return lowers the energy consumption to provide thermal comfort temperature in office buildings of semi-arid climate.

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