RESEARCH ARTICLE

Advanced energy architectural configurations and its influence on the indoor environment in various climatic regions

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Abstract: One of the most important functions of buildings is to provide comfort with minimum reliance on energy consumption. Many research focuses on the physical part of the building, which has resulted in a lack of investigation considering design and configuration. After the announcement of the Saudi vision of 2030, which aims to improve building performance, the aim of this research is to investigate the influence of models and sub-models of complex architectural configurations in various climatic regions. This will not only have its impact in the kingdom of Saudi, but it will also benefit users and institutions globally. These models have not been investigated before in terms of energy performance and thermal comfort, which makes this research highly essential. The research will use TAS EDSL modelling, which is considered as one of the most powerful and advanced tools for predicting buildings’ energy performances. It can be seen that in all regions, the relationship between the indoor temperature and relative humidity has an inverse pattern. Having high relative humidity will make it difficult to achieve indoor comfort temperatures levels for the users with higher indoor air temperatures. This might require an increase in the indoor air velocity by natural pressure or even by mechanical means, such as fans. It will be concluded that linear and radial shapes are not recommended for extreme regions, whether they be hot or cold.

Subjects: Environmental Studies & Management; Engineering & Technology; Built Environment

Keywords: architectural design; building configurations; indoor building environment; sustainable building

ABOUT THE AUTHOR
Mamdooh Alwetaishi is an assistant professor at the University of Taif, College of Engineering. He has obtained his MSc course in Renewable Energy and Architecture from the University of Nottingham in 2011, and awarded PhD in Sustainable Building Technology from the same institution in the year of 2015. Dr Alwetaishi’s major field is in sustainable building technology, green buildings, building design in different climates and other subjects which are related to building efficiency. Dr Alwetaishi is the head of Civil Engineering Department at Taif University since 2016. In this article, he is dealing with a very complex architectural design to investigate the impact of shape on building energy performance.

PUBLIC INTEREST STATEMENT
In this study, the author has investigated the influence of advanced and complex building design taking into account Centralised, Linear, Clustered and Radial forms. Although all the forms and sub-forms have the same area/m², there are major differences between all of them with respect to building energy efficiency and thermal comfort. The study used a very advanced computer modelling, which are called TAS EDSL and CFD Fluent. It can be advised that linear and radial shapes are not recommended in extreme conditions, such as very hot or very cold.
1. Introduction

Building shape is an important aspect to consider in green and passive designs, as it affects the energy load for the building, regardless of the local weather and climate (Enshen, 2005; Okeil, 2010; Oral & Imaz, 2003; Wang, 2006). Most of the published research focuses on the physical part of the building’s form and envelope, such as phase change material, heat transfer and influence of thermal mass. However, insignificant attention has been paid to the influence of the shape of the building, regardless of its area, volume and orientation (Chen, Yang, & Wang, 2017; Suraya, Rashdi, & Embi, 2016). Moreover, some other studies have indicated that there are no guidelines and recommendations on the architectural aspects with regard to the impact of the building’s form on energy efficiency and energy demands (AlAnzi, Seo, & Krati, 2009). Building form is a major factor in sustainable buildings, as its impact on energy performance, as well as energy consumption are important issues to consider (Wang, 2006). This is connected to passive design that is identified to be one of the leading parameters in affecting building performance in various climatic regions (Badescu et al., 2011; Filippin, Larsen, Beascochea, & Lesino, 2005; Lam, Yang, & Liu, 2006; Lomas, 2007; Sadineni, Maddala, & Boehm, 2011). Moreover, Lomas (2007) and Okeil (2010) have realised that building geometry has a major influence on ventilation, which will aid the control of air patterns in and outside of buildings.

Depecher has produced a valuable parameter to assess building shape called a “shape coefficient”, which might be defined as the rate between the external skin surface of building (F0) with its inside volume (V0) (Qi & Wang, 2014). Moreover, there are some elements in association with the building shape, such as relative compactness, window to wall ratio and glazing type (AlAnzi et al., 2009). There are three major elements that defines the building envelope, which are walls, roofs and transparent parts. All these construction materials should be given full consideration with respect to the local climate (Marrahimi, Mohamed, & Haw, 2016). In order to investigate the impact of shape on buildings, it is difficult to use simple formulas to calculate solar radiation, but computer energy simulation is advisable to solve this issue (Zhang, Zhang, & Wang, 2016). In addition to that, other methods have emerged where the use of Google maps can be used in order to calculate the shape coefficient (Qi & Wang, 2014).

1.1. Impact of building shape on energy building performance

The study of AlAnzi et al. (2009) has indicated the performance of the most basic shapes that might be used in the design stage. The case study has been carried out in office buildings. The paper has come out with three main factors affecting building shape. The first one is the distance between buildings, which will have an effect on the air speed around the buildings, especially in the case of high rise buildings. Next, the factor of glazing to wall ratio, and finally, the type of glazing system used in the building are considered. Moreover, the total area of the building shape also might be responsible for high differences in the amount of energy required for cooling and heating. This is due to the area of the external wall, which is exposed to the outdoors. It is accepted in energy building performance and thermal comfort that one of the most effective elements in heat transfer is the total area of the external wall. Furthermore, the exchange with the outdoors will become larger as the total area is increasing as stated by AlAnzi et al. (2009). In Malaysia, Suraya et al. (2016) have looked at the impact of some basic shapes on lowering the cooling load. The research used Ecotect, powered by Autodesk, in order to analyse the buildings. The paper has concluded that buildings with close forms might have higher cooling load than compact ones. Modifying the building form and shape has a significant effect on the cooling load of buildings. In addition to that, as the outer surface of the building, which is exposed to the sun, increases, cooling load will increase too. A study was done by Zhang et al. (2016) in China climate. The work highlights that the shape coefficient is the most important factor affecting the performance of the energy of buildings, which is the area of buildings’ external surface (F0) to its inner volume (V0). In another study carried out by Alwetaishi and Elamary (2016), in a hot and humid climate, the work focused on the impact of building shape design on the indoor energy performance combined with the cost of structure. The authors have selected a number of shapes, which are usually used in the stage of design, such as circle, triangle, octagon, square, pentagon,
hexagon and heptagon. It was observed that triangle shape performed better in terms of energy performance and cost of structure, although they all use the same area of the ground. In research carried out in a cold climate (China), the author investigated the impact of inclined walls in order to improve the performance of buildings in cold climates. It was revealed that north facing walls should remain as they are, while east, south and west should be tilted at 40°, 30° and 50°, respectively (Depecker et al., 2001).

1.2. Building shape in various climatic regions

In order to obtain appropriate designs in certain climate conditions, it is essential to carefully adjust the building envelope, including the number of external walls, amount of transparent materials and roofs. In addition to that, the orientation is considered as part of the building envelope, as mentioned before in the introduction part (Figure 1). In terms of hot regions, some studies have indicated that building shape has a quite important influence on the cooling load in summer, and therefore should have more attention (Depecker et al., 2001; Pessenlehner & Mahdari, 2003; Wilhelm & Kambiz, 2017). The work also indicates that relative compactness, window to wall ratio and glazing type are the leading factors, which effect energy consumption in hot regions. Similarly, the work of Wilhelm and Kambiz (2017), which was conducted in the climate of UAE, a “hot region”, shows that building shape can save a considerable amount of energy. Furthermore, orientation and glazing type can aid to making the performance of the building shape better. Moreover, Rackes, Melo, and Lamberts (2016) have added to these top factors the building size, internal gain and solar gain obtained from the roofs in buildings located in hot regions. On the other hand, sunlight is a very important factor for passive heating in cold climates (Alwetaishi & Elamary, 2016). In cold climates, it is advisable to have a smaller building volume and a larger outdoor surface exposed to sunlight in order to have more solar radiation, which will maximise heat conduction, absorption, directed via a glazing system. In addition, it is recommended in cold climates to have more transparent materials in the building to maximise solar gain (Goia, 2016). In higher latitude locations of cold regions, the sun is low, daytime is limited and it is always cloudy. This makes it difficult to utilise the passive technique of heating naturally from the sun. However, the layer of snow on the top of roofs can help to protect the building from the freezing outdoors, acting as an insulation layer (Hosseini & Akbari, 2016). Finally, Suraya et al. (2016), who studied the impact of building shape in Malaysia’s “hot and humid region”, concluded that a building envelope with a loose form will have a higher cooling load. As a result, in hot regions, it is advised to have more compact building forms. Moreover, the outdoor surface should be minimised as much as possible to minimise heat exchange with the outdoor environment. However, there are other reasons which may control the building’s shape, such as density of country (Marrahimi et al., 2016). It is quite essential to highlight that achieving thermal comfort is not always fixed, and it differs from one region to another [31].

2. Impact of orientation on buildings

Orienting buildings can be considered as the easiest approach in architectural design, using passive solar strategy in order to achieve thermal comfort in buildings, as well as reducing the total energy consumption. This approach does not require any mechanical means, and has to be done at the first stage of design, considering the local location of the site as demonstrated in Morrissey, Moore, and Horne (2011). In addition to that, Bekkouche et al. (2011) and Hamdani, Benouaz, and Cherier (2012) have stated that orientation is in the prime principle of the knowledge of architectural design requirements. In harsh climate regions, where the temperature fluctuates dramatically, orientation is quite important (Assem, 2011; Kruger, Pearlmutter, & Rasia, 2009; Schlueter & Thesseling, 2009). The major concern in the region of Gulf countries is the cooling load, where the temperature rises sharply over the summer period as stated by Kruger et al. (2009). On the other hand, Hamdani et al. (2012) have reported that orientation does not have a considerable impact on building energy performance, and thermal insulation has more of an effect than orientation. Sabouri (2012) has stated that if the building was well orientated, this will reduce the total energy consumption by 20%. This should be emphasised especially on the roof, west and east walls, as they are exposed to the sun during most of the daytime (Assem, 2011). On the other hand, some other authors are of the opinion that orienting the building has a quite limited impact.
on building energy performance (Hamdani et al., 2012). In the published work, the author has investigated the implementation of orientation and thermal insulation. On top of that, Raychaudhuri (1965) has reported that the longer face of the building should be orientated to the north and south. It seems that there is an argument surrounding the effectiveness of applying orientation into buildings, most of which opinions indicate that orientation has a significant impact on buildings regardless of their local location. However, when it comes into comparison with other techniques, such as providing thermal insulation, orientation may not be the most efficient way.

2.1. Methodology
The present work applies the energy modelling simulation commercially through TAS Software, which was developed by Environmental Design Solutions Limited (EDSL) in 1989. It is considered as one of the most commonly used tool to predict building energy performance. In addition, it has been used globally in many cases, and in applications as mentioned in Ahmed (2012), Ali (2013), Elisabeth and Andre (2004) and Launder and Spalding (1974). The TAS version (9.3.3) with the license number of NW3P-BWHW-QX6K-IQHX can be used to predict many building energy outcomes, including indoor air temperature (IAT) and the relative humidity (RH) of the internal space of a specified building. This work aims to investigate the impact of architectural building design on internal conditions in various climate regions globally (Figure 1). It will be assumed that the buildings are unoccupied, as this will negate the influence of heat gain released from indoors. The interned properties of the examined buildings is introduced in Table 2. Two of the most interesting and dramatic results shapes of the models will be investigated using Ansys CFD to study the external influence of air flow.

2.2. Discussion and results
Riyadh's climate is extreme, and it is rare to find such a climate where the temperature rises dramatically in summer while in winter it drops below 15°C, leading to a temperature swing as high as 20°C between summer and winter. It was found that linear shapes have attributed to lower degrees in winter. In this season, there is a need for heating load, which means that such shapes are not recommended for a sustainable performance in winter (Table 3). The findings of air flow, which was investigated using CFD, also support the results of TAS EDSL (Figures 13 and 14). As the linear shape stretches along the building length, it blocks air from movement. In fact, it is leaving one side of building facing high speed of air while the other is in lack of movement. On the other hand, the model of R1 and C14 in radial and centralised forms were found better in winter, respectively. It is clear that linear shapes generally, which has most of its external walls facing south, have their impacts on the indoor temperature by increasing the amount of heat conducted indoors (Figure 3). Radial shapes, which have equal wings facing all directions, were found to be recommended in winter, due to its external envelope which allows most of the building's solid walls to face all the directions, especially south and west that are more responsible for elevated heat exchange. With respect to RH, it is reasonably acceptable in winter, which is within the thermal comfort level of indoors. In summer, it was revealed that clustered shapes are more appropriate for hot and dry climates, as this shape has less of an amount of external exposure to the extremities and harshness of the outdoor environment. In contrast, the shape CE1 was found at the bottom of the list in terms of energy efficiency. Alwetaishi and Elamary (2016) is against this. The work carried out there studied the impact of building shape on indoor performance combined with the cost of structure. However, the research mentioned was conducted in the city of Jeddah, where the climate is hot and humid. This might have resulted in some differences.

The results obtained from Kuala’s location support the findings of Alwetaishi and Elamary (2016). Since the climate in Kuala is similar to Jeddah, which is hot and humid, this proves that recommendations of a certain shape are not applicable in any other locations. The explanation of this is because of the little temperature swing in between the indoors and outdoors, which minimises the amount of heat exchange (Table 4). Similar to hot and dry regions, it is not recommended to use fragmented forms. This will aid in exposing the external walls to the harsh outdoor conditions (Figures 5 and 6). The tropical climate has nearly an identical climate in summer
and winter, as it can be seen in Figures 6 and 7. Humidity in tropical regions is a major concern, which makes it difficult to cool the body by natural convection. This is a simple technique, which is more effective in hot and dry regions. Humidity prevents natural heat convection to take place. In
contrast, the climate in Rome is moderate in both winter and summer. The climate is cold in winter, and warm in summer. This kind of region requires fragmented forms of buildings in order to allow more of the building envelope to be exposed to direct sunlight. This will ensure maximum heat transfer, especially in the south and west directions, which receive the maximum amount of

Figure 4. Flow of research methodology.

Common architectural design configurations

Studying all the possible and complex shapes out of each configuration ‘Same area of plan is fixed’

Using advanced computer modeling (TAS EDSL) for investigation Indoor temperature and relative humidity

All proposed models were analyzed in various climatic regions

The most interesting models were further investigated using advanced CFD Ansys Fluent to investigate impact of building shape on air flow around building

Figure 5. Riyadh IAT and RH in winter.

Riyadh (Hot and Dry)
solar radiation. As far as temperature distribution goes in the city of Rome in winter, there is a difference of 1.5°C in the peak of the temperature (Figure 9), and this gap is also similar in summer with about 1.5°C (Figure 10). In Rome (or a similar climate), it is recommended to design with linear shapes, as well as radial, as these forms provide more external walls with glazing systems, which aids passive solar heating to take place. However, as indoor temperature rises within and above the thermal comfort level in summer, it is beneficial to utilise natural ventilation. This will aid in releasing extra heat to the outdoors (Table 5).

With regards to the cold climate of Stockholm, centralised shapes were found to be the best for indoor building performance, as it can be seen in Figures 11 and 12. This makes sense, as these types of building configurations are centralised that protects the building from harsh climates. As a result, it can be highlighted that centralised shapes, triangle especially, generally are appropriate for hot and humid climates, as well as cold climates (Figure 14). On the other hand, models of R1 and R3 were found with a minimum peak of temperature, which were just under 25°C in winter. This indicates that radial shapes are not recommended in extreme regions, whether that was in very hot or very cold climates (Table 6).

2.3. Governing equations
In the following section, the system of the governing equations applied for solving the flow over the selected geometries are presented.
Reynolds-Averaged Navier Stokes Equations

The Reynolds form of the continuity and momentum equations for turbulent flow, called here RANS equations, at each point of the flow field can be represented by the following equations after neglecting the body force:

\[ \nabla \cdot (\rho \vec{u}) = 0 \]
\[
\frac{\partial (\rho \bar{u})}{\partial t} + \nabla \cdot (\rho \bar{u} \bar{u}) + \nabla p = \nabla \cdot (2\mu \bar{S} + \bar{R})
\]  

(2)
In the above system of equations, \( \vec{u} \) is the velocity vector, \( \rho \) is the pressure, \( \rho \) is the density, \( \mu \) is the molecular viscosity, \( \dot{S} \) is the strain rate tensor and \( \dot{\vec{t}} \) is the turbulent stress tensor which are given as:

\[
S_{ij} = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)
\]

(3)

\[
\vec{R}_{ij} = -\rho \overline{\vec{u}_i \vec{u}_j} = -\frac{2}{3} \rho k \delta_{ij} + 2\mu_t \dot{S}_{ij}
\]

(4)

where \( \delta_{ij} \) is the Kronecker delta and \( \overline{\vec{u}_i \vec{u}_j} \) are the average of the velocity fluctuations. The turbulent viscosity is defined as:

\[
\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}
\]

(5)

The turbulent kinetic energy, \( k \), and its dissipation rate, \( \varepsilon \), can be estimated by solving the following equations:

\[
\frac{\partial (\rho k)}{\partial t} + \nabla \cdot (\rho \vec{u} k) = \nabla \cdot (\mu + \mu_t / \Sigma_k) \nabla k + 2 \mu_t \dot{S}^2 - \rho e
\]

(6)

\[
\frac{\partial (\rho \varepsilon)}{\partial t} + \nabla \cdot (\rho \vec{u} \varepsilon) = \nabla \cdot (\mu + \mu_t / \Sigma_\varepsilon) \nabla \varepsilon + (2C_{1\varepsilon} \mu_t \dot{S}^2 - C_{2\varepsilon} \rho e) \varepsilon / k
\]

(7)

The coefficients for the so-called STD \( k-\varepsilon \) turbulence model are given as follows (Launder & Spalding, 1974):

\[
C_\mu = 0.09, \quad \Sigma_k = 1, \quad \Sigma_\varepsilon = 1.3, \quad C_{1\varepsilon} = 1.44, \quad C_{2\varepsilon} = 1.92
\]

3. Conclusion

The research has investigated the influence of complex architectural design on indoor energy performance in various climatic regions. A background review related to the topic was introduced. It has included the impact of building shape on the energy performance, influence of building shape in various climatic regions, and the significance of orientation. Several models have been designed based on the most common architectural concepts, which are centralised modelling, linear modelling, clustered modelling and radial modelling. Each one of these models has sub-models, which cover more complex architectural designs (Table 1). Four different locations were selected, which are Riyadh, which represents the hot and dry regions; Kuala, which represents hot
### Table 1. Developed models examined “with fixed space area”

| Design concepts used globally (Examples) | Description | Coding of models | Model examined (Designed) |
|----------------------------------------|-------------|------------------|--------------------------|
| 1. Centralised modelling design        | The centralised origination is a stable, concentrated composition which consist of a number of elements of space grouped a large dominant centred mass (Ching 2007). | CE1 | ![Centralised Modelling Design Example](image1) |
|                                        |             | CE2 | ![Centralised Modelling Design Example](image2) |
|                                        |             | CE3 | ![Centralised Modelling Design Example](image3) |
|                                        |             | CE4 | ![Centralised Modelling Design Example](image4) |

(Continued)
| Design concepts used globally (Examples) | Description | Coding of models | Model examined (Designed) |
|----------------------------------------|-------------|-----------------|--------------------------|
| 2. Linear modelling design              | Linear organisation consists of a series of spaces. This sort of organisation usually consists of repetitive spaces which are linked together | L1                      |                          |
|                                        |             | L2                      |                          |
|                                        |             | L3                      |                          |
|                                        |             | L4                      |                          |
| Design concepts used globally (Examples) | Description | Coding of models | Model examined (Designed) |
|----------------------------------------|-------------|-----------------|--------------------------|
| 3. Clustered modelling design           | Cl1         |                 |                          |
|                                        | Cl2         |                 |                          |
|                                        | Cl3         |                 |                          |
|                                        | Cl4         |                 |                          |

Residential building in Singapore. Available online: http://en.artintern.net/index.php/news/main/html/1/3381
| Design concepts used globally (Examples) | Description | Coding of models | Model examined (Designed) |
|----------------------------------------|-------------|------------------|--------------------------|
| Radial modelling design                | Radial organisation is combined of both centralised and linear forms. It has a dominant central core from which linear organisations focus inward on its central space. | ![R1](image1.png) | ![R1](image2.png) |
|                                        |             | ![R2](image3.png) | ![R2](image4.png) |
|                                        |             | ![R3](image5.png) | ![R3](image6.png) |
|                                        |             | ![R4](image7.png) | ![R4](image8.png) |

Gartnavel Royal Hospital available online: [http://www.asylumprojects.org/index.php?title=File:Glasgow_Asylum_Now.jpg](http://www.asylumprojects.org/index.php?title=File:Glasgow_Asylum_Now.jpg)

[189x93]Table 1. (Continued)
| Layers         | Width (mm) | Conductivity (W/m² °C) | Total U value (W/m² °C) |
|---------------|------------|-------------------------|-------------------------|
| External wall | Block      | 100                     | 0.85                    | 0.89                     |
|               | Sand       | 1000                    | 1.28                    | 0.30                     |
|               | Concrete   | 125.0                   | 0.87                    |                          |
|               | Sand dry   | 10000                   | 0.32                    |                          |
| Ground        |            |                         |                         |                          |
| Roof          | Concrete   | 150                     | 0.3                     | 2.49                     |
|               | Concrete screed | 50             | 0.41                    |                          |
| Glazing       | Type of glazing | Width (mm) | Solar reflectance | Solar absorptance | Solar transmittance | Emissivity | Total U value (W/m² °C) |
| Single        |            | 10.00                   | 0.070                   | 0.115                   | 0.7          | 0.845                   | 5.53                    |
### Table 3. Major findings of Riyadh

|                      | Winter | Summer |
|----------------------|--------|--------|
|                      | CE1    | CE2    | CE3    | CE4    | CE1    | CE2    | CE3    | CE4    |
| Centralised Forms    |        |        |        |        |        |        |        |        |
| MIN                  | 10.9   | 10.92  | 10.8   | 10.82  | 35.46  | 35.14  | 34.15  | 35.16  |
| MAX                  | 14.52  | 14.56  | 14.48  | 14.49  | 40.27  | 39.82  | 39.90  | 39.87  |
| Linear Forms         |        |        |        |        |        |        |        |        |
| MIN                  | 11.22  | 11.03  | 11.1   | 10.57  | 34.78  | 34.81  | 35.16  | 34.83  |
| MAX                  | 14.9   | 14.62  | 14.62  | 14.15  | 39.44  | 39.41  | 39.84  | 39.34  |
| Clustered forms      |        |        |        |        |        |        |        |        |
| MIN                  | 10.73  | 10.74  | 10.71  | 10.69  | 34.82  | 35.1   | 35.02  | 34.91  |
| MAX                  | 14.1   | 14.34  | 14.22  | 14.13  | 39.27  | 39.77  | 39.6   | 39.42  |
| Radial forms         |        |        |        |        |        |        |        |        |
| MIN                  | 10.52  | 10.69  | 10.92  | 10.94  | 34.81  | 35.13  | 34.93  | 35.03  |
| MAX                  | 13.91  | 14.19  | 14.38  | 14.63  | 39.2   | 39.72  | 39.38  | 39.71  |

### Table 4. Major findings of Kuala

|                      | Winter | Summer |
|----------------------|--------|--------|
|                      | CE1    | CE2    | CE3    | CE4    | CE1    | CE2    | CE3    | CE4    |
| Centralised forms    |        |        |        |        |        |        |        |        |
| MIN                  | 29.26  | 29.13  | 29.18  | 29.15  | 30.97  | 30.77  | 30.8   | 30.79  |
| MAX                  | 31.07  | 30.88  | 30.98  | 30.9   | 32.76  | 32.44  | 32.54  | 32.47  |
| Linear forms         |        |        |        |        |        |        |        |        |
| MIN                  | 29.15  | 29.04  | 29.12  | 28.93  | 30.75  | 30.65  | 30.78  | 30.56  |
| MAX                  | 30.93  | 30.77  | 30.79  | 30.65  | 32.44  | 32.25  | 32.41  | 32.1   |
| Clustered forms      |        |        |        |        |        |        |        |        |
| MIN                  | 28.77  | 29.09  | 29     | 28.89  | 30.43  | 30.78  | 30.64  | 30.54  |
| MAX                  | 30.25  | 30.79  | 30.65  | 30.46  | 31.76  | 32.42  | 32.19  | 31.98  |
| Radial forms         |        |        |        |        |        |        |        |        |
| MIN                  | 28.83  | 29     | 28.93  | 29.07  | 30.47  | 30.63  | 30.57  | 30.66  |
| MAX                  | 30.45  | 30.75  | 30.6   | 30.87  | 31.89  | 32.22  | 32.07  | 32.3   |

### Table 5. Major findings of Rome

|                      | Winter | Summer |
|----------------------|--------|--------|
|                      | CE1    | CE2    | CE3    | CE4    | CE1    | CE2    | CE3    | CE4    |
| Centralised forms    |        |        |        |        |        |        |        |        |
| MIN                  | 7.25   | 7.17   | 7.17   | 7.19   | 26.64  | 26.36  | 26.4   | 26.44  |
| MAX                  | 9.92   | 9.77   | 9.82   | 9.78   | 29.62  | 29.27  | 29.38  | 29.33  |
| Linear forms         |        |        |        |        |        |        |        |        |
| MIN                  | 7.23   | 7.15   | 7.31   | 6.94   | 26.09  | 26.02  | 26.49  | 25.8   |
| MAX                  | 9.88   | 9.74   | 9.81   | 9.5    | 28.96  | 28.94  | 29.25  | 28.77  |
| Clustered forms      |        |        |        |        |        |        |        |        |
| MIN                  | 7.12   | 7.17   | 7.12   | 7.11   | 25.83  | 26.27  | 26.17  | 26.01  |
| MAX                  | 9.37   | 9.72   | 9.6    | 9.48   | 28.39  | 29.09  | 28.96  | 28.68  |
| Radial forms         |        |        |        |        |        |        |        |        |
| MIN                  | 6.93   | 7.07   | 7.06   | 7.06   | 25.68  | 26.11  | 25.88  | 26.15  |
| MAX                  | 9.36   | 9.57   | 9.58   | 9.71   | 28.53  | 29.15  | 28.73  | 29.23  |
and humid regions; Rome, which represent moderate regions; and finally Stockholm, which represent cold regions. In hot and dry climates, it was revealed that linear shapes are not recommended due to high cooling and heating loads required. This is because of its large area of external wall that is exposed to the harsh climate in both summer and winter. As a result, it was found that clustered shapes are recommended in hot and dry climates. With respect to hot and humid climates, this sort of regions assess fragmented building shapes to accord more of natural ventilation. It has to be mentioned that the various building shapes have limited impacts in this region, attributed to the neglection of attention to temperature swings in between summer and winter. Having said that, one should not to disregard the fact that this kind of location has an excessive amount of solar radiation, hence, it is advised to try to avoid facing the surfaces of external walls towards the south direction. In terms of cold climates, similar to hot, both extreme regions should not use radial models, as well as linear, which leads to a large area of the external walls facing the harsh climate. Consequently, in extreme climates, either hot or cold, it is recommended to utilise centralised and clustered shapes.

It is noticeable that in all regions, the relationship between the indoor temperature and RH has an inverse pattern. As the temperature rises, humidity drops (see Figures 2–9). Having high RH will make it difficult to achieve thermal comfort levels for the users with higher IATs. This might require an increase in the indoor air velocity by natural pressure or even by mechanical means, such as fans.

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Table 6. Major findings of stock

|                      | Winter   |        |        |        | Summer   |        |        |        |
|----------------------|----------|--------|--------|--------|----------|--------|--------|--------|
|                      | CE1      | CE2    | CE3    | CE4    | CE1      | CE2    | CE3    | CE4    |
| Centralised forms   | MIN      | 1.53   | 1.42   | 1.46   | 1.45     | 20.86  | 20.52  | 20.55  | 20.58  |
|                      | MAX      | 2.62   | 2.56   | 2.56   | 2.55     | 21.05  | 20.67  | 20.71  | 20.74  |
|                      | L1       | L2     | L3     | L4     | L1       | L2     | L3     | L4     |
| Linear forms        | MIN      | 1.44   | 1.36   | 1.48   | 1.24     | 20.37  | 20.2   | 20.7   | 19.84  |
|                      | MAX      | 1.75   | 1.67   | 1.79   | 1.55     | 20.48  | 20.33  | 20.84  | 20     |
|                      | CL1      | CL2    | CL3    | CL4    | CL1      | CL2    | CL3    | CL4    |
| Clustered forms     | MIN      | 1.23   | 1.41   | 1.35   | 1.29     | 19.87  | 20.44  | 20.26  | 20.07  |
|                      | MAX      | 1.53   | 1.73   | 1.66   | 1.6      | 19.92  | 20.57  | 20.4   | 20.18  |
|                      | R1       | R2     | R3     | R4     | R1       | R2     | R3     | R4     |
| Radial forms        | MIN      | 1.17   | 1.3    | 1.27   | 1.35     | 19.67  | 20.11  | 20     | 20.22  |
|                      | MAX      | 1.48   | 1.61   | 1.58   | 1.66     | 19.8   | 20.3   | 20.15  | 20.39  |
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