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Improvement of Human Thermal Comfort in Built Environment using BIM simulation methods, case study in Alexandria, Egypt

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1 ABSTRACT

Recently, there has been a high demand for urban sprawl because of rapidly increasing population. On the other hand, Building Regulations do not consider either human thermal comfort or energy consumption in the built environment. The quality of outdoor spaces in the built environment could be determined by many factors. This paper will investigate the impact and effect of three factors which are building orientation, relationship between building height and street width and microclimate conditions. This paper introduces a method to evaluate the efficiency of the outdoor built environment through the simulation process using Building Information Modelling (BIM) technology. This research aims to solve the problems of thermal comfort and energy consumption in the built environment. These problems were mainly the result of building codes that were not sensitive to the built environment as the codes focus on the buildings themselves. The case study is located in downtown Alexandria city, Egypt. Its area is approximately one square kilometre. This research supports urban planners and designers in making decisions before implementation to reach thermal comfort in the built environment. It contributes to revealing the importance of factors affecting the outdoor built environment and taking them into consideration while establishing new codes or amending existing building regulations.

Keywords: Built Environment – Building Regulation – Building Codes - Thermal Comfort – Energy Efficiency – BIM.

2 INTRODUCTION

Of all the design fields, urban design has the greatest impact on the nature of cities and city life. No matter How logically the land-use pattern is prescribed by city planners, the beauty and utility of its buildings and the nature of the landscape, it is the overall combination of forms and spaces as seen in time and over time that gives a city its character. City planning has broadened its scope of concern in an attempt to be comprehensive in its outlook. Landscape architecture has considerably extended its domain of interest from a horticulture base to include urban environments, while architecture has many practitioners who focus on different aspects of the built environment. Architecture has contracted its scope of concern spinning off sub-fields as new environmental problems have arisen. One of the current generation's challenge is to understand the broad impact of our built environment on thermal comfort better. Building regulations may be the only comprehensive ones that can contain all factors to achieve a better built environment and healthy cities in the future and improve the existing built environment.

Building Information Modeling (BIM) It is to provide users with the ability to integrate, analyze, simulate and visualize the geometric or non-geometric information of a facility. One of the most significant characteristics of BIM is that it can provide the required information in an organized pattern.

3 BUILT ENVIRONMENT

The term 'built environment' refers to aspects of our surroundings that are built by humans, that is, distinguished from the natural environment. It includes not only buildings, but the humanmade spaces between buildings, such as parks, and the infrastructure that supports human activity (Committee on Physical Activity 2005). The Centre for Digital Built Britain defines the built environment as; 'All forms of buildings (residential, industrial, commercial, hospitals, schools), (Lang, 2005). Broadly defined, the built environment includes the buildings and spaces we create or modify (Karen and Oleru 2008)(McClure and Bartuska 2007). The built environment is a material, spatial and cultural product of human labour that combines physical elements and energy in forms for living, working and playing (WIKI 2012) (Blog 2015) (Matt 2015). In recent years, public health research has expanded the definition of "built environment" to include healthy food access, community gardens, “walkability", and “Bick ability” (built environment 2021).

Well-being in the built environment is a topic that features frequently. However, despite this surge in attention, there are still many questions on how to nurture, measure, and design for well-being in the built environment effectively (Luo, et al. 2018). Physical and physiological well-being depends on current states as well as on previous history of exposures, while anticipation of future events can drive neural mechanisms and psychological balance. For example, solar ingress in built spaces might be favoured, particularly in a cold climate or season, to bring passive heating and decrease lighting energy use (Mangone, Kurvers and Luscuere 2014). However, bright sunlight could cause glare and reduce visual task performance. Yet, direct exposure to natural light particularly in the morning (Baron 1990) (Mangone, et al., 2014) is beneficial.

The building industry appears to be entering another period of change in essence of minimising energy, carbon and environmental footprints of various building types (Owusu and Asumadu 2016). Globally, energy demand of buildings amounts to one third of world energy use. This change is being driven by a need to optimise and conserve resources, especially energy (Freedman 2015). The architects as important stakeholder has important roles to play in accomplishing this onerous goal (GANIYU and ADETUNJI 2015) (Newton, et al. 2012) (Pickles 2011) (Lehmann, 2011; Shanghai Manual, 2011) (Janda, 2009) (Toledo, 2006).

4 BUILDING REGULATIONS

Regulations are designed to protect buildings and the people and property inside them from any extreme events. They also ensure system safety, as well as accessibility and practical and achievable levels of energy efficiency (Francis & Steven, 2018). Building codes underpin the work of architects, engineers, builders and developers (USAID, 2013).

The existence of building regulations goes back almost 4,000 years. The Babylonian Code of Hammurabi. The protection of the health, safety, and welfare of the public is the basis for licensure of design professionals and the reason that building regulations exist. (Francis & Steven, 2018). The beginning of modern codes can be traced to the 1897 publication of the NFPA’s National Electrical Code. Early attempts to prevent fires, predecessors of today’s zoning laws and safety codes included requirements for wider streets, limitations on building spacing and height, and elimination of thatched roofs and wooden chimneys in cities. Sanitation concerns were the moving force behind some early codes and over the years, have led to plumbing standards, lighting and ventilation requirements, minimum room dimensions and other health and safety requirements we take for granted in today’s building codes (Report: The Value and Impact of Building Codes 2013) (Ching 2016) (Bank 2015) (Jawaida, Pipraliab, & Kumarb, 2018).

5 BIM INTEGRATION

The concept of building information model BIM was coined by Charles M. Eastman at Georgia Tech (Eastman, et al., 2008) and from 1970s he has worked on an extension of the BIM. His main research focuses on product modelling, data modelling and information modelling in engineering (Eastman, 1994) (Sacks, et al., 2010). The concept of BIM means building a building virtually prior to building it physically, in order to work out problems, and simulate and analyse potential impacts (Morlhon, et al., 2014). BIM can be used as a tool for generating and managing data during the life cycle of structures. BIM covers building geometry, spatial relationships, geographic information, and quantities and properties of building components (Namlı, et al., 2019) (Salman, et al., 2012) (Lee, et al., 2006) (Kymmell, 2008).

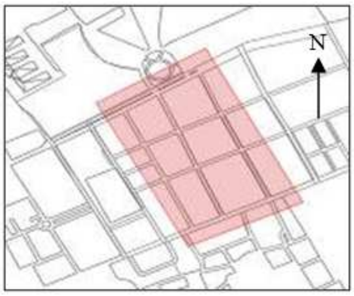

Fig. 1: Selected Block to be studied

Recently, BIM, has been able to digitise a great amount of building information and that is why it has received much attention in the field of construction project management (Wang, et al., 2014). Applying BIM in delivering construction projects has been on the rise (Guo & Feng, 2019) (Oraee, et al., 2019).

Meadati (2007) expresses that BIM is only used at an early stage and tries to integrate BIM by the 3D as-built model to increase the capability of BIM during the maintenance period. In terms of automation in BIM, several scholars have worked on this area, and accuracy and reliability of the model were their main concerns (Meadati, 2007).

6 CASE STUDY

6.1 Description

The case study is located in downtown Alexandria city, Egypt. Its area is approximately one square kilometre. A block bounded by 3 streets in two perpendicular directions will be studied as shown in figure 1.

6.2 Methodology

An analytical comparison of two cases using BIM simulations and software aimed to find solutions to the current situation and achieve better results in the future. Autodesk Revit was used to create a 3D model of the case study as shown in fig.4, B and to produce shadows results. DesignBuilder software was used to run a full simulation process on both cases as shown in fig 4, A&C. The following are the steps followed for both cases before the debate process, and the determinants change for each case.

(1) Surveying and noting the study area, building height and street widths as shown in figure 2.

Fig. 2: Fouad street live shots

(2) Drawing a site map on the Architectural Revit program using BIM technology as shown in figure3.

Fig. 3: The development of work on building the case study. Left: autocad site map, Middle: Google site map, Right: Revit 3d model as masses

(3) Determine the parameters and build the three-dimensional model of the case study based on the difference between the relationships between the width of the street and the height of the buildings and the determination of setbacks.

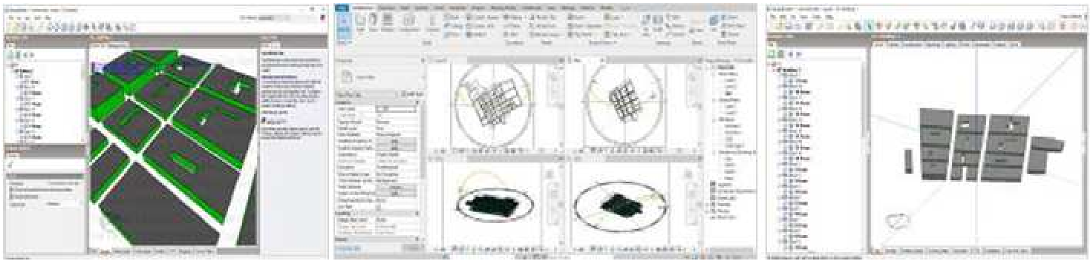

Fig. 4: Screen Shots While building 3d model and run simulation. Left: DesignBuilder Simulation, Middle: Autodesk Revit, Right: BesignBuilder model

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(4) Definitions and Abbreviations of parameters used to determine and limit the case study simulation cases are: H = Hight of the building, W = Street width, X = Setback Value from property line

6.3 Solar and Energy Study

Each case will study the sun moving from sunrise to sunset by using BIM simulation and its effect on building façades and thermal comfort in the built environment.

The simulation was conducted in the summer and winter seasons, and the results were extracted for the two days representing each season. June 21st is the representative day of the summer. December 21st is the representative day of the winter. The effect of the movement of the sun, shade and shadows was observed in areas of the street and also on the facades of the buildings at three times of the day, which were eight in the morning, twelve noon, and five and four in the afternoons in summer and winter respectively.

6.4 Case I (Explore, Parameter's Equations & Simulation study)

The first case represents the current situation that has been established in the implementation of Egyptian Building Law No. 119 of 2008. The determining factors for the first case are only the relationships between street width and building height. As the executive regulations of the Building Law stipulates, the height of the building must be equal to 1.5 the width of the street.

H = 1.5 x W X = 0

These equations mean that the height of the buildings is equal to one and a half times the width of the street, without any setbacks from the property line, with regard to construction on the whole plot of the land area, but with the presence of internal skylights that differ between residential and service.

6.4.1 Study Simulation in summer

The simulation results in summer show first a site plan view to illustrate areas of shade and shadows on street level and then in a perspective view with coloured façades that represent the temperature on each façade.

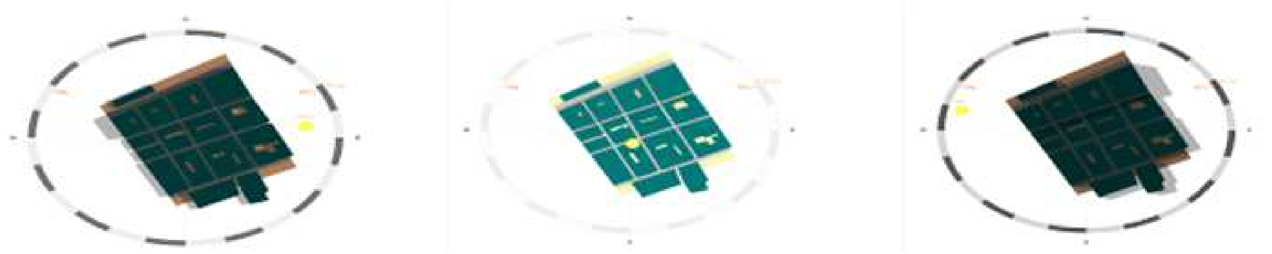

Fig. 5: Site plan Shade and Shadow in summer. Left: 8 o'clock, Middle: 12 o'clock, Right: 17 o'clock

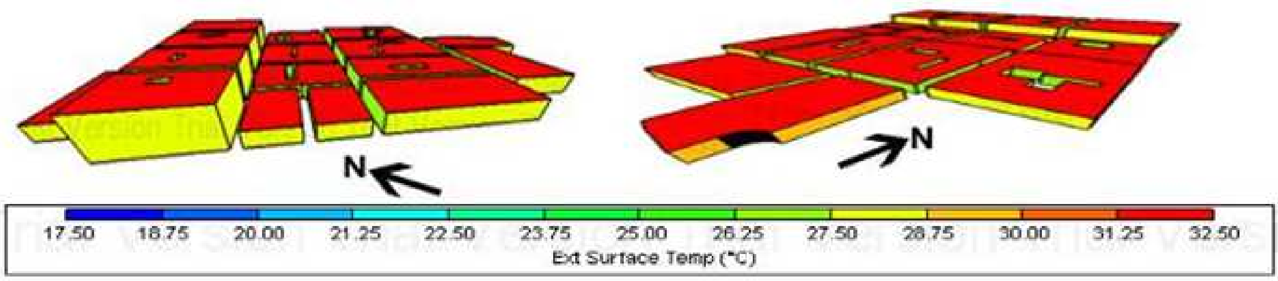

Fig. 6: Exterior surface temperature (°C) in summer. Left: Show South, West façades, ight: Show North, East façades

6.4.2 Study Simulation in Winter

The simulation results in winter show a site plan view and a perspective view which illustrate the difference between the degree of inclination of the sun.

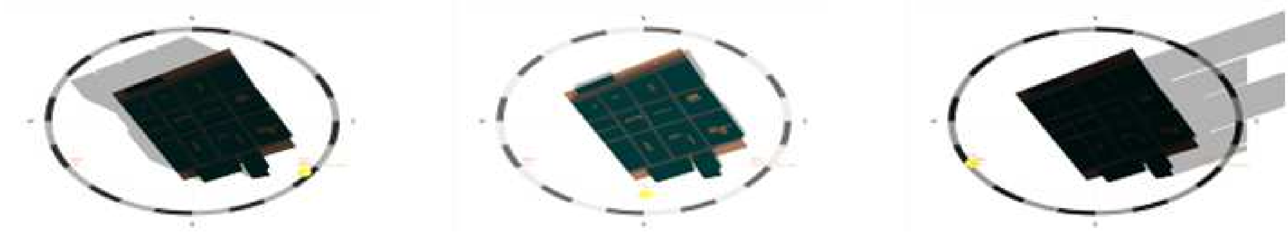

Fig. 8: Site plan Shade and Shadow in winter. Left: 8 o'clock, Middle: 12 o'clock, Right: 16 o'clock

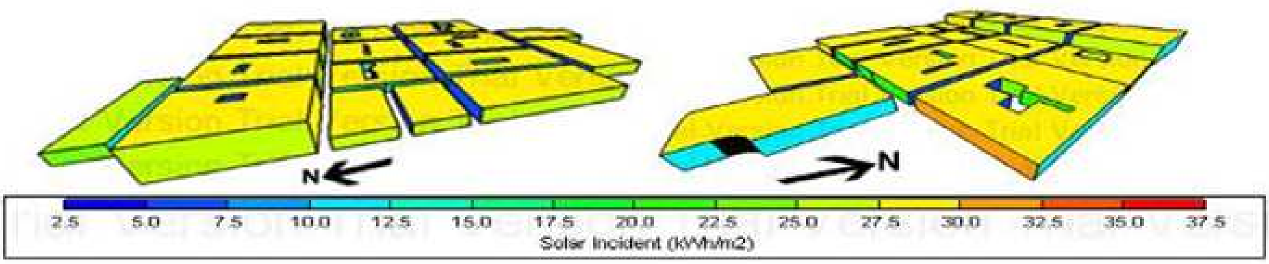

Fig. 10: Solar Incident (Kw/m2) in Winter. Left: Show South, West façades, Right: Show North, East façades

6.5 Case II (Explore, Parameter's Equations & Simulation study)

The second case represents the proposed case for amending the Building Regulation, taking into account the orientation for buildings and the voids related to this orientation. The factors affecting the second case are not limited to building height and street width, but extend to orientation, setbacks.

$H = W$ $\qquad\qquad$ $X = 2.5$

These equations mean that the height of the buildings is equal to the width of the street. There is a setback from the property line of two and a half meters, which means that building on a part of the area of the land lot, while maintaining the presence of an internal light-well.

6.5.1 Study Simulation in summer

The simulation results in summer show a site plan view to illustrate areas of shade and shadows on street level and then on a perspective view with coloured façades that represent the temperature on each façade.

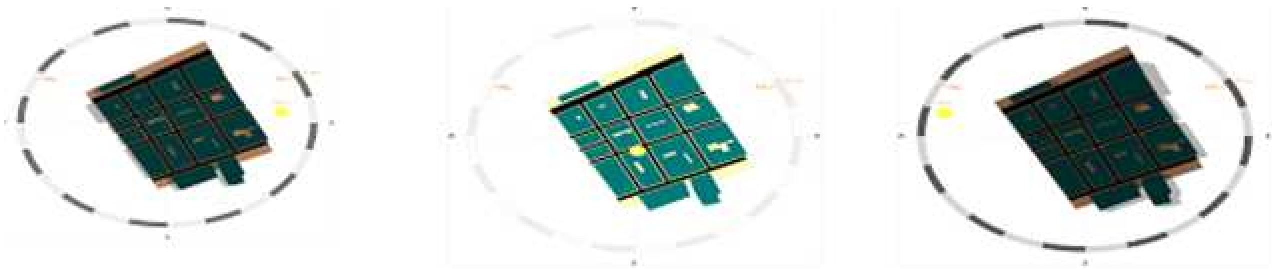

Fig. 11: Site plan Shade and Shadow in summer. Left: 8 o'clock, Middle: 12 o'clock, Right: 17 o'clock

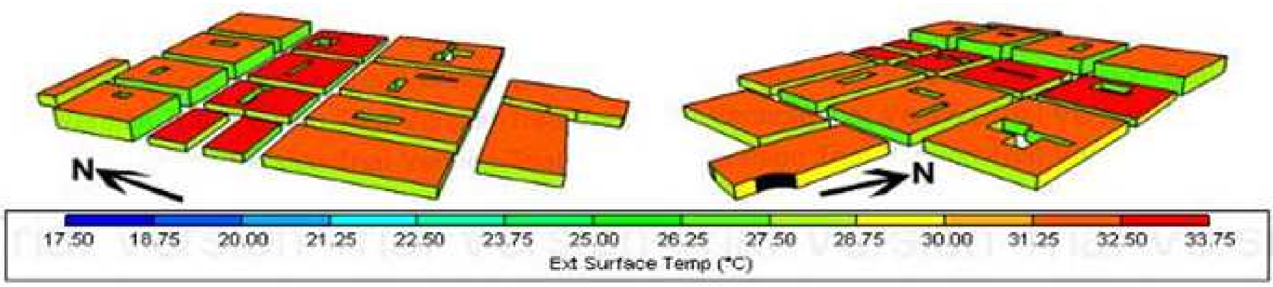

Fig. 12: Exterior surface temperature (°C) in summer. Left: Show South, West façades, Right: Show North, East façades

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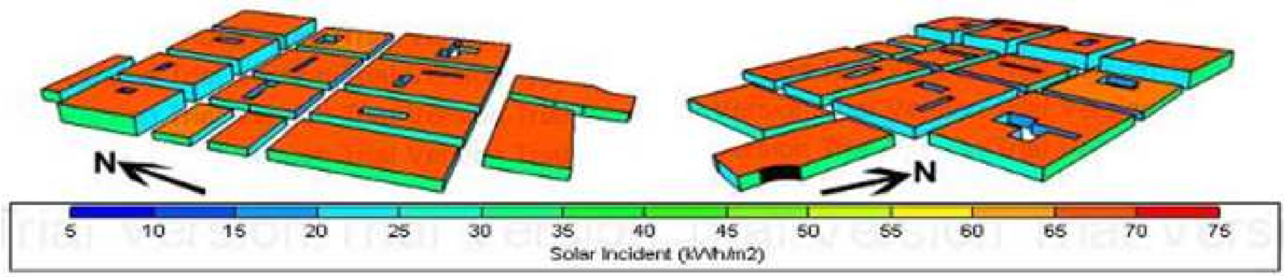

Fig.13: Solar Incident (KWh/m2) in Summer. Left: Show South, West façades, Right: Show North, East façades

6.5.2 Study Simulation in Winter

The simulation results in winter show a site plan view and a perspective view which illustrate the difference between the degree of inclination of the sun.

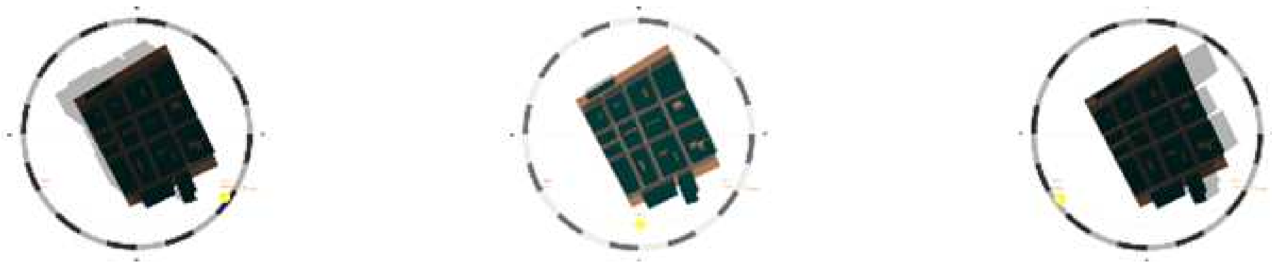

Fig.14: Site plan Shade and Shadow in winter. Left: 8 o'clock, Middle: 12 o'clock, Right: 16 o'clock

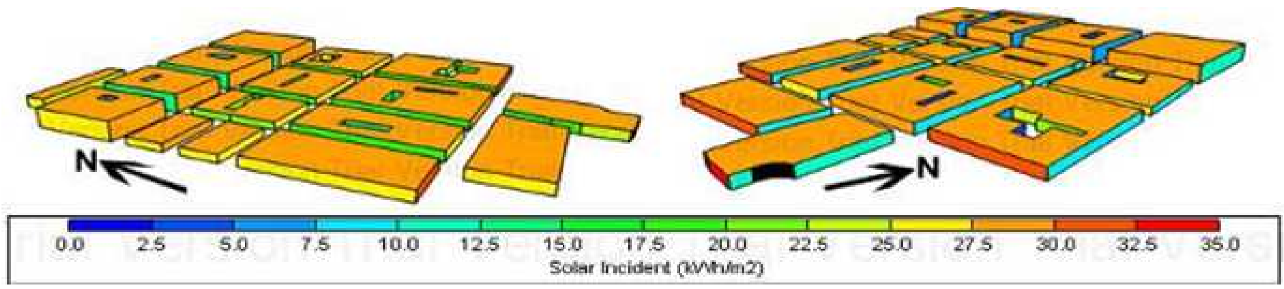

Fig.16: Solar Incident (KW/m2) in winter. Left: Show South, West façades, Right: Show North, East façades

6.6 Results

By comparing the results between the two cases, we will find that changing the equations affecting the height relationship with the width of the street beside setback value that are corresponding with the building volume, affected the shade and shadow areas, the exterior surface temperatures of roofs and façades with different orientations, as well as the amount of solar incident.

7 DISCUSSION

In the summer it is best to have more shaded areas as protection from the sun and to cool down the atmosphere in streets and inside buildings. It is desirable to decrease temperatures of the roofs and façades and thus the need for energy consumption in cooling or HVAC systems will decrease accordingly. Also, this gives designers an opportunity to use responsible and local building materials.

By looking at the results shown in Table 1, it is noticed that in Case II, the temperature to which the roofs are exposed decreased by two degrees Celsius, while on the southern façade it decreased by 3 degrees Celsius. On the other hand, the eastern façade was not significantly affected, in contrast to the western façade, which decreased by more than 4 degrees Celsius.

As for the winter season, the best situation in it differs like in the summer because we are looking for warmth and we contribute to increasing the temperatures exposed to the façades and surfaces in order to reduce the need to operate artificial heaters that consume large quantities of energy and harm the personal health and the built environment. Also, intend to have higher temperatures in spaces inside and outside buildings would affect production process as it will be more comfortable for human beings to work and produce effectively.

	Case I	Case II
Summer Condition		
Shade and Shadow	Small as shown in fig. 5	Wide as shown in fig. 11
Exterior surface temperature values for each façade (°C) as shown in fig. 6&12		
Roofs	(31 - 33) °C	(29 – 31) °C
South	(25 - 28) °C	(23 - 25) °C
West	(27 - 29) °C	(22.5 – 26.5) °C
East	(25 - 27) °C	(25 - 27) °C
Solar Incident Values for each façade (KWh/m^2) as shown in fig. 7&13		
Roofs	(65 – 75) KWh/m^2	(60 -70) KWh/m^2
South	(25 - 35) KWh/m^2	(15 - 30) KWh/m^2
West	(40 - 50) KWh/m^2	(30 - 45) KWh/m^2
East	(30 - 40) KWh/m^2	(20 -35) KWh/m^2
Winter Condition		
Shade and Shadow	Spread as shown in fig. 8	Shrunk as shown in fig.14
Exterior surface temperature values for each façade (°C) as shown in fig. 9&15		
Roofs	(15 - 16) °C	(17 – 18.5) °C
South	(18 – 19.5) °C	(18.5 – 20.5) °C
West	(16.5 - 18) °C	(17.5 - 19) °C
East	(14.5 - 16) °C	(16 - 17) °C
Solar Incident Values for each façade (KWh/m2) as shown in fig. 10&16		
Roofs	(25 - 30) KWh/m^2	(27.5 - 30) KWh/m^2
South	(17.5 - 25) KWh/m^2	(22.5 - 35) KWh/m^2
West	(15 – 22.5) KWh/m^2	(17.5 - 25) KWh/m^2
East	(7.5 – 17.5) KWh/m^2	(10 - 15) KWh/m^2

Table 1: Results: comparison for both cases I & II

By observing the results shown in Table 1, we will find that Case II is better in terms of the temperatures exposed to surfaces and facades which are higher than in Case I. For example, the southern façades in Case II are a degree and a half higher than that of Case I. The surfaces have increased temperatures by two degrees Celsius. The façades of the eastern and western buildings rose by one degree.

8 CONCLUSION

Building Regulations affect the built environment directly. Thermal comfort in the built environment which means in streets and the surrounding buildings cannot stand alone without considering interior thermal comfort in buildings. Building regulations should also give more concern to the outside of buildings as well as organising and considering the building itself. Architects, designers, constructors and stakeholders must be aware of new techniques that appear in this field and know how to use them, benefit from them and upgrade them to contribute to improving human well-being. The use of Building Information Modelling technology is increasing and it is the upcoming future.

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