Industrialized Wall Components Impacts on Cooling Load Reduction and Carbon Production

Mahmoud Shakouri Hassanabadi and Seyed Saeed Banihashemi

***Abstract*—Green building has now become a flagship of sustainable development in Malaysia that takes the responsibility for balancing long-term economic, environmental and social health. High total load green house gas emissions and inefficient energy consumption are the issues that the building sector in Malaysia is struggling with. To cope with these issues, Malaysian construction industry has been urged to use more innovative construction techniques like industrialized building system and building information modeling. This paper aims at evaluating the efficiency of various types of prefabricated wall components with regard to resource consumption and environmental impact and consequently, draws an analogy between them and the conventional types. The case study in this paper is a double storey bungalow located in Kuala Lumpur. It was modeled in Revit Architecture and exported to Autodesk Ecotect Analysis for energy simulation. Results show that the selected prefabricated walls, in terms of reducing the cooling loads, perform better than the conventional walls but this reduction is not significant. In general, this conclusion is drawn that IBS technology doesn't play a conspicuous role in energy efficiency. However, its contribution to promote sustainability may fall in other categories.**

***Index Terms*—IBS, cooling load, carbon production, wall panels, green building**

I. INTRODUCTION

Industrial sectors, including the building sector, started to recognize the impact of their activities on the environment in the 1990s. Significant changes were needed to mitigate the environmental impacts of building sector. The building sector had to focus on how buildings were designed, built and operated [1]. Green building has now become a flagship of sustainable development in Malaysia that takes the responsibility for balancing long-term economic, environmental and social health [2]. The Malaysian green building index (GBI) has been developed recently by association of consulting engineers Malaysia (ACEM) and pertubuhan arkitek Malaysia (PAM) and it offers an opportunity to create environmentally efficient buildings by using an integrated approach of design so that the negative impacts of building on the environment and occupants are reduced. The concept of sustainable development can be traced to the energy (especially fossil oil) crisis and the environment pollution concern in the 1970s [3].

Energy consumption is the main cause for greenhouse gas emissions worldwide. It is estimated that the construction sector accounts for about 30% of these emissions [4]. The International Energy Agency predicts that the global energy demand will increase by more than 50% by 2030 if policies remain unchanged and more than 60% of this increase belongs to the developing countries. This will lead to a 52% increase in emissions of carbon dioxide (CO_2), the main greenhouse gas [5].

With the growth in innovative construction methods, it has become imperative that design tools and new industrialized building components, to be provided, can give insights into the sustainability of a building at the design and construction stages, and help the project team to incorporate the notion of constructability with green building principles.

Hence, this paper aims at evaluating the efficiency of various types of prefabricated wall components with regard to resource consumption and environmental impact and consequently, draws an analogy between them and the conventional type.

II. LITERATURE REVIEW

Buildings have an enormous and continuously increasing impact on the environment, using about 40% of natural resources extracted in industrialized countries [6], consuming nearly 70% of electricity and 12% of potable water [7], and producing between 45 and 65% of the waste disposed in landfills [8]. Moreover, they are responsible for a large amount of harmful emissions, accounting for 30% of greenhouse gases, due to their operation, and an additional 18% caused indirectly by material exploitation and transportation [9]. At the same time, the bad quality of indoor environments may cause health problems to employees in office buildings, thus, decreasing productivity [10].

In order to mitigate the impact of buildings along their life cycle, green building (GB) has emerged as a new building philosophy, encouraging the use of more environmentally friendly materials, the implementation of techniques to save resources and reduce waste consumption, and improvement of indoor environmental quality, among others [11]. This would result in environmental, financial, economic, and social benefits.

In line with the growing global trend in applying sustainability, Malaysia introduced its national sustainability assessment tool in 2010. Green building index (GBI) is Malaysia's industry recognized green rating tool for buildings to promote sustainability in the built environment. It is specifically developed for tropical climate, environmental and developmental context [12]. The major objectives of GBI include Energy Efficiency, indoor environmental quality, sustainable site planning and

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Manuscript received November 17, 2011; revised December 26, 2011.

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management, material and resources, water efficiency and innovation in which energy efficiency along with material and resources comprise 32% of total marks in residential buildings in scale of 100. This shows the significance of modifying the conventional building construction and use of better materials to enhance the efficiency in the building envelope.

To cope with these challenges, Malaysian construction industry has been called for incorporating innovative construction technique and to switch from traditional to modern techniques like industrialized building system (IBS). IBS is defined as a construction technique in which components are manufactured in a controlled environment (on or offsite), transported, positioned and assembled in a jobsite with minimal additional site works [13]. It is claimed that IBS has a potential usage to promote sustainability from the controlled production environment, minimize waste generation, usage of energy efficient building materials and promote effective logistics [2].

In Malaysia, [13] has classified IBS into five categories, which are steel formwork systems, steel frame system, timber frame system, block work system and pre-cast concrete framing panel and box system.

A. *Steel Formwork System*

This system is categorized as an IBS because the process of construction is carried out using a systematic and mechanized method that is by using reusable steel formwork panels. The system allows the rapid on-site placement of cast in situ concrete to form beams, columns, slabs and walls.

B. *Steel-Framed Building and Roof Trusses*

According to [14] Steel is a strong and stiff material that is suitable for the construction of frame building. It offers detailing flexibility to architects due to providing long-spanning structure. It is normally used for multi story frames, tall and slander buildings and also for roof construction. The advantages of using steel frame system are high constructability and simplicity of construction as well as greater construction speed.

C. *Prefabricated Timber Framing System*

The prefabricated timber framing system is normally used in the conventional roof truss and timber frames. The timber is prefabricated by joining the members of the truss and using steel plate.

D. *Block Work System*

As [14] pointed out in his paper, this system depends on modular dimension at the design stage, which is identical to Lego blocks to some extent. Furthermore, it applies to load bearing walls by incorporating the columns and the beams as integral part of the walls for all house types. The elements of block work system include interlocking concrete masonry units and lightweight concrete blocks. They are fabricated and cured in the factory.

Precast Concrete Systems here is defined as any precast components that are used in construction industry.
They are categorized as:

1) Precast concrete framing, panel and box systems
2) Precast concrete wall system
3) Building with precast concrete slab

To limit the scope, this paper studies the impacts of precast concrete walls vis- à-vis conventional masonry walls in terms of resource consumption and environmental impact.
One of the areas that IBS has shown a great merit is the construction of prefabricated wall panels or sandwich panels. Precast, insulated composite wall panels, commonly known as concrete sandwich panels, are typically used for the construction of building envelopes [15].

Such panels consist of two outer layers of concrete separated by a layer of insulation such as polyvinylchloride, polyurethane, polyethylene or polystyrene foams, balsa wood and syntactic foams. [16].

III. RESEARCH METHODOLOGY

The case study (Fig. 1) is a double storey bungalow located in Kuala Lumpur. It was modeled in Revit Architecture and exported to Autodesk Ecotect Analysis, which both of them are the epitome of BIM tools, for energy analysis. A conventional 27cm brick wall with a layer of cement mortar and granite stone on the exterior surface and a layer of plaster on the interior side of the wall was used as a benchmark. Three types of sandwich panels with two different sizing were selected for the comparison purpose. Then, Monthly space loads and resource consumption in terms of CO2 production were calculated for each alternative.

TABLE I shows the list of components used and their specifications. It is hypothesized that material used in the external shell has a direct impact on monthly load and carbon emission in the building. It should be noted that these are heating and cooling loads, not energy loads. Obviously for the same space load requirement, we could install a very efficient system or totally inefficient one. The inefficient system, whilst servicing the same space loads, would require a far greater amount of energy than the efficient one.

Other simulation considerations are as follow:

1) The number of occupants was assumed to be four people.
2) The active system for maintaining internal comfort was customized to cover only cooling loads.
3) The thermostat range was set between 18-26 c^0 .

Ecotect provides a range of thermal performance analysis options. At its core is the chartered institute of building services engineers (CIBSE) Admittance Method used to determine internal temperatures and heat loads. This thermal algorithm is very flexible and has no restrictions on building geometry or the number of thermal zones that can be simultaneously analyzed. [19]

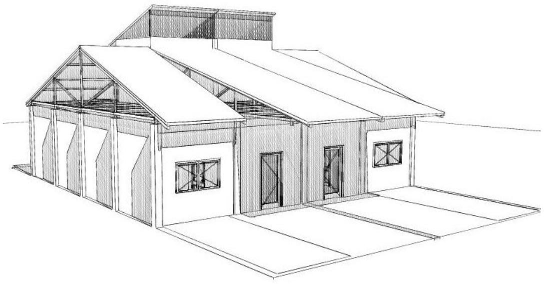

Fig. 1. The double story bungalow

TABLE I: WALL LAYERS SPECIFICATIONS

Type	Layer Name	Width (mm)	Density (Kg/m^3)	Specific Heat (J/kgK)	Thermal Conductivity (W/m.K)
A-1	Paint	3	1250	1088	0.431
	Concrete	75	950	656.9	0.209
	Rock Wool	30	200	710	0.034
	Concrete lightweight	75	950	656.9	0.209
	Paint	3	1250	1088	0.431
A-2	Paint	3	1250	1088	0.431
	Concrete lightweight	100	950	656.9	0.209
	Rock wool	30	200	710	0.034
	Concrete lightweight	100	950	656.9	0.209
	Paint	3	1250	1088	0.431
B-1	Paint	3	1250	1088	0.431
	Concrete lightweight	75	950	656.9	0.209
	Air gap	30	1.3	1004	5.56
	Concrete lightweight	75	950	656.9	0.209
	Paint	3	1250	1088	0.431
B-2	Paint	3	1250	1088	0.431
	Concrete lightweight	100	950	656.9	0.209
	Air gap	30	1.3	1004	5.56
	Concrete lightweight	100	950	656.9	0.209
	Paint	3	1250	1088	0.431
C-1	Paint	3	1250	1088	0.431
	Concrete lightweight	75	950	656.9	0.209
	Polystyrene foam	50	100	1130	0.035
	Concrete lightweight	75	950	656.9	0.209
	Paint	3	1250	1088	0.431
C-2	Paint	3	1250	1088	0.431
	Concrete lightweight	100	950	656.9	0.209
	Polystyrene foam	50	100	1130	0.035
	Concrete lightweight	100	950	656.9	0.209
	Paint	3	1250	1088	0.431
Base	Granite	20	2650	900	2.9
	Cement mortar	10	1650	920	0.72
	Brick masonry	220	2000	836.8	0.711
	Plaster	20	1250	1088	0.431

TABLE II: WALL THERMAL PROPERTIES

Wall Type	U value (W/m^2.K)	Admittance (W/m^2.K)	Thermal Decrement (0-1)	Thickness (mm)	Weight (kg/m^3)
Base	1.8	4.36	0.31	270	534.5
A-1	0.56	2.52	0.607	186	156
A-2	0.49	2.65	0.408	236	203.5
B-1	0.902	2.69	0.11	186	150
B-2	0.75	2.81	0.08	236	197.5
C-1	0.43	2.59	0.64	206	155
C-2	0.39	2.7	0.44	256	202.5

IV. ANALYSIS AND DISCUSSION

Cooling load is the rate at which energy is removed at the cooling coil that serves one or more conditioned spaces in any central air conditioning system [18]. The total building cooling load consists of sensible and latent loads; the former includes the heat transferred through the building envelope such as walls, roof, floor, windows, doors etc and the latter encompasses the heat generated by occupants, equipment, and lights [18]. The sensible load affects the dry bulb temperature, while the latent load affects the moisture content of the conditioned space [19].

Malaysia is a tropical country, hence, ambient temperature doesn’t fluctuate wildly, but since the building is more exposed to solar radiation, sensible loads play a major role in heating the internal zones. As a result, to minimize the flow of heat into an air conditioned building, proper measures such as enough insulation for the walls should be provided. Higher thermal conductivity of an insulation material means lower thermal resistance; therefore in order to get an optimum thermal insulation, thicker thickness is required to be used [20].

As thick insulation reduces the space of building significantly, thickness of insulating material is an important criterion in designing building envelope and the calculations should be based on cooling load for energy savings. Thermal transmission in a certain material depends upon the thermal property, in this case the thermal conductivity, and the thickness of that material. The lower the thermal conductivity value, the lower the thermal transmission. Similarly, thicker insulation material results to the lesser thermal transmission [18]. TABLE I shows the layers of the wall types used in this study with their thermal properties. Three types of insulation are used in this case study; 30 mm of rock wool for the types A-1 and A-2, 30 mm of air gap for the types B-1 and B-2 and 50 mm of polystyrene foam is used in types C-1 and C-2.

Although the thermal conductivity of rock wool with the value of 0.034 W/mK is the lowest compared to the other two types, the polystyrene foam is 20mm thicke than the rock wool. Consequently, type C-2 would be the most optimum choice.

It should be noted that Factors such as mass density and specific heat of the materials have influence on another property known as thermal decrement [21].The time it takes for heat wave to propagate surface to the inner surface named as ‘time lag’ or ‘phase lag’ and the decreasing ratio of its amplitude during this process is named as ‘decrement factor’ or ‘attenuation factor [22]. More thermal decrement factor would lead to more stabilized internal temperature. As a result, in hot and humid climate, thermal decrement should be higher. Due to the existing variety in thickness, density and specific heat of the wall layers, the impact of thermal decrement on cooling load, in our model, does not follow a regular pattern. Hence, studying the impact of thermal decrement requires further research which is beyond the scope of this paper.

Walls are affected by three heat transfer mechanisms; conduction, convection and radiation. The incoming of solar radiation into the outer wall surface will be converted to heat by absorption and transmitted into the building by conduction. At the same time, convective thermal transmission occurs from air outside of the building to the outer surface of the wall and the inner surface of the wall to the air inside of the building. Since the inside temperature in Malaysia is lower than outside temperature, conduction makes the most portions of heat gains from outside of the wall [23]. This thermal transmission process through the wall can be calculated by the following equation [20].

$$q = U(T_i - T_o) \qquad (1)$$

where q is the heat loss in walls, U is the overall heat transfer coefficient which determines heat loss through the building envelope [24].

T_i is inner temperature, and T_o is the mean outer temperature. q Can be determined using the wall conductance U and can be written as follow:

$$U = [R_i + R_w + R_{in} + R_o]^{-1} \tag{2}$$

where R_i and R_o, are inner and outer surfaces' thermal resistance values. R_w is the total thermal resistance of the wall materials without the insulation; R_{in} is the thermal resistance of the insulation material. So, the thermal resistance of the insulation material may be given as

$$R_{in} = \frac{x}{k} \tag{3}$$

where x and k are the thickness and thermal conductivity of the insulation material, respectively [20].

When all U values obtained through modeling and compared together (TABLE II), it is found that among all the wall types for the tropical climate of our case, wall type C-2 with the least U value in the group is the most suitable in terms of minimum heat transfer rate. This is due to the lower thermal conductivity values and the higher thickness of its layers in comparison with other types. Wall type C-2 is formed of 2 layers of 10mm lightweight concrete and a layer of 50mm polystyrene foam as an insulator in between. Hence, its thermal conductivity is lower as compared to the other wall types.

TABLE III: MONTHLY COOLING LOADS (wh)

Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Base	2230564	2120762	2553706	2514920	2665484	2769663	2518185	2366516	2341586	2068768	2014167	1932990
A-1	2188370	2088340	2505502	2470625	2628178	2722658	2474876	2321476	2304449	2031807	1985776	1905212
A-2	2058471	1966918	2371687	2337406	2493541	2577573	2334537	2190540	2177374	1910532	1869776	1790665
B-1	2075509	1980939	2372788	2342372	2493077	2571689	2338426	2199735	2186168	1927804	1882183	1814253
B-2	2073022	1977863	2369572	2338854	2490176	2566857	2334271	2196722	2182682	1924114	1880669	1811996
C-1	2077350	1983529	2392120	2357687	2515122	2600810	2356260	2209774	2196322	1926991	1885905	1805004
C-2	2046185	1954382	2357052	2322784	2478429	2558951	2318320	2175805	2163423	1898752	1858802	1780745

TABLE IV: MONTHLY CARBON PRODUCTION (kg)

Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Base	71253	71253	81575	80337	85146	88474	80441	75596.	747800	66085	64341	61747
A-1	69905	66710	80036	78921	83954	86972	79057	74157	73613	64904	63433	60860
A-2	65756	62831	75761	74666	79654	82338	74574	69974	69554	61030	59728	57201
B-1	66300	63279	75796	74825	79639	82150	74699	70268	69835	61582	60124	57954
B-2	66220	63181	75693	74712	79546	81996	74566	70172	69723	61464	60076	57882
C-1	66359	63362	76414	75314	80343	83080	75268	70589	70159	61556	60243	57659
C-2	65363	62430	75294	74199	79179	81743	74056	69504	69108	60654	59378	56884

V. RESULTS

TABLEs III and IV show the monthly and TABLE V shows the annual cooling loads and Carbon production required to maintain the comfort level of the house according to each wall type used. The annual carbon given is the equivalent amount of cooling load in terms of Co2 (kg) production. Fig. 2 and Fig. 3. Show that the selected prefabricated walls, in terms of reducing the cooling loads, perform better than the conventional wall. Among the six types of tested walls, Type C-2 with 25913630 wh cooling load and reduction of 7.7% in comparison with the base model, is the most optimum and type A-1 with the cooling load of 27627269 wh and 1.6% decrease, is the least optimum choice compared to others. After that, A2, B2, B1 with 7.1%, 6.9% and 6.8% respectively stand in the second to the fourth place. The same trend applies to the amount of carbon production.

TABLE V: ANNUAL COOLING LOADS AND CARBON PRODUCTION

Types	Annual Cooling Load (Wh)	Annual Carbon (kg)
Base	28097312	897540.645
A-1	27627269	882524.184
A-2	26079020	833066.825
B-1	26184943	836450.655
B-2	26146798	835232.159
C-1	26306874	840345.514
C-2	25913630	827783.825

According to TABLE II, the base wall has the highest U-value which contributes to its significant impact on raising the cooling load and consequently, more carbon emission. Masonry wall is lacking the insulation layer. The lack of insulation allows the outside heat to flow more into the interior environment. Although by increasing the thickness of the wall, the increase in the cooling load can be compensated, but it will have a bad effect on the weight of the structure. Hence, using lighter IBS wall panel is more favorable.

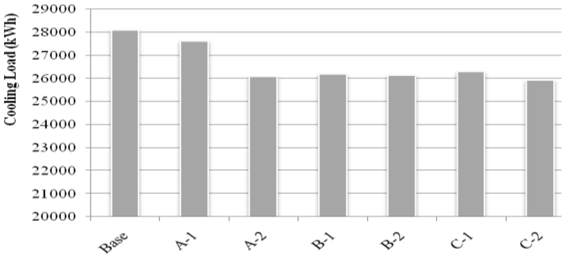

Fig. 2. Annual cooling loads

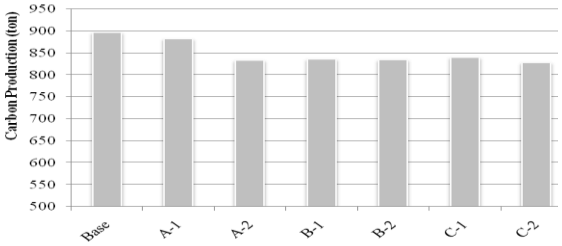

Fig. 3. Annual carbon production

VI. CONCLUSION

Designing a building entails considering a plethora of factors. In this competitive market, being able to make quick decisions and choosing the best option is considered as an advantage. With respect to project appraisal and the impact of sustainable criteria such as occupant comfort, heating and cooling loads of the building and carbon emission on the design, BIM can aid the design team to collect the vital information from the model to analyze and select the most beneficial alternative in the early stages of the design.

TABLE VI: U VALUES AND COOLING LOADS DIFFERENCES BETWEEN BASE WALL MODEL AND IBS WALL PANELS

Types	Difference in U-value estimations Compared to Base Model (W/m2K)	Difference in Cooling Load estimations Compared to Base Model (Wh)
A-1	-1.24	-470043
A-2	-1.31	-2018292
B-1	-0.898	-1912369
B-2	-1.05	-1950514
C-1	-1.37	-1790438
C-2	-1.41	-2183682

Regardless of slight reduction in cooling loads by applying prefabricated panels to the exterior envelope of the building vis- à-vis conventional masonry walls (fig. 2, fig. 3, TABLE VI), it is observed that the IBS practice has no notable impact on saving energy and reducing CO_2 footprint. In general, this conclusion is drawn that IBS technology doesn't play a conspicuous role in energy efficiency. However, its contribution to promote sustainability may fall in other categories.

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Seyed Saeed Banihashemi was born in Ardabil, Iran in 1985. He received his degree in architecture from Iran in 2008 and started his master degree in construction management at University Teknologi Malaysia in 2010. From 2008 to 2010, he worked as a design studio member and field engineer in a construction firm. His practical experience is mostly in design and project management..

His research interests are mainly building information modeling, industrialized building system, energy analysis and also green building rating tools. Currently, as a part of his thesis research, he is trying to integrate industrialized building system with building information modeling by virtue of developing IFC algorithms for some prefabricated components.