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Embodied Energy in Building Construction

S. Balubaid[a*], R. M. Zin[b], M. Z. Abd Majid[b], J. S. Hassan[a], Samihah Mardzuki[a]

[a]*Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[b]*Construction Research Alliance, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*

*Corresponding author: b2003alubaid@yahoo.com

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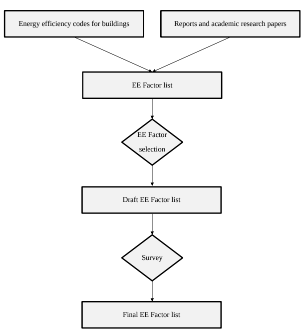
Graphical abstract



Abstract

Building construction systems that come in different forms and types need to be properly selected before being use, this may have different impact on overall embodied energy of the building construction. Hence, in order to achieve and maximize the construction contribution, the designer plays a big role in choosing the appropriate energy efficient construction. The designers need to be equipped with the right knowledge and tool which gathers a possible range of embodied energy indicators in order to select energy efficient construction. This paper aims at confirming the Malaysian common construction systems and compares it with the historical literature while it also explore energy efficiency in building construction. It is based on the common construction knowledge and also on the published literatures through a critical review of the possible range of embodied energy indicators and construction systems. The study demonstrated and confirmed that Malaysian common building construction systems can be categorized into six groups: Structural frame, Slab, Internal wall, External Wall, Roof and Staircase. This finding is highly significant for the future design in the area of energy efficiency.

Keywords: Building construction; embodied energy; energy efficiency; indicators

■1.0 INTRODUCTION

The past thirty years have seen a global call for designing buildings for better energy efficiency, more especially after the global energy crisis of the early 1970s. However designers such as architects and engineers are unable to grasp the concepts of energy efficiency collectively. This is partly due to the lack of knowledge of energy efficiency requirements which is prevalent among the designers, a huge amount of energy has been consumed because of imperfect solutions on construction systems, architectural planning and design [1].

Using alternative building construction systems, methods and techniques can reduce environmental effect and also reduce embodied energy as well as CO_2 emission [2-7]. Thus, in the early phases, one key to achieve improvement is to consider the relevant engineering interdependencies, by using the appropriate building modeling methods[8, 9], to help the less experienced designers and to support the design process and the involved design experts. The paper provides a thorough review of the relative contribution of common construction systems in line with embodied energy. This paper is part of an ongoing research work to develop a suitable tool for assessing embodied energy of construction systems.

■2.0 METHODOLOGY

A systematic literature review was conducted on studies on Energy Efficiency (EE) and common construction. In order to achieve the aim, the work is divided into two stages, the first stage is to confirm the common construction systems in Malaysia. This was achieved using interviews. The second stage is EE Factor identification as shown in Figure 1 is the ongoing research.

2.1 Interview

Interviews was conducted with Malaysian construction experts in order to identify the common construction systems in Malaysia. For these interviews, the researcher used two data collection methods. The first method which conducted using key informant interviews [10] in order to utilize rich information sources. Usually the population of this method is small. Thus there was an element of a judgment approach has been used in order to make sure that interviewees in this stage came from a range of construction engineer backgrounds and from all over Malaysia. Samples of 5 national engineering fields were chosen. The second stage involved semi-structured interviews (in-depth interviews with open-ended questions). The sampling strategy in this stage has been changed, in order to confirm the common construction systems. The framework of the common construction systems was constructed after 15 interviews.

The interviewees for this stage were chosen primarily and invited to participate by email attached with an official letter, then call the participant to arrange a convenient time for the meeting.

The interviews were shaped by the broad construction systems topics, and explore more of Malaysian construction systems during the interviews. The general questions regarding the company type, company role, respondent's education level and respondent's experiences in construction industry has been taken. It also included in the discussion them mean points such as the common Structural frame, common slab systems, common internal wall systems, common external wall, common roof systems and common staircase systems with regard to building construction in Malaysia. The interviews session ranged from 30 minutes to 40 minutes. All interviews were transcribe then coded using Nvivo10 software to identify Malaysian common construction systems.

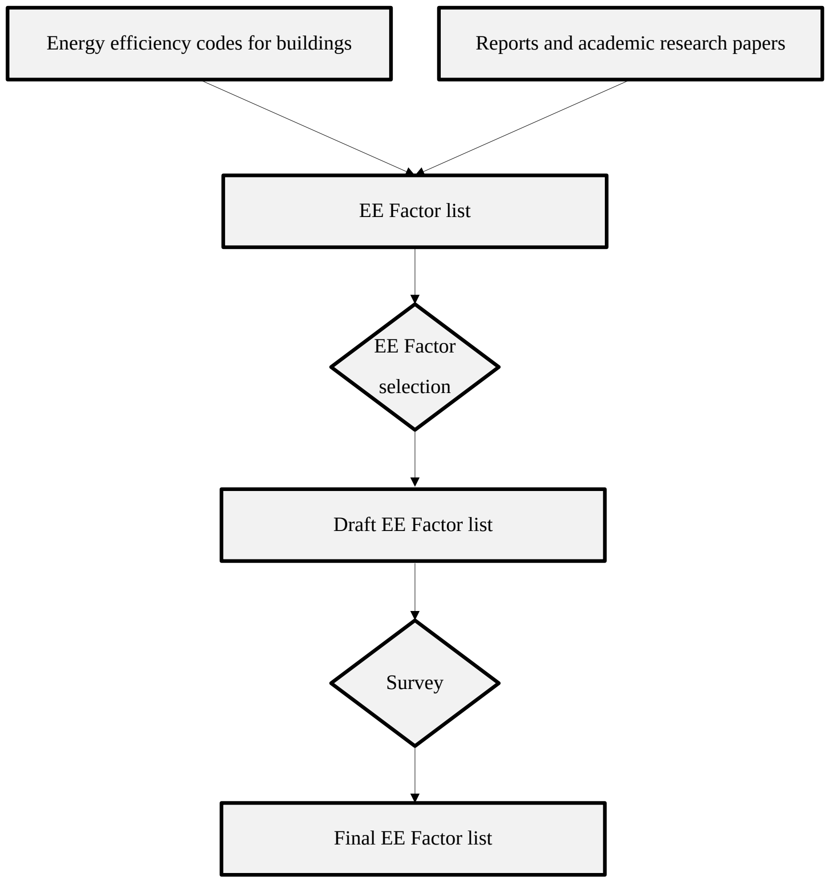


Figure 1 Method for factor identification

2.2 Sample Size for Qualitative Studies

Several debates are on sample size and their adequacy. There are many point of views and argument among the Scholars about the concept of saturation. In qualitative research saturation is the most important factor in the topic of sample size [11]. We can reach the saturation if the data collection processes no longer provide any new data.

While in qualitative research, many experts avoid the topic of ''how many interviews are adequate, there is indeed variability in what is suggested as a minimum. There are articles, book chapters, and books recommending values between 5 and 50 participants as adequate [12]. Undertaking market research emphasise that 20-30 in-depth interviews are required to reach saturation. Sandelowski [13] believe that a sample size of 10 could be judged as enough for certain kinds of homogeneous case sampling. He concluded that determining an adequate sample size in qualitative research is depending on the experience and judgment in evaluating the quality of the collected information.

2.3 Coding Strategy

To establish the common construction systems hierarchy, the researcher gathered various common construction systems abroad. Then coding strategy further grouped the common construction systems. The coding was conducted based on [14] common construction systems values: Structural frame, slab systems, internal wall systems, external wall, roof systems and staircase systems as outlined in the theoretical discussion above. During the coding process, several sub-values were identified and put into sub-value groups according to [14] theory.

■3.0 COMMON CONSTRUCTION SYSTEMS FOR BUILDING STRUCTURE

The common building construction systems mean existing building construction in large numbers. Construction systems can be grouped based on the interest of construction users [15]. common building construction systems in a country may not be the same with another country. For instance the common construction systems in Singapore are as given in Table 1. Meanwhile the common construction systems in Hong Kong are shown in Table 2.

Each construction system has its own advantages. For example, Pre-fabrication can be considered as faster construction, improved quality and reduced waste [17]. On the other hand, every system has different levels of effect on the embodied energy. Cabeza, Barreneche [18] concluded that energy efficient building has correlation with carbon dioxide emission (CO_2) either directly or indirectly through materials and processes. Thus designer should choose appropriate construction system and its process in order to be more environmental friendly and achieve energy efficient building.

Table 1 Common construction systems in Singapore [source: BDAS 201316]

Main System	Sub-System
Structural System	Precast Concrete System • Full precast • Precast column/wall with flat plate and perimeter beams • Precast beam and precast slab • Precast beam and precast column/wall • Precast column/wall and precast slab • Precast slab only • Precast column/wall only Structural Steel System • Steel beam and steel column (without concrete encasement) • Steel beam and steel column (with concrete encasement) Cast In-situ System • Flat plate with perimeter beams • One-directional beam • Two-directional beam Roof System (non-RC) • Integrated metal roof on steel truss • Metal roof on steel truss or timber truss • Tiled roof on steel beam or precast concrete beam or timber beam • Metal roof on cast in-situ beam • Tiled roof with cast in-situ beam
Wall system	Curtain wall / full height glass partition / dry partition wall/ prefabricated railing • Curtain wall / Full height glass partition • Prefabricated railing • Dry partition wall • Dry Partition wall with tile / stone finishes Precast Concrete Wall • Precast concrete wall with skim coat • Precast concrete wall with plastering, tile / stone finishes Lightweight Concrete • Lightweight concrete panel with skim coat • Lightweight concrete panel with plastering Cast In-situ RC Wall • Cast in-situ RC wall with skim coat • Cast in-situ RC wall with plastering, tile / stone finishes Precision Block wall • Precision block wall with skim coat • Precision block wall with plastering, tile / stone finishes Brickwall / blockwall with or without plastering

Table 2 Common construction systems in Hong Kong [source: 21]

Main system	Sub-system
Structural frame	• In-situ RC frame • In-situ load bearing cross-wall • Precast RC frame • Structural steel with fireproofing • Steel encased in concrete
Slab	• Flat slab • Insitu RC slab • Precast slab with in-situ topping • Prestressed concrete slab • Steel deck with in-situ concrete topping
Building envelope	• Concrete block/brick with applied finishes • Curtain wall • In-situ concrete wall • Precast concrete walls with pre-installed windows and finishes • Pre-finished concrete formwork with in-situ filling
Roof	• In-situ concrete roof • Precast concrete roof • Steel decking with in-situ concrete topping • Steel roof truss with composite decking
Internal wall	• Dry wall • Concrete block/brick • In-situ RC wall

4.0 EMBODIED ENERGY

The building sector consumes around 40% of energy a year in building's life cycle [19]. according to [20] Energy in buildings is generally classified into two broad types:

- Maintenance energy, and
- embodied energy : Energy goes into production of a materials

The first type is that use for servicing and maintenance the building during building life cycle. While a variety of definitions of the term embodied energy have been suggested, this paper will use the definitions that was provided by [22, 23] who defined Embodied energy as all of the necessary energy inputs required to produce and construct a building. Building embodied energy is depend on the decision of building construction system and construction techniques.

To date various methods have been developed and introduced to measure embodied energy of building such as input-output analysis, top-down method and Hybrid approaches which combine both input-output analysis and process analysis[23-27]. However, there is no attempt to differentiate between different types of building construction systems.

5.0 EMBODIED ENERGY EFFICIENCY IN BUILDING CONSTRUCTION SYSTEM

To select energy efficient building construction system is not an easy choice, since the selection is not based on a one criterion. Designer has to consider various project related factors [28] that may have significant impact on energy. In a study Majzub [29] considered the weight of components as one of these factors that can play big roles in building classification. The researcher believed that the weight factor has significant influence on components such as transportability, production method and their erection method on site thus will influence energy efficiency. Cabeza, Barreneche [18] concluded that in various methodologies, Carbon emission CO_2 should be considered as one of the major factors to assess energy efficient buildings. Other studies have shown that less energy consumption in building can be achieved through advanced technologies and energy efficient materials in the building design are considered. On the other hand, this will usually lead to an increase in cost. Each of which should be optimized to reach the best solution among the prescribed solutions by a set of constraints and parameters that should be considered [30]. Building's life cycle stages consist of the following stages [19]:

- Building construction material production phase
- Transportation phase
- Construction phase
- Maintenance phase
- Demolition phase

Identification of the EE factors of each stage play an important role to develop an assessment for building energy efficiency Yang, Li [31]. In order to establish and identify the factors of the embodied energy for buildings, we have to review the existing methods, academic research papers and energy codes. Then the expert's opinion on embodied energy will be sought [32]. Figure 1 demonstrates the common method to identify comprehensive set of EE indicators.

5.1 Energy Building Material in Production Stage

In recent years, there has been an increasing amount of literature on energy building material in production stage as shown in Table 3. One question that needs to be asked, however, is whether we can reduce embodied energy drastically in production stage if technique or plan such as theuse of recycled material is practised.

Chen [33] points out that the recycled steel (10 MJ/kg) could save more than 70% of the energy in production stage when compared to the virgin steel (32 MJ/kg). The study also concludes that the recycled aluminum (8 MJ/kg) could save more than 96% of production energy as compared to the virgin aluminum (191 MJ/kg).

Table 3 Energy Building Material Transportation stage (*Source:* Venkatarama, 2001 [20])

Type of material	Thermal energy (MJ/kg)
Cement	5.85
Lime	5.63
LP	2.33
Steel	42.0
Aluminum	236.8

5.2 Energy Building Material Transportation Stage

Varieties of materials are used for the building construction. These materials consume energy and need resources such as equipments to carry it from cradle to gate [25, 34]. These kinds of energy have to be consider for the analysis [20]. This view is supported by Kim [35] who found out that energy in transportation stage in building construction was nearly 8 percent of its total embodied energy.

Building material transportation energy depends on transport method, material weight and the distance travelled. From these factors, reasonable accurate transportation embodied energy can be calculated [36]. The transportation distance has to be considered. It is depend on the construction activity location. According to Venkatarama (2003) who highlights that for every 1 km of transportation distance, crushed stone aggregate and sand consumed is about 1.75 MJ/m^3. He also assummed that steel and cement are usually transported using trucks diesel, and energy can spend during transportation with 1 MJ/tonne/km.

5.3 Energy Construction Stage

In the Construction Stage process, a direct energy consumed on-site and off-site operations such as transportation, prefabrication, construction, and administration [25, 37]**.** Pullen [38] concluded that around 28 percent of energy in construction stage can be attributed to equipment and 3 percent to labor.

■6.0 RESULT AND DISCUSSION

6.1 Common Building Construction Systems

Regarding **Structural frame** group, most of the participants in the interview exhibited some of the seven sub-groups described by [14], The sub- groups observed are shown in Table 4. The common **Structural frame** are; 'Cast in-situ concrete frame', 'In-situ concrete load bearing wall', 'Precast concrete frame' and 'Structural steel frame'. This seems to be four sub-groups as most of the interviewed. **Structural frame** sub-groups as described by [14] and exhibited by the interviewees were 'In-situ concrete load bearing wall', 'Pre-tensioning structure' and 'Steel encased in concrete (Composite structure)' (see Table).

Within the **Slab** group, five sub-group were identified during the research process were also described by [14]. For many engineering **Slab** group seem to be divided into four sub-groups. **Slab** sub-groups as described by [14] and exhibited by the interviewees was 'Pre-stressed concrete slab' (see Table 4). Also coded as sub-groups were quotes from engineers.

Compared with **Internal wall that have been** described by [14], most of the participants in the interview exhibited some of the eight sub-groups. The sub-groups described and observed are shown in Table 4. The common **Internal wall** are; 'Cast in-situ concrete wall', 'Light weight brick', 'Light weight panel', 'Precast concrete wall' and 'Traditional brick and plaster wall'. This seems to be five sub-groups as most of the interviewed. **Internal wall** sub-groups as described by [14] and exhibited by the interviewees were 'Clay bricks', 'Curtain wall' and 'Precision block wall' (see Table 4). Also coded as sub-groups were quotes from engineers.

It is somewhat surprising that **External Wall** was noted with only five sub-groups out of ten sub-groups in these interviews. For many engineering **External Wall** group seem to be divided into five sub-groups. **External Wall** sub-groups as described by [14] and exhibited by the interviewees was 'Curtain wall', 'Dry wall system', 'Fall height glass panel', 'Precast sandwich panel with in-situ filling' and 'Prefabricated timber panel' (see Table 4).

The results of these interviews show that **Roof system** can be divided into five sub-groups. The sub-groups described and observed are shown in Table 4. The common **Roof system** are; 'In-situ concrete roof', 'Prefabricated steel roof truss', 'Steel decking with in-situ Concrete topping', 'Steel truss roof with Composite decking' and 'Timber truss with roof tiles'.

There are similarities between the **Staircase systems** expressed by interviewees in this study and those described by [14]. The sub- groups described and observed are shown in Table 3. The common **Staircase systems** are; 'Cast-in- place', 'Prefabricated' and 'Steel'. Meanwhile most of the participants exhibited only one of the four sub-groups.

Table 4 common building construction systems

Group	Sub-group
Structural frame	Cast in-situ concrete frame
	In-situ concrete load bearing wall
	Precast concrete frame
	Structural steel frame
Slab	In-situ RC flat slab
	In-situ RC slab
	Precast slab with in-situ topping
	Steel deck with in-situ concrete topping
Internal wall	Cast in-situ concrete wall
	Light weight brick
	Light weight panel
	Precast concrete wall
	Traditional brick and plaster wall
External Wall	Block wall with applied finished
	Brick wall with applied finished
	In-situ concrete wall
	Metal cladding
	Precast concrete wall with Pre-installed windows and finishes
Roof	In-situ concrete roof
	Prefabricated steel roof truss
	Steel decking with in-situ Concrete topping
	Steel truss roof with Composite decking
	Timber truss with roof tiles
Staircase	Cast-in- place
	Prefabricated
	Steel

■7.0 CONCLUSION

The selection of building construction system has to be made carefully as each construction system has different impact on energy efficiency. Development of tools to select embodied energy construction systems is considered timely as it may help less experienced designer with limited energy efficiency knowledge to make decisions in the same way as experts. The review of previous researchers revealed that the common construction systems for buildings can be grouped into several main groupings such as Structural Frame Systems, Wall Systems and Slab Systems. The main criteria that need to be considered by the designer in order to evaluate embodied energy of these construction systems that has been indentified include among others recycling of materials, CO_2 emission, and transportation. Through the understanding of EE, common construction systems and Embodied Energy Construction System (EECS) indicators is expected to direct the research on creating a decision making model which can improve the current EECS adaptation in local building construction.

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