Investigating the performance guarantee system for building envelope glass and frames in Thailand

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Abstract. In Southeast Asia, reduction of energy usage is a necessity because of an increasing trend in building energy consumption. The building envelope performance strongly affects the building’s energy performance necessitating its consideration in energy usage studies. Many studies have been conducted that have encouraged the growing use of green materials in Southeast Asia. However, the studies that have focused on the building envelope are few. It is, therefore, unclear whether the adopted products would perform at the level for which is decided at designed. This study analyses how to rate material performance and the glass and frame production process along with the performance guarantee system used on building envelopes in Thailand located in Southeast Asia. Data were collected in a literature review and field survey. The field survey is an interview survey which was conducted with academicians who focus on the glass industry, architects and façade contractors, and a factory survey which was conducted in a glass factory and aluminium factory in Thailand. As a result, this study presented the material performance decision factor, the production process, and the product testing phase including checking of production performance and the practically referred standards.

1. Introduction

In Southeast Asia, a reduction in energy usage is necessary because building energy consumption is continuing to increase. In most countries, there is an increased interest in energy conservation, not only to take advantage of the environmental certification system and energy-saving-related criteria, but also to define the environmental performance value of the building envelope. It is necessary to consider building envelope performance because it strongly affects energy conservation of high-rise building.

Many studies are being conducted to popularize the use of environmentally-friendly materials in Southeast Asia. According to a previous study [1], efforts toward standardization for environmentally-friendly building-material popularization have begun, particularly in Vietnam, Thailand, and Indonesia, with the goal of energy conservation.

However, there are few studies that focus on whether the building envelope performance is secured or not in Southeast Asia. Therefore, it is unclear whether the adopted specification and products would sustain the required performance levels.

This study aims to clarify whether building envelope performance decisions are taking into consideration the environmental performance rated to the glass and frame production process and performance guarantee system used for the building envelope in tropical regions. Recently, many high-rise buildings have adopted glass as the envelope. Thailand is located in Southeast Asia and hence suitable for the case-study.
2. Method

The research data was collected in a field survey performed in March and September in 2018 to clarify the following:

1. The building envelope performance decision-making process
2. The process used to determine the performance of glass and frames used in the building envelope
3. The standards used in these processes based on a literature survey

Table 1 shows the details of the field survey. The field survey used an interview process to clarify the specification decision process and factory investigation to investigate the glass and frame production process and the performance guarantee system. In the interview survey, eight subjects were interviewed including architects and contractors to investigate about building envelope specification decision process and two subjects were interviewed including academicians who focus on the glass industry and factories in March and September 2018. In addition, a factory survey was conducted for six cases including a glass material factory, glass product company, aluminum factory and glass installer.

The standards which are referenced at specification decision stages and production manufacturing stages organized by using website information and reports from related organizations. This information was used to identify the environmental factors from the building standards systems. It was also used to compare the Japanese industrial standards (JIS), Thailand industrial standards (TIS), and the American Society for Testing and Materials (ASTM) standards for glass and frames used in the building envelope. Based on this, an overview and test preparation situation were prepared for each standard.

Table 1. Field survey overview.

| Main Business | Established year | Number of Staff | Research Objectives |
|---------------|------------------|-----------------|---------------------|
| Business      |                 |                 |                     |
| A             | Architect        | 1968            | 85                  |
| B             | -                | 1977            | 20                  |
| C             | -                | 1990            | 30                  |
| D             | Façade           | 1969            | 600                 |
| E             | Contractor       | Glass façade   | 2000                |
| F             | Contractor       | Aluminum façade| 2001                |
| G             | Contractor       | Japanese general contractor | 1964 | N/A |
| H             | Japanese general contractor | 1964 | 28 |
| I             | Manufacturer     | Glass Material  | 1990                |
| J             | Manufacturer     | Glass Material and Product | 1963 | 800 |
| K             | Manufacturer     | Glass Product   | 1998                |
| L             | Manufacturer     | Glass Product   | 1999                |
| M             | Manufacturer     | Aluminum frame  | 1992                |
| N             | Other            | Glass installer | 2005                |
| O             | Other            | Professor       | -                   |
| P             | Other            | Professor       | -                   |
3. Required performance of building envelope

3.1 Specification decisions

In this section, the process of building envelope specification determination and the preparation of specification documentation is investigated.

The survey results from the specifications of the building envelope were organized in Table 2. The targets of the analysis were four companies (C: Architect, E: Glass façade contractor, F: Aluminum façade contractor, H: Japanese general contractor) all of which ensured a sufficiently broad spread of results. The typical case considered in the interview was a high-rise building with glass building envelope. The contractual relationship between the project and the decision-maker for specification in terms of the building envelope was also investigated. As for the specification of the building envelope, it was classified into items related to environmental performance (glass type, frame type, performance value, envelope type) and items related to design (glass color, frame color). The employment contractual relationship was classified as CASE 1 to 3 in Fig.1.

The process of specification determination for the building envelope was then finalized. Regardless of the environmental performance and design properties, the interview survey found that the specification decisions were made either in, or close to, the design stage, and that the performance would be considered from design to construction stage, a considerable period of time.

Table 2 presents the findings regarding the specification decision makers. It is found that the owner, designer and consultant possessed great power, mainly in the determination of the specifications for the building envelope. The main contractor, project manager and construction manager were involved in the project, but they were not particularly involved in the specification of the façade. As can be seen in Fig.1, the contractual form of construction in Thailand is often administered by the CM method. The contractual relationship, the architect and consultant were directly linked to the owner in many cases.

| Interview Target | Project Detail | Contract on employment | Decision | Specification Determinant |
|------------------|----------------|------------------------|----------|---------------------------|
| C: Architect     | 30 F Complex   | CASE1                  | Glass Type | Owner: ○ |
|                  |                |                        | Frame Type | Architect: ○ |
|                  |                |                        | Performance | Consultant: ○ |
|                  |                |                        | Envelope Type | F Contractor: ○ |
|                  |                |                        | Glass Color | M Contractor: ○ |
|                  |                |                        | Frame Color | PM: ○ |
|                  |                |                        | ○         | CM: ○ |
| E: Glass Contractor | 79F Condominium | CASE2                  | Glass Type | Owner: ○ |
|                  |                |                        | Frame Type | Architect: ○ |
|                  |                |                        | Performance | Consultant: ○ |
|                  |                |                        | Envelope Type | F Contractor: ○ |
|                  |                |                        | Glass Color | M Contractor: ○ |
|                  |                |                        | Frame Color | PM: ○ |
|                  |                |                        | ○         | CM: ○ |
| F: Aluminum Contractor | 88F Hotel | CASE1                  | Glass Type | Owner: ○ |
|                  |                |                        | Frame Type | Architect: ○ |
|                  |                |                        | Performance | Consultant: ○ |
|                  |                |                        | Envelope Type | F Contractor: ○ |
|                  |                |                        | Glass Color | M Contractor: ○ |
|                  |                |                        | Frame Color | PM: ○ |
|                  |                |                        | ○         | CM: ○ |
| H: Japanese General Contractor | 33F Hotel | CASE3                  | Glass Type | Owner: ○ |
|                  |                |                        | Frame Type | Architect: ○ |
|                  |                |                        | Performance | Consultant: ○ |
|                  |                |                        | Envelope Type | F Contractor: ○ |
|                  |                |                        | Glass Color | M Contractor: ○ |
|                  |                |                        | Frame Color | PM: ○ |
|                  |                |                        | ○         | CM: ○ |

M contractor: main contractor
F contractor: Façade contractor
Fig 1. Employment contract type.

The building envelope specification document preparation are presented in Table 3. The subjects of analysis were seven companies (A, B, C: Architect, D: Façade contractor E: Glass façade contractor, F: Aluminum façade contractor, H: Japanese general contractor) providing sufficient results for the analysis. The interview cases all involved high-rise buildings using glass for the building envelope. The person responsible for creating the specification for the project was investigated.

As shown in Table 3, the person who created the specification document was the architect in most cases. Some cases, for example D, E and F, involved the owner or a consultant as the creator of the specification.

In other words, owner, designer and consultant were strongly involved in specification decisions and producing the specification document. The façade contractor, who was responsible for the construction of the building envelope, was not particularly involved in the specification decision-making stage. For this reason, it was the owner, the designer and the consultant who made decisions on the performance requirements for the building envelope. It was thus, important to encourage these stakeholders, such as the owner, the designer and the consultant, to improve the building envelope’s environmental performance in order to promote the sustainable building.

Table 3. Author of specification document.

| Interview Target | Project Detail | Façade Specification Document |
|------------------|----------------|-------------------------------|
|                  | Owner | Architect | Consultant | F Contractor | M Contractor | PM | CM |
| A                | 22 F Office | ○ | ○ | ○ | ○ | ○ | ○ |
| B                | 6 F Office | ○ | ○ | ○ | ○ | ○ | ○ |
| C                | 30 F Office | ○ | ○ | ○ | ○ | ○ | ○ |
| D                | 30 F Complex | ○ | ○ | ○ | ○ | ○ | ○ |
| E                | 73F Condominium | ○ | ○ | ○ | ○ | ○ | ○ |
| F                | 88F Hotel | ○ | ○ | ○ | ○ | ○ | ○ |
| H                | 33F Hotel | ○ | ○ | ○ | ○ | ○ | ○ |

M contractor: main contractor  
F contractor: Façade contractor
In addition, the performance decision item, as shown in Table 2, is typically finalized by the architect or consultant because they are knowledgeable about the building envelope and the associated standards. The performance is an item that is continually considered and reviewed up to the stages just before construction. In case the performance is to be worse. As one of reasons, the product cost was raised. Therefore, products with different performance characteristics were specified at the design stage to the products used in the construction stage. Even if the product performance was sufficiently high, it is possible that there is a difference between the required performance and the actual performance, and it may be the case that the actual performance is lower than the required performance. Therefore, it is necessary to investigate quality assurance at the construction stage also.

3.2 Required performance value

This section is focused on the specification performance decision as mentioned in the previous section. It is focused on reviewing the standards to identify what performance value will be decided, and to extract items related to performance among the standards referenced in many instances.

Table 4 refers to several standards for determining the performance characteristics of the building envelope. The subjects of the analysis were six companies (A B C: Architect, D: Facade contractor, E: Glass facade contractor, F: Aluminum facade contractor) to ensure a sufficiently broad spread of results. The interview was aimed at cases involving high-rise buildings using glass as the building envelope. The standards referred to at the performance decision stage were noted. Building Type was classified into Green Building (GB), building incorporating LEED or TREES, or Not Green Building (N GB), building incorporating neither LEED nor TREES, depending on whether the environmental certification system was acquired or not.

Essentially, it could be said that ASTM was used along with Thailand law, UK, Australian, and Japanese regulations. In case where the owner wanted to get the green certification, it was necessary to refer to green certification, such as LEED or TREES. As for the reasons for referring to the ASTM, it became apparent from the interview survey that, when the construction of high-rise buildings adopting curtain-walls was required in Thailand, the architects employed were mostly Americans; hence the American standards have been referred in many cases.

| Building Type | Reference Standard |
|---------------|-------------------|
| A GB          | BS, American standards |
| B GB          | American standards, OTTV, CSI |
| C GB          | LEED, ASTM, Thailand Standards |
| N GB          | ASTM |
| D GB          | LEED, BS, Australian Standards, AAMA |
| E GB          | BS, ASTM, Australian Standards, JIS |
| N GB          | BS, ASTM, Australian Standards, JIS |
| F GB          | ASTM, (BS, JIS) |
| N GB          | ASTM, (BS, AS/NZ) |

GB: Green Building (Building incorporating LEED or TREES)  
N GB: Not Green Building (Building incorporating neither LEED nor TREES)
The status of the JIS [2], ASTM [3] and TIS [4] standards regarding building envelope performance is compared in Table 5. The standards which focus on glass and building envelope are prepared in both ASTM and JIS, but it is no standard in TIS. It can be said that it is possible that the performance regulation in Thailand is decided not industrial standard but law or another publication in Thailand. Although the number of standards incorporated into the ASTM is large compared to the TIS and JIS, many are optional standards making it necessary for the operator to select and use them appropriately.

Table 5. Comparison between the JIS [2], ASTM [3] and TIS [4] regarding building envelope.

| Target production                              | JIS | ASTM | TIS |
|------------------------------------------------|-----|------|-----|
| Solar heat Coefficient / Shading Coefficient   | ○   | ○    | ×   |
| Thermal Transmittance                         | ○   | ○    | ×   |
| Visual light transmittance                    | ○   | ○    | ×   |
| Reflectivity                                  | ○   | ○    | ×   |
| Air leakage efficiency                        | ○   | ○    | ×   |
| Water tightness                               | ○   | ○    | ×   |
| Wind pressure resistance                      | ○   | ○    | ×   |
| Thermal insulating properties                 | ○   | ○    | ×   |

4. Glass and frame production process

4.1 Overview of glass industry

This section presents an overview of the Thailand glass industry. The glass production process is carried out by, three domestic glass manufacturing companies, between 30 and 40 domestic glass processing companies and two domestic companies that consistently carry out processing from material glass to product glass. It is understood that there are many companies that purchase material glass and only process glass. Therefore, it can be said that manufacturing sector is more subdivided into various manufacturing processes. Because of this, it was necessary to ascertain whether each factory used the correct manufacturing and testing method.

4.2 Glass and frame production process

In this section the manufacture of building envelope glass and frame in Thailand is organized into a flow-chart.

The survey results regarding the main manufacturing methods were organized and presented in Table 6 and the manufacturing process for building envelope glass and frame is shown in Fig. 2. The subjects of the analysis were six companies (I: glass manufacturing company, J: glass manufacturing and processing company, K, L: glass processing company, M: aluminium processing company, N: assemble glass and frame company). The product manufacturing process and test stage which each company conducted were investigated and recorded.

It can be said that products from all companies were manufactured as custom made items. However, the product glass of J specialized in glass manufacturing and processing, were standardized products. N processed frames and assembled glass and frames. N and J manufactured a smaller variety of materials than K and L, which processed glass, and M which processed frames. For example, at the glass processing stage, since K and L were made-to-order, the size of glass could be custom-selected each time in comparison with mass-producers such as J. Compared M with N, it could be said that many types of frames could be manufactured because N finish like coloring by three different methods.
It can be seen from Fig. 2 that there were few differences in the processing methods used for glass and frame. When comparing each company in terms of a particular process, such as the glass processing stage or frame processing stage, the manufacturing itself was performed in the same way, but there were differences during the manufacturing process. Regarding the testing times of the test, the material was first confirmed before manufacturing. Some company, such as I and M, performed tests at the midway point and the completed products were also checked after manufacturing in most factories.

Table 6. Main manufacturing method in each factory.

| Main manufacturing method | Custom made | Mass production |
|---------------------------|-------------|-----------------|
| I                         | ✓           | ✓ (Material glass) |
| J                         | ✓           | ✓ (Product glass) |
| K                         | ✓           | ✓               |
| L                         | ✓           | ✓               |
| M                         | ✓           | ✓               |
| N                         | ✓           | ✓               |

Fig. 2 Manufacturing and Processing in each factory.
4.3 Test situation

In this section, the building envelope glass and frame product testing used in the manufacturing factories described in the previous section is summarized in detail.

Details of the type of testing performed in a selection of manufacturing factories are described in Table.7. As in the previous section, the target of the analysis was 6 companies to ensure a sufficiently broad spread of results.

From Table.7, it can be seen that product inspections were often performed before and after processing. Inspection activities that were done before processing included confirmation by visual inspection, confirmation of numerical values such as material weight and dimensions, and confirmation of the test report from the factory which manufactured the material.

Visual observation of the testing process was also conducted at I and M companies. Especially, when processing at increased temperatures, these companies also inspected whether the temperature was kept constant or not.

After processing, all factories performed tests following certain test standards. Tests were carried out using each company's own test equipment. In this section, test standards adopted by each company are organized and presented. Each company references not only TIS but also overseas standards which were generally stricter than TIS. J and K has own company standards which were also stricter than the TIS, having been generated by referring to the standards used in other countries such as the International Organization for Standardization (ISO) and JIS.

| Table 7. Test contents detail at each stage. |
|---------------------------------------------|
| **Pre-Processing** | **Processing** | **Post-Processing / Pre-Shipping** | **Test standards** |
| I | Value Check -sample | Value check -sample | Visual (by Laser Camera) | TIS, ISO, JIS, Australian standards |
| J | Check × | Test (following Standards) | TIS, Company Standards |
| K | Check × | Visual, Test (following Standards) | TIS, Company Standards |
| L | Visual, Value Check × | Test (following Standards) | TIS, ISO, Other Company Standards |
| M | × | <Before assembly> Profile projector, Tensile test, Hardness Test etc. | TIS, ASTM, ISO, JIS |
| N | Material test report Check × | Wind load test, Façade test, airtightness, water tightness etc. | TIS, ASTM, AAMA (America Architectural Manufactures Association), EN (European Standard), BS (British Standard) ISO/IEC, ILAC (International Laboratory Accreditation Cooperation), MRA (Mutual Recognition Arrangement) |

The status of JIS [2] and TIS [4] standards development is organized and presented in Table.8. From Table.8, it can be seen that the TIS did not cover the standards sufficiently, making it necessary to refer to the ASTM and JIS.


Table 8. Comparison of the contents of test standards between the JIS [2] and TIS [4].

| Target production | Test contents                                      | JIS  | TIS  |
|-------------------|----------------------------------------------------|------|------|
| Clear glass       | Transmittance, Reflectivity, Emissivity, Solar heat gain coefficient | ●    | ●    |
| Laminated glass   | Thickness/Length measurement, Heat-resistant/Humidity resistance etc | ●    | ○    |
| Heat absorbing glass | 5mm Solar heat gain coefficient, Quality        | ●    | ○    |
| Insulated glass   | Thickness test, Acceleration of the dew point/durability test etc | ●    | ○    |
| Heat reflecting glass | Size measurement, Solar heat gain coefficient/Light Resistance test etc | ●    | ○    |
| Low Thermal emissivity glass | Size measurement, Transmittance, Emissivity etc   | ×    | ○    |
| Frame             | Wind pressure resistance/air permeability/ Water tightness / Adiabaticity test, etc | ○    | ×    |
| Float and Polished plate glass | Thickness/Length measurement | ●    | ○    |
| Plate type glass  | Thickness/Length/Width measurement                | ●    | ×    |
| Wired glass       | Thickness measurement, Fire retardant property test etc | ●    | ×    |
| Tempered glass    | Thickness test, Falling ball/Crushing test etc    | ●    | ○    |
| Double strength glass | Size/Crook/Surface compression measurement         | ●    | ×    |
| Building glass    | Security performance test by falling ball test    | ○    | ×    |
| Aluminium         | Tension/Bending/Conductance/Stress corrosion cracking etc test | ●    | ○    |

Legend ●: mandatory standard ○: optional standard ×: no standard

5. Conclusion

In this study, the specification decision process regarding building envelope and the glass and frame production process used to building envelope materials were investigated.

Regarding the process of specification determination, it became clear that most specifications were produced mainly by the owner, designer and/or consultant during the design stage. However, the performance until construction was considered, and not only Thailand standards were referred, but standards of other countries were also referred, such as the ASTM. Therefore, in order to make decisions on the building envelope specification considering environmental performance, it was necessary to confirm decisions from the design stage to the construction stage, and to develop system which could deepen the understanding of environmentally-friendly building processes for owners, designers and consultants.

In addition, regarding the manufacture of glass and frames, each company had a similar manufacturing process. Since the Thailand standards were not sufficient for the product testing, in terms of specification decisions, reference was made to other countries' standards. The testing stage and the number of performed tests were different, so it was necessary to formulate guidelines for product testing and quality assurance.

In Thailand, although the building envelope’s specification has typically been finalized based on the building standards at the specification determination stage, it is uncertain whether the products used during the construction stage are the same as those determined at the design stage. At the manufacturing stage, although tests were conducted, there was a possibility that the quality would not be constant because the applicable product testing standards which were referred to at the product testing stage was dependent on the individual factory.

Therefore, in order to guarantee building envelope performance, it is desirable to improve and increase legal standards in Thailand. In addition, product testing standards should also be made legally binding.

In this study, it was not possible to investigate product usage in the construction stage. It will be necessary to investigate this aspect in the future.
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