

Louvered door research and development for user needs and energy efficiency in Thailand's context

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ABSTRACT:

This research and development project aims to investigate and propose practical louvered door solutions in terms of energy saving, human dimension (physical, psychology, social and cultural human factors), as well as feasibility regarding production and engineering. One project achievement comes from an interdisciplinary collaboration among specialists in indoor air quality and energy management, user-centred design, as well as product design and engineering. To achieve energy efficiency where practicality could be reached, the research results have led to design criteria in three aspects including architecture and indoor environment (energy efficiency, thermal comfort and indoor air quality), human dimension (convenience in operation and maintenance, styling preferences, privacy and security), as well as production and engineering (feasibility in production and installation, durability and ease of repair). Four design directions were generated and produced. Prototypes for each design direction were tested for four main aspects including energy-efficiency performance in a laboratory via the blower door technique (area leakage, pressure and air flow volume), usability by scenario testing with follow-up interview, styling preferences through visual tool kit with follow-up interview, and production and engineering feasibility by expert testing and interview. In assessing all the aspects, and based on conclusions drawn from evaluation, the most promising design direction does not correspond with the highest energy-efficiency performance; rather, it is the direction that best compromises between energy efficiency and human dimension. Apparently, to achieve the design of energy-efficient architecture, solutions should not be concerned solely with technical and scientific aspects, but must accept a need to integrate additional human dimensions that influence energy efficiency for both practicality and acceptability purposes.

CONFERENCE THEME: On measurement

KEYWORDS: louvered door, human comfort, energy efficiency, human dimension, user needs

INTRODUCTION

Architectural Design and Construction in Thailand was, in ancient times, very different to current practices. The climate back then was not as extreme and it was still possible to bring temperature down to a human's comfort zone by improving the microclimate. The majority of houses/buildings were made of wood and assembly was non-airtight with many operable windows. There was a crawlspace of sufficient height that no one had to really crawl at all. It was in fact used, when there was no flood, as "office" space. A high-pitch gable roof was typically the style of choice, because it allowed for stack ventilation in the attic. The classic planning pattern consisted of many semi-outdoor spaces such as patios and balconies and people frequently spent time in these semi-outdoor areas. Given all this, it is sensible to say that the houses/buildings were designed to be truly climate-responsive. It was, by nature, that natural ventilation played an important role in providing both comfort and good indoor air quality (IAQ), with operable windows and doors acting as essential elements in an indoor environment. Subsequently, infiltration and ex-filtration had become preferable as supporting criteria, whereas wooden structures and wooden architectural elements which are not air-tight were significant factors.

Milder climate condition aside, in earlier times, another prominent factor was a safer neighbourhoods that allowed this change in ventilation to happen. Explosive population growth however ushered in land-use limitations, a decrease in society's security and privacy as well as increased atmospheric pollution. In answer to this, modern architectural design gradually eroded Thai architectural design. Houses have become more and more compact to accommodate the need for efficiency use of space. Entire buildings have gradually become more and more airtight to house the need for air-conditioning systems. However, in contradiction to this, IAQ has still remained an issue. This has led to a need for louvered doors, essentially to allow for a modest portion of natural ventilation, as a passive repair when occupants require the removing of odour and humidity. Given all these reasons, a development of louvered doors and sometimes, windows came in as a vital feature that naturally allows for needed ventilation for both comfort and IAQ, while retaining privacy and possibly security.

The world has indeed become warmer, and Thailand is no exception. Thailand is located near the equator, which is to say that the country already possesses a hot and humid climate. The destruction of rain forests and natural resources in the region, coupled with global warming, have elevated Thailand's climate out of the human comfort zone towards an incomparably hot climate. During the hot season, the temperature in Thailand can reach 38–40° Celsius. This climate shift has necessitated a change in architectural design. Furthermore, air-conditioning systems – mechanical ventilation – have become an unavoidable solution to the problem of Thai modern architecture, allowing temperature and high humidity levels to be brought down to meet human comfort needs. As a consequence, electricity consumption in Thailand has grown rapidly with electricity consumption levels tripling during the last two decades alone (EPP0 2009). In 2009, electricity usage in the residential sector was about 25 per cent of the country's total consumption (MEA 2010) with one fifth of residential electricity consumption utilised for air-conditioning (DEDE 2004). While there have been growing demands for efficient household energy consumption in Thailand, there has not been enough research and development concerning energy-efficient louvered doors.

Most louvered doors in Thailand have unadjustable slats which remain open to allow air to pass through constantly. Louvered doors, featuring angle-adjustable slats to accommodate energy-efficient needs in air-conditioned buildings, offer the option of being closed to reduce the cooling load of air-conditioning systems. However, existing adjustable louvered doors are not capable of completely preventing infiltration and ex-filtration due to inherent leakages. It has, furthermore, been found that these adjustable slats are usually left opened on all occasions. With this in mind, adjustable louvered doors clearly do not aid in energy efficiency with respect to air-conditioning systems as intended (Lehtonen et al. 2008). Many studies on household energy efficiency reveal similar phenomena, that of energy-saving household appliances often being left on day and night (Lilley et al. 2005, Lockton and Harrison 2009, Lockton et al. 2009). This evidently demonstrates a need for taking a human dimension – user needs and behaviours – into consideration across design fields (Brown et al. 2010, Hadjri and Crozier 2009, Lehtonen 2010, Preiser 1995). To date, many architectural design projects have used post-occupancy evaluation to get end-user feedback on the performance of the building following the building being occupied. However, information gathered in such a manner can only be used to either remedy minor things in a building or be used as a lesson learned for future projects. It would indeed prove more fruitful for the project if this working approach were to occur throughout the design process (Hadjri and Crozier 2009, Preiser 1995).

I. ENERGY-EFFICIENT LOUVERED DOOR RESEARCH DESIGN PROJECT

I.1 PROJECT OVERVIEW

This project was carried out between 2004–2008 with the Residential Energy Conservation Promotion Fund from the Energy Policy and Planning Office of the Ministry of Energy in Thailand. Although louvered doors are commonly used in Thailand, available designs on the market fail to accommodate energy conservation. The main funding objective was thus to develop *louvered doors that could decrease the energy loss of air-conditioning systems in residential buildings*. It is known however, that louvered doors are not the only solution to this problem. Transom louvers are also used to provide ventilation without compromising security. Higher technical solutions such as thermally activated sensors that automatically close louvers could also be open to consideration. However, according to the given scope of this funding, the central concern was placed firmly on energy-efficient louvered door design.

Besides the funding objective to develop louvered doors to accommodate energy conservation by preventing infiltration and ex-filtration in air-conditioned housing; the project also aimed to develop louvered doors that would enhance the human dimension, respond to residents' needs and behaviours, as well as remain feasible to produce, install, maintain and repair. To achieve all project objectives, an interdisciplinary team – consisting of IAQ and energy management, user-centred design, as well as product design and engineering specialists – worked closely together throughout the duration of the project. The project began with a research period that helped to specify design criteria. Later, based on the aforementioned design criteria, different design directions were generated. Each design was then evaluated using the appropriate methods to gain adequate feedback for design selection and development.

1.2 DESIGN CRITERIA

At the beginning of the project, a literature review and survey consisting of 165 Thai households were carried out in 2005 to gain an understanding of requirements that should be concerned when designing louvered doors to achieve energy efficiency where practicality could be reached. Both studies focused on human comfort and indoor air environments in residential architecture, more specifically, louvered doors and their usage in air-conditioned housing as well as residents' behaviours and needs related to louvered doors. Insights derived from studies were used to establish the louvered door design criteria in three aspects including architecture and the indoor environment, the human dimension, and production and engineering. All design criteria used in the project is discussed below:

1.2.1 Architecture and the indoor environment

The principles for passive and active building design are in partial conflict. This is because passive buildings are devoted to natural ventilation together with infiltration and ex-filtration; whereas active buildings need to be air-tight as leakage is not desirable. Nowadays, building materials and construction in Thailand largely depend on air-tight materials and assembly methods, such as reinforced concrete, brick and mortar, aluminium windows, etc. However, in order to achieve good IAQ, that is, remove odour and humidity in spaces where they are created such as toilets, bathrooms and kitchens (Buranasomphob, 1978), louvered doors have constantly appeared as the dominant solution. It is practical to suggest that air-conditioned spaces should not be adjacent to non air-conditioned spaces. It would also be practical to recommend that vestibules should be provided between air-conditioned and non-air-conditioned spaces. Nevertheless, it has been found that in typical Thai modern houses, louvered doors are commonly installed in toilets, bathrooms and kitchens, and are located immediately adjacent to air-conditioned spaces such as bedrooms and living rooms (Lehtonen et al. 2008). According to this finding, it is foreseeable that ventilation and leakage of humid air will continue to place a significant burden on air-conditioning systems. Air-conditioning systems in Thailand ordinarily function through several main features: de-humidify the air, cool it down, and circulate it. Infiltration of hot and humid air into air-conditioned spaces should be avoided for energy conservation purposes. Therefore, louvered doors should not only function perfectly as a gateway to attaining good IAQ, but should also, when in use, operate as air-tight elements that avoid infiltration into adjacent air-conditioned spaces. With this in mind, human comfort and good IAQ are equally important.

1.2.2 The Human dimension

Aspects of Human dimensions are concerned with how a louvered door meets residents' needs and behaviours, ensuring practicality and acceptability. To meet human dimension requirements, the slats of a louvered door should be both convenient to open when air-conditioning is required, and to close when it is not. It should be easy to clean and maintain, since slats easily collect dust and dirt. It should provide residents' privacy by preventing him/her from being seen from the other side of the door, especially when the door is installed in areas where privacy is highly required such as toilets, bathrooms, and areas facing outdoors. As a louver structure weakens, a door's strength is

compromised making it almost effortless to break into. As such, a stronger louvered door structure that enhances residents' security is also needed. In addition, as doors are also a part of the interior, many residents take their aesthetic appearance into consideration. Since aesthetics and styling remain additional decisive factors, their design should allow them to easily co-ordinate with different interior styles. In a real situation, *sale price* is another important criteria for the decision to purchase, which can determine the economic success of the product (Ulrich and Eppinger, 2000). However, due to project limitation, the *unit cost* influencing the sale price could not be estimated and therefore *sale price* was not included in the project's human dimensions.

1.2.3 Production and engineering

To ensure local production and local market feasibility, the louvered door should be easy to produce, install and maintain. Moreover, the door should be strong and durable as well as mould- and rust-resistant because it is often installed in moist and humid areas. When a door breaks, it should be repairable. Hence, the project focused on developing low-technological – manually operated – louvered doors.

1.3 DESIGN DIRECTIONS

Four design directions were generated from the design requirements previously mentioned. Please note that as the scope of the project was to propose *conceptual* louvered door solutions, the project's main focus was the principles of the doors while detailed designs such as louvered blade designs and material selection were not part of the design project and therefore not considered variables to affect design directions. Furthermore, a screen for insect control, an important feature for tropical architecture (Buranasomphob, 1978), was recommended to be installed in each door design. The design directions proposed for this project included:

1.3.1 Design A

Design A (Fig. 1) is an add-on to an existing louvered door with unadjustable slats. It is a solid panel that can be attached to the louvered door and hinged on one side. The design works as another opening door that can be opened to ventilate the room or closed to prevent the room's infiltration and ex-filtration.

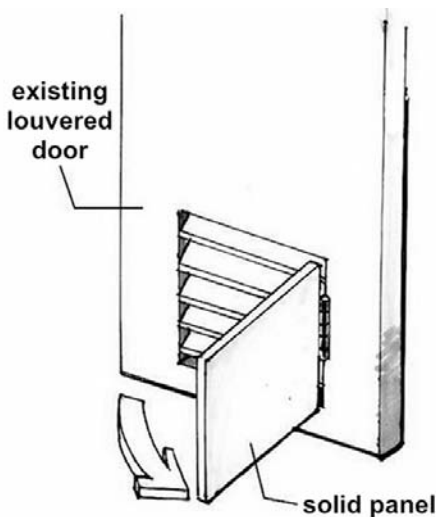


Figure 1: Louvered door design A

1.3.2 Design B

Design B (Fig. 2) is an add-on to an existing louvered door with unadjustable slats. It is a solid panel with a sliding system, which can be attached to the louvered door. The design works as another sliding door that can be opened to ventilate the room yet closed to prevent any infiltration and ex-filtration.

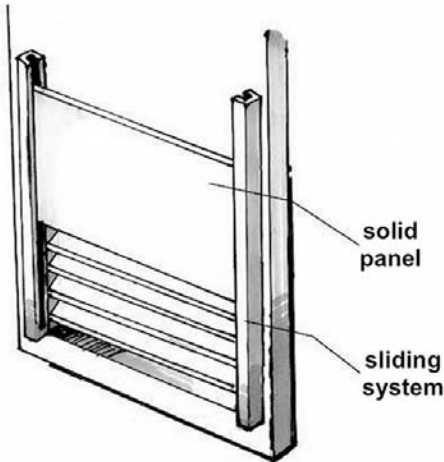


Figure 2: Louvered door design B

1.3.3 Design C

Design C (Fig. 3) is a louvered door with angle-adjustable slats. When needed, a slat controller in the middle of the door can be used to conveniently open and close all slats. There is a rubber sealer on the edge of each slat to increase air-tightness when the louver is closed.

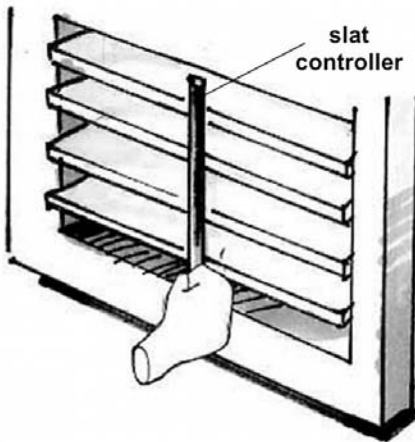


Figure 3: Louvered door design C

1.3.4 Design D

Design D (Fig. 4) is a door with a set of vents. Inside the door, there is a solid panel which can be lifted up to allow air to pass through the vents and can be pulled down to prevent air leakage.

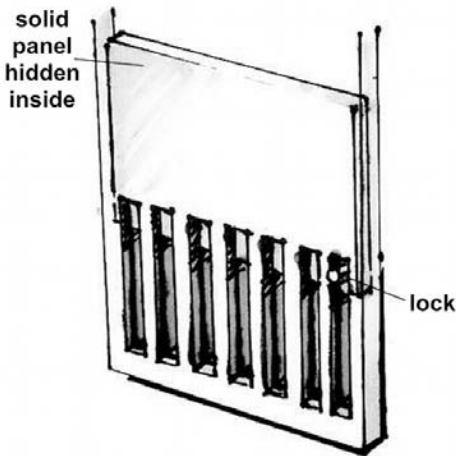


Figure 4: Louvered door design D

2. METHODS

All prototypes for each design direction were assessed in terms of energy-efficiency performance, usability, styling preference, as well as production and engineering feasibility. Four testing sessions for design direction assessment included:

2.1 ENERGY-EFFICIENCY PERFORMANCE TESTING

Prototypes for all design directions were tested for energy-efficiency performance in a laboratory via the *blower door technique* (Fig. 5). The blower door technique takes into account relationships between area leakage, pressure, and air-flow volume. Our modified *blower door* contained a variable speed fan so that the pressure in the test chamber could be adjusted. In order to measure the leakiness of each designed door, the blower door measured both the air flow through the fan and the pressure difference between the inside and outside of the chamber. (INFILTEC 2008)

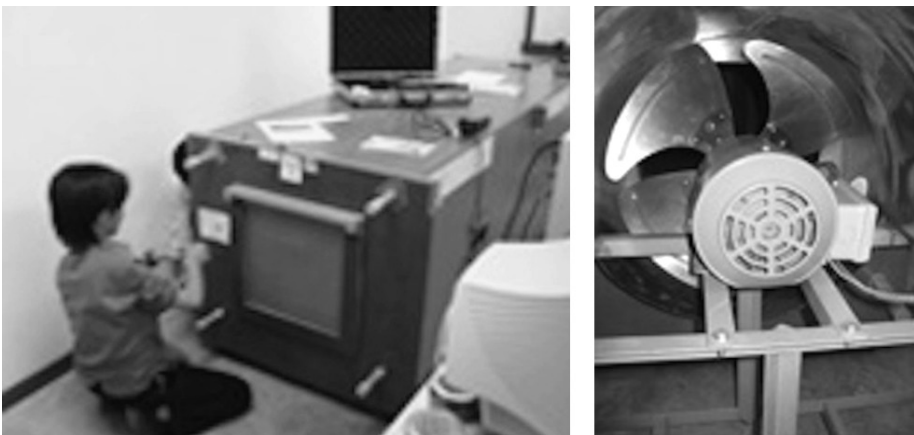


Figure 5: Blower door technique

2.2 USABILITY TESTING

Prototypes for all design directions were set-up in a simulated environment. By using the *usage scenario method* (Fig. 6), 18 participants with various profiles – ages, genders, living types and backgrounds – were asked to perform tasks with each prototype according to given situations relating to four aspects including, ease of louver open-close operation, ease of cleaning and maintenance, privacy, and security. In *follow-up interviews*, participants were then asked to rank each design direction, then to give their opinion based on their degree of satisfaction in all four factors mentioned earlier.



Figure 6: Scenario testing

2.3 STYLING PREFERENCE TESTING

Styling testing divided interior styles into 6 categories; general, warm, classic, elegant, modern and natural. To verify user styling preference, a *visual tool kit* (Fig.7) consisting of 48 cards was presented to all participants aiding them in their assessment. The card set included images of each louvered door design – both open and closed – mapped onto each interior style, helping participants realistically visualise the louvered door design in context. Then with *follow-up interviews*, the participants were asked to rank each design in terms of aesthetics and suitability for different interior styles.



Figure 7: Visual tool kit

2.4 PRODUCTION AND ENGINEERING FEASIBILITY TESTING

The same prototypes were also used for *expert testing and interview* (Fig. 8) on materials and production process, installation, maintenance, durability and repair-ability. Participants in this section needed to have knowledge and experience in architecture, interior, contractor, product design and engineering, furniture design, and production. Four experts were invited to participate in this assessment activity. Each expert was asked to investigate each design in terms of cost-estimation, ease of installation, door structure and durability, ease of maintenance and repair, as well as mould- and rust-resistance. During the session, all experts were asked to demonstrate their method for installing each design, offering opinions and suggestions for improving the practicality and feasibility of design. The final process asked experts to rank the four designs with respect to the five factors mentioned above.



Figure 8: Expert testing and interview

3. RESULTS

The testing results are in two measurement formats. The first format is *quantitative* – the ranking order showing the performance level of each design towards each assessment factor. The second format is qualitative – taking participant opinions regarding design from interview data. A *frequency distribution analysis method* was used to analyse data for ranking. Qualitative data from all participant opinions was summarised and used for confirming the results of ranking as well as giving more insightful information. Given that *the materials and louvered blades in all designs are the same*, the analysis of testing results in all 3 aspects – energy saving, human dimension, as well as production and engineering – can be concluded as follows:

3.1 ENERGY SAVING

As the materials are of the same type, thermal conductivity is not considered a variable here. The variable of most concern in energy saving is leakage through each louvered door. Please note that leakage is a key factor simply because hot and humid *fresh* air is a significant burden on cooling load. Results from air leakage experiments affirmed that the best model for preventing air leakage is design C. However, the average velocity of air leakage for design A, B and D did not differ significantly from that of design C (Lehtonen et al. 2008).

3.2 THE HUMAN DIMENSION

3.2.1 Ease of louver open-close operation

Design C is the most convenient to open and close because participants described it as easy and effortless to operate. Design D is ranked second as it can be conveniently opened and closed both neatly and tightly. Participants did however feel that the inside mechanism used in design D remained heavy and needed a lot of effort to lift and pull, possibly rendering it unsuitable for children and the elderly (Lehtonen et al. 2008).

3.2.2 Ease of cleaning and maintenance

Design C proved easiest to clean due to fewer parts and a less complex mechanism when compared to the other door designs. However, its design did need to be cleaned more often, since its slats were exposed. Moreover, the slat controller proved quite difficult to clean due to its location on the door. Design D ranked second as when it was compared to design C, the groove and crevice parts were more difficult to clean, especially the niche overlap between the opening and closing. However, if most of the time the vents are closed, design D is unlikely to have much dirt and should not need to be cleaned often (Lehtonen et al. 2008).

3.2.3 Privacy

Participants felt that the double-door structure of design B can prevent users from being seen or heard by someone on the other side of the door which lead to an increased sense of privacy. Design A and D were ranked second as their slats can only be closed and open from the inside. Participants experienced a greater sense of privacy as people outside cannot open the door slats (Lehtonen et al. 2008).

3.2.4 Security

Design B has the strongest structure giving it the highest sense of security. The possibility for breaking in is significantly reduced as it is difficult to tamper with its interior sliding mechanism. This makes design B suitable for installing between the inside and outside areas of a house. A solid panel with a locking mechanism inside design D works like a double door making participants feel safe as people from the outside would not be able to break in easily. However, due to large vents, insects and small animals could pass through easily if vents were to be left open. To solve this problem, the installation of an insect screen for Design D was highly recommended (Lehtonen et al. 2008).

3.2.5 Aesthetics and suitability to various interior styles

Design D has the highest rank for its beauty and suitability to various interior environments. Most participants liked this design as it looked simple and mellow and could easily be co-ordinated with a variety of interiors. As the ventilation pattern itself works graphically, the pattern differentiates the door from other typical louvered doors on the market. Design C also works well in classic, elegant and warm styles (Lehtonen et al. 2008).

3.2.6 Resident preferences

Following testing, when asked which door participants would most like to be installed in their homes, design D was the one most selected as both an inside and outside door (Lehtonen et al. 2008).

3.3 PRODUCTION AND ENGINEERING

3.3.1 Cost of production

Design A has the lowest cost of production while the production cost of design B, C, and D increase accordingly (Lehtonen et al. 2008).

3.3.2 Ease of installation

Only design A and B are possible to install to an existing louvered door, it is however quite a complicated process. Design C and D can only be installed as new doors (Lehtonen et al. 2008).

3.3.3 Structure and durability

Design B has a strong to very strong structure in both open and closed positions. Due to a sliding mechanism, the door does not have any moving mechanical parts that are easy to break. Nevertheless, this condition will depend on the quality of rails and installation process. Design D has a moderate to strong structure. This design does however need to be produced as a completely new door from the factory. Additionally, some fragile mechanisms hidden inside the door may be at risk of fracture during distribution and transportation. Design C has moderate to poor structure because there are many moving parts when opening and closing the adjustable slats. Moreover, the rubber seal at the edge of the slats may work loose and deteriorate after a certain period of time (Lehtonen et al. 2008).

3.3.4 Ease of repair and maintenance

Design A and B are relatively easy to repair and replace parts. Design C is moderately easy to repair as the mechanism and components can clearly be seen from the outside. Design D has the lowest ranking as this door has not been designed for disassembling prioritising instead strength and security. Should a problem with the internal mechanism of this door arise, exchanging the old door for a new one would be an easier solution than repair. However, the mechanism which is completely immobile does have an advantage. It makes it harder to damage and does not require frequent repair when compared to the other doors with external mechanisms (Lehtonen et al. 2008).

3.3.5 Mould- and rust-resistance

Design C has the best mould- and rust-resistance due to a louvered system that can be fully opened. This renders it easy to clean and minimises moisture. Although design A and B have quite similar structures, design A can prevent accumulation of mould and rust better than design B because design B has a rail section with narrow grooves that retain moisture. Furthermore, if the door were to be made of wood, any resulting swelling and bending of the rails could easily cause difficulty to

Energy saving [Es]		Human dimension [Hd]						Production [P]							
R1	C +2	C	C	B	D B	D	C	D	+2	A	C D	B	A B	A C	R1
R2	A B D +1	D	D	D A	—	C	D	B	+1	B	—	D	C	B	R2
R3	— -1	B	A	—	A	—	—	G	-1	C	B	A	D	—	R3
R4	— -2	A	B	C	C	B A	B A	A	-2	D	A	C	—	D	R4
	1.1 energy saving	2.1 ease of open-close	2.2 maintenance	2.3 privacy	2.4 security	2.5.1 aesthetics: modern	2.5.2 aesthetics: classic	2.6 user preference		3.1 cost	3.2 installation	3.3 durability	3.4 repair+maintenance	3.5 mould+rust resistance	

Figure 9: EsHdP framework used for evaluating all of the louvered door designs proposed during the project

its operation. Design D is the least efficient regarding rust and mould prevention. Most of this product's complex structure and mechanism installed inside could face similar problems. The process for moisture ventilation is more difficult than in other designs. In order to prevent rust and mould, design D requires a solution that will ventilate moisture without further compromising its structure and strength. Therefore, as design D stands, no matter what material it is made from, it cannot be used externally where high humidity is present (Lehtonen et al. 2008).

4. REFLECTIONS ON THE RESULTS

The testing results reveal that the design that achieves the best performance with respect to energy-saving is not the same design that is most suitable to user needs and behaviour, neither is it the same design that is most feasible in production and engineering. Furthermore, testing results are in various measurement formats – *quantitative* results for velocity air leakage testing as well as human dimension and production ranking, and *qualitative* results from user and expert interviews and observation. Converting all data into ranking-results helps to put all information onto the same platform. Results can thus be more readily compared. In view of that the *EsHdP framework* (Fig. 9) was created to assist in analysing possible design directions from testing results, evaluating these directions and choosing one or more designs most likely to fulfil the objectives of the project.

As shown in Fig. 9, the horizontal axis contains all design criteria in each category including energy saving (1.1), human dimension (2.1-2.6), and production (3.1-3.5). The vertical axis is in scale of rank (R1 = 1st rank, R2 = 2nd rank, R3 = 3rd rank, and R4 = 4th rank). R1 and R2 refer to the efficiency of each design relative to a particular criterion, so the value is on the positive scale (R1 = +2, and R2 = +1) while R3 and R4 refer to inefficiency of each design relative to particular criterion, so the value is on the negative scale (R3 = -1, and R4 = -2). This assessment framework used in this project can be applied to other architectural and product design projects focusing on *energy efficiency*. However, the assessment criteria within each category should be adjusted accordingly depending on the nature of the project and the users. After ranking all design directions on the framework according to the testing results, all values – both plus and minus – for each design in each category are summed-up. The sums are then used to evaluate how well each direction has performed relative to the design criteria for each category. As mentioned earlier, energy saving, human dimension, and production are essential factors for the success of energy-saving design. Ideally the most promising design that will be selected for further development should be positioned on a positive scale in all criteria. However, in many cases, the assessment results may not be as ideal. As energy efficiency is the main focus of the project, the efficiency result of energy saving of the selected designs for further development has to be positioned on a positive scale, which is in the (+Es) section. Furthermore, without appropriate human dimension, an energy-saving design will never have the chance to perform energy-efficiently since no one would like to possess an unusable or undesirable product. And even when owning a louvered door, an owner may prefer not use it to aid in energy efficiency as intended because it does not suit their personal behaviours. Therefore, the efficiency of selected designs in the human dimension category also has to be on a positive scale, which is in the (+Hd) section. On the contrary, production of the designs proposed can be easily refined by design and engineering to meet the criteria such as changing materials or adjusting production processes. Therefore the efficiency of the selected designs in this category can be either on a positive scale (+P) or negative scale (-P). Hence, any design that passes the EsHdP assessment and is brought forward for further development has to match one of the two assessment options, which are (+Es)(+Hd)(+P) or (+Es)(+Hd)(-P).

As shown in Fig. 9, regarding performance in energy saving, design C is ranked first (R1), receiving +2 points. From a calculation of all factors, the results of each design are as follows; design A (+Es: +1)(-Hd: -9)(+P: +3) and design B (+Es: +1)(-Hd: -2)(+P: +5) have a positive scale in all categories except the human dimension category. This means that design A and B do not pass the EsHdP assessment framework. Design C (+Es: +2)(+Hd: +2)(+P: +2) has a positive scale in all categories while design D (+Es: +1)(+Hd: +10)(-P: -2) has a positive scale in all categories except production. Therefore, design D and C should be considered for further development. Even though design C has positive scale in all design criteria categories when it comes to the decision making for their own house, most participants decided to purchase design D for both indoor and outdoor use because

design D can satisfy most of the factors adequately. Emotional factors in terms of beauty and interior style matching also play an important role in creating a good first impression and persuading purchase decisions. Given all these reasons, the team have recommended design D for further development. However, design D is still in need of development regarding resistance to mould and rust, cost effectiveness in production, and ease of repair. Furthermore, some techniques used in design C such as sealing and less effort during operation can further be integrated into design D.

5. DISCUSSION

The limitation of this research and development is that due to the given scope of the funding, the project only focused on louvered door solutions. In fact, other alternatives are also possible to provide natural ventilation and at the same time enhance energy efficiency in air-conditioned spaces, human dimensions, as well as production and engineering. In addition, sale price influencing economic success of the louvered doors and detailed designs such as louvered blade designs and material selection were excluded from the project.

Nevertheless this paper shows how interdisciplinary collaboration among specialists from various fields could lead in a promising direction with respect to louvered door design. Apparently, to achieve the design of energy-efficient architecture, design solutions should not be concerned solely with *technical* and *scientific* aspects, but must accept a need to integrate additional *human dimensions* that influence energy efficiency through practicality and acceptability by the consumer. This project exemplifies how human dimensions can play an important role in the design of louvered doors and the possibility of performing to their full capacity. In a real context where louvered doors are sold and used, the energy-efficient performance of a door will depend on several factors. For instance, the most energy-efficient louvered door, left on a hardware store shelf, will never have the opportunity of performing at all; and the slats of the most energy-efficient and good-looking louvered door, installed in a house, may end up being left open all day and night due to being inconvenient to open and close. Understanding user needs and behaviours towards design will ensure that the design solution be more *usable*, *desirable*, and *satisfying*; and lead to overall design success.

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