Energy Performance of Detached House Building Envelope: Financial Investment Perspective

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Abstract

This research aims to study the financial feasibility of designing an energy-saving building envelope, according to Thailand Energy and Environment Assessment Method (TEEAM). First, the author studies Thailand's energy-saving assessment frameworks and compare assessment categories and rating scores. The results present that the building envelope category is the category with the highest proportion of score in all assessment frameworks. The scoring in the building envelopes category accounts for 23-40% of the total score (approximately 60-88% achieving a minimum tier). This study focus on TEEAM (R-49.02) as an energy-saving assessment and the design of glazing type, exterior materials, and ceiling insulation materials are examined in the sample house. Second, this study examined the cooling energy-saving performance of 29 building envelopes via using energy simulation program (eQUEST v3.64). The results classified saving performance into 4 classes. Finally, the result of energy-saving costs is analyzed compared to an increase in construction costs. To consider the feasibility of financial with 3 indexes, Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PB). The low-efficiency class contributes to 8% energy savings, while construction costs increase by 5%, which provides the IRR at 21%, NPV of 12,130 baht, and PB less than 5 years.

Keywords: energy-saving building, assessment frameworks, building envelope,financial feasibility

1. Introduction

Energy is the primary component in the development of the economy and social quality of the country. The energy consumption in Thailand has increased continuously at
an annual average rate of 4.4%. In 2010, the energy consumption in the residential sector accounted for 13.5% of the total country consumption, which increased 1.52 times compared to that in 1990. It is continuously increasing towards 2.95 times in 2030. (Energy Policy and Planning Office, 2011) As a result, the government has issued control measurements for building energy consumption to reduce the energy consumption crisis of the country. One of those strategies is to impose the Ministerial Regulation Prescribing Type or Size of Building and Standard, Criteria and Procedure in Designing Building for Energy Conservation B.E. 2552. This design standard aims to reduce building energy consumption by improving the building's envelope with high thermal performance materials. However, that improvement also increases the construction cost for building envelope retrofit. Thus, this approach might not motivate or convince consumers/ homeowners interested in saving energy. The results of this study could provide the design guideline that homeowners can improve the building envelopes achieving an energy-efficient house with the highest financial return.

2. Research Methodology

The research methodology includes two parts: 1) a review of energy-saving building assessment frameworks of Thailand, 2) model setting and simulation of energy consumption in single houses, and 3) calculation of financial feasibility. The detailed information presents as following topics.

2.1 Energy-saving building assessment frameworks of Thailand

This study reviews design conditions and limitations of four energy-saving building design assessment frameworks commonly used in Thailand, including TREES-NC version 1.0, TEEAM (R-49.02), Ecovillage, and Housing Estate Energy Conservation Excellent Award Criteria. The detailed information of each framework are summarized as follows:

TREES-NC version 1.0

This assessment framework was established by the Thai Green Building Institute [TGBI]. This assessment framework is developed by the LEED standards to be applicable used in the context of Thailand's environment. There are two sections in TREE-NC: the condition compliance section and the efficiency assessment section. The rating score of this framework divides into four tiers: Certified (30-37 points), Silver (38-45 points), Gold (46-60 points), and Platinum (more than 61 points). There are nine assessment categories: 1) Building Management (3 points), 2) Site and Landscape (16 points), 3) Water Conservation (6 points), 4) Energy and Atmosphere (20 points), 5) Materials and Resources (13 points), 6) Indoor Environmental Quality (17 points), 7) Environmental Protection (5 points), and 8) Green Innovation (5 points). The Energy and Atmosphere category has the highest score, which accounts for 23% of the total score. If the design achieves a full score of this category, it probably gains 76% of a minimum score of the certified tier. The most content of this category consists of thermal resistance of building materials as defined in the Ministerial Regulation B.E.2552, ASHARE90.1-2007, and TEEAM (NR-49.01).

TEEAM (R-49.02)

TEEAM has been developed by the Department of Alternative Energy Development and Efficiency (DEDE), which is used to assess energy performance and environmental impact for residential buildings in Thailand. This assessment framework includes three scoring ranges: 1) Bronze label (45-49 points), 2) Silver label (60-74 points), and 3) Gold label (greater than 75 points) (Chindavanig, 2007). There are nine conservation energy categories including 1) Site and Location (4 points), 2) Site Planning and Landscape (8 points), 3) Building Envelope (40 points), 4) Air-Condition System (10 points), 5) Lighting System (12 points), 6) Passive Design and Renewable Energy (12 points), 7) Sanitary System (4 points), and 8) Design Innovation for the Sustainable Energy and Environment (10 points). The building envelope category has the highest score of 40% of the total score, which accounts for 88% of a minimum score for the bronze label. The most content of this category consists of am improvement of the thermal properties of building materials.

Ecovillage

This assessment framework has been established by the National Housing Authority (NHA) to assess energy-saving performance and environmental friendly from a master plan design through facility management. Ecovillage has two parts, which are specifications and evaluations. There are four scoring ranges: Certified (more than 50 points), Silver (more than 60 points), Gold (more than 70 points, and Platinum (more than 80 points). The framework comprises of five assessment categories including 1) Site Planning and Landscape (28 points), 2) Building (42 points), 3) Building System (15 points), 4) Management (10 points), and 5) Innovation (5 points). The building envelope category has the highest score of 33%, which could account for 66% of a minimum score for the certified tier. The most content of this category provides an improvement of thermal resistance property of building materials as similar to TEEAM (R-49.02).

Housing Estate Energy Conservation Excellent Award Criteria

This assessment framework has been developed by DEDE, which aims to be making real estate developers have an awareness of building energy consumption. There are three design categories proposed in this assessment framework: 1) Environmental design (20 points) consisting of 10 points Site Planning and 10 points in the Landscape Design. 2) Architectural design (45 points) consisting of 43 points in the building envelope and 2 points in construction materials. And 3) Engineering ad mechanical design (47 points) consisting of 16 points air-conditioning system, 8 points in the lighting system, 7 points in the sanitary system, and 16 points in passive design and renewable energy. The category of building envelope design also has the highest score of 38% of the total score. The most content of this category is similar to TEEAM (R-49.02) and Ecovillage.

According to the review, the process of classification and score weighting system of four assessment frameworks shares similarities. The design of building envelope components contributes a significant impact between 23-40% of the total score, accounting for 66-88% of a minimum tier, as shown in figure 1.

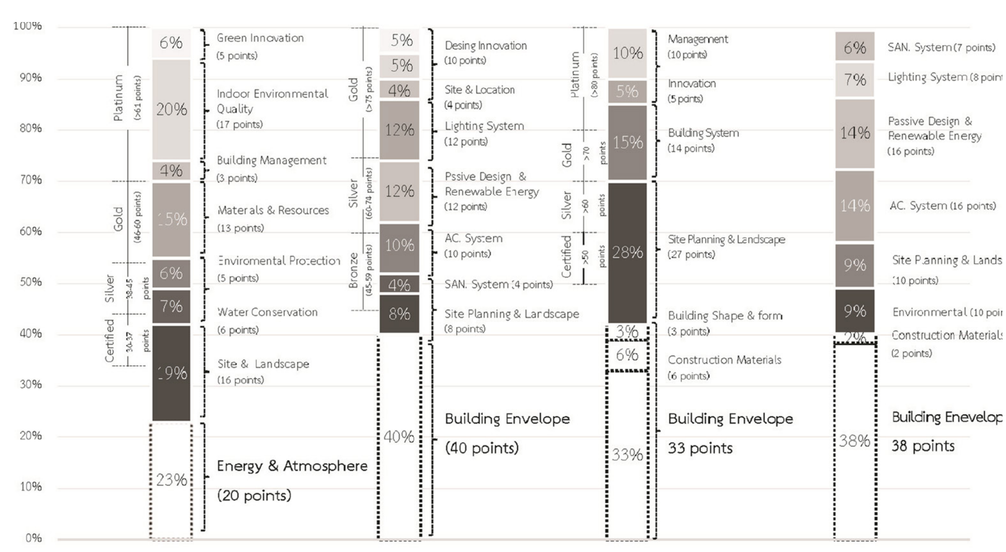
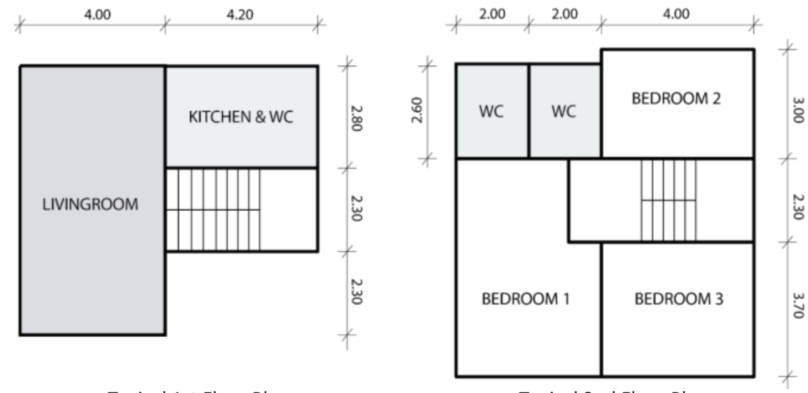


Figure 1. Proportion of rating scores of each design category and ranking awards in four energy-saving and environmental assessment frameworks.

In comparison to the significant design elements and rating scores of the four assessment frameworks, TEEAM (R-49.02) provides the highest score in the design in improving the high thermal performance of the building envelope. Consequently, this research chooses TEEAM (R-49.02) as the design standard for improving household energy consumption, which the score comprises three ranges: Low Tier (score 14-21 points), Middle Tier (score 22-32 points), and High Tier (score 33-40 points) (Suwanchaisakul & Dendoung, 2017).



Typical 1st Floor Plan

Typical 2nd Floor Plan

Figure 2. Floor plans and layout of a typical two-storey detached houses

2.2 Model setting and simulation of energy consumption in single houses

This study uses eQUEST model v3.64 (Hirsch & Associates, 2009) computer program to perform annual energy consumption of the studied houses. This software is commonly used in the studies of building energy analysis and provides acceptable accurate results. The studied houses used in this energy simulation is a part of a previous joint study (Jareemit, 2016) that surveyed 328 detached houses in 167 projects from 13 real estate development companies in Bangkok Metropolitan during 2014-2015. Figure 2 presents the design characteristics of the representative house, which accounts for 33% of the total housing stock. The area of a typical detached house is 160 m^2. The house has two stories comprising a living room, dining area, and kitchen on the first floor, while the second floor comprises three bedrooms and two bathrooms. Window to wall ratio (WWR) in each building envelope ranges from 7.3% to 33.4%. The envelope facing East has the smallest WWR, while the higher WWR occurs in that facing West and South. Figure 3 presents the model of the studied house in the energy simulation and the simulation results.

Regarding the simulation input, the building materials and its thermal properties of exterior wall, glazing window, and ceiling insulation, shown in Table 1, are constructed a total of 29 design scenarios. The simulations are performed under an average 10-years weather data obtained from Bangkok's meteorological station.

This study assigns that the use of air conditioners for weekday (Monday-Friday) are operated from 6.00 p.m.- 6.00 a.m., and it has a full operation for weekend and holidays. The setpoint of the room air temperature assumes 25 ^{o}C.

2.3 Financial return analysis

The calculated energy savings and construction cost from those 29 design scenarios are compared with those of the base case buildings. This calculation uses NPV (Eq. 1), IRR (Eq. 2), and PB. (Eq. 3) to assess financial returns). The construction cost in 2015 is used to examine the approximate current cost and used in this analysis.

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{ES_t}{(1+i)^t} - I_0 \qquad \text{(Eq.1)}$$

$$\sum_{t=1}^{n} \frac{ES_t}{(1+IRR)^t} - I_0 = 0 \qquad \text{(Eq.2)}$$

$$PB = \frac{Total\ Construction\ Cost}{Annual\ Energy\ Cost\ Saving} \qquad \text{(Eq.3)}$$

Table 1. Thermal properties of envelope materials used as an input in the energy model.

Type of glazing	U-value (BTU/ hr-ft2-F)	SHGC
Clear glazing, 6 mm thick	1.11	0.81
Green tinted glazing (single glazing), 6 mm thick	1.09	0.61
Reflective glazing, 6 mm thick	0.86	0.19
Low-E (double glazing), 24.5 mm thick	0.23	0.28
Green tinted glazing (double glazing), 24.5 mm thick	0.57	0.41
Type of exterior wall	**U-value (BTU/ hr-ft2-F)**	**Rt-value (hr-ft2-F/BTU)**
General masonry brick, 100 mm thick	0.69	1.45
Light-weight masonry brick, 100 mm thick	0.23	4.35
General masonry brick and EIFS insulation thick 3 inches	0.057	17.54
General masonry brick and fiberglass insulation thick 3 inches	0.080	12.53
Light-weight masonry brick and EIFS insulation thick 3 inches	0.051	19.60
Light-weight masonry brick and fiberglass insulation thick 3 inches	0.069	14.54
Type of ceiling insulation	**U-value (BTU/ hr-ft2-F)**	**R-value (hr-ft2-F/BTU)**
General gypsum board, 9 mm thick	0.086	-
General gypsum board, 9mm thick and fiberglass insulation thick 3 inches	0.043	11.54
General gypsum board, 9mm thick and fiberglass insulation thick 6 inches	0.029	23.08
General gypsum board, 9mm thick and polynum insulation sheet thick 0.5 inches	0.050	8.26
General gypsum board, 9mm thick and polynum insulation sheet thick 1.2 inches	0.028	24.34

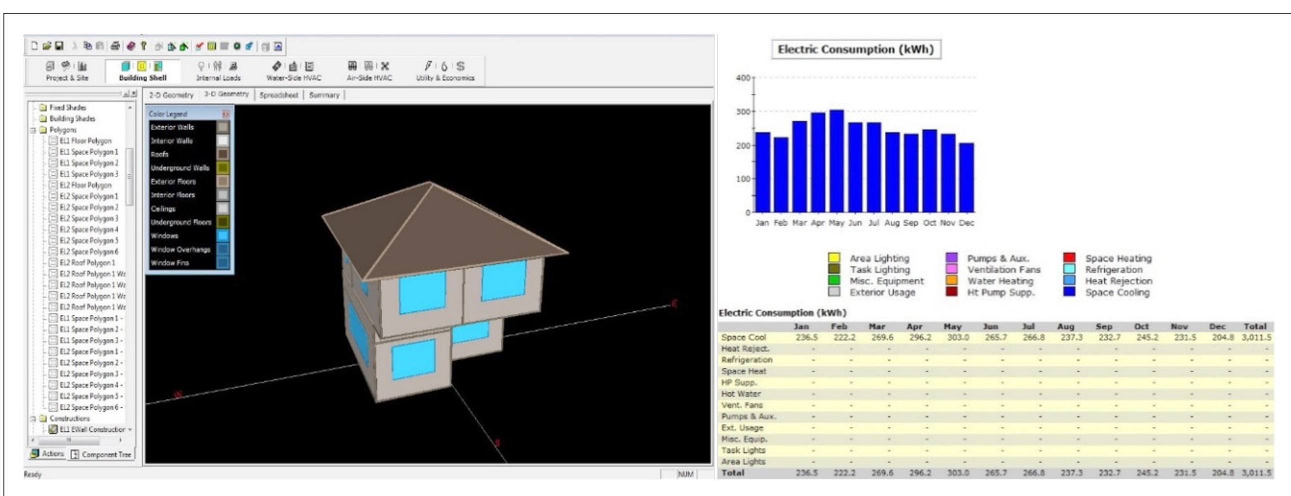


Figure 3. Setting a modeled typical house in the eQUEST v3.64

Where

NPV = Net Present Value (baht)
n = total number of periods (material lifetime, 20 years)
t = time of energy cost saving
ES_t = energy cost saving
i = discount rate (inflation rate 3%)
I_0 = total construction cost
IRR = internal rate of return (%)

3. Results and discussion

3.1 Energy-saving potentials by improving building envelope materials

Glazing

From the energy simulation of four glazing materials, it is found that the reflective glass offers the highest energy-saving performance 25.8% higher than that of the

regular clear glass. The Low-E (double glazing), green-tinted glass (double glazing), and green-tinted glass (single glazing) offer energy-saving performance property at 21.4%, 15.9%, and 8.3% higher than the regular clear glass, respectively. (See figure 4).

Exterior wall materials

Increasing thermal resistance of exterior walls by adding 3 inches insulations delivers the same savings performance with energy consumption of approximately 3,000 kWh/year. This improvement can save energy consumption by 7.2-7.5% from that of the generic masonry brick. The energy savings from the lightweight brick shows 5.8%.

Ceiling Insulation

Figure 6 presents the calculated energy consumption from four types of ceiling insulation. It is found that adding ceiling insulation has a small impact on building energy savings when compared to other techniques. It might be that the majority use of air-conditioners in bedrooms (on the 2nd floor) is during nighttime. As a consequence, this ceiling insulation slows down the process of heat release from the building (Tantasavadi, Chenvidyakarn, & Pichaisak, 2011).

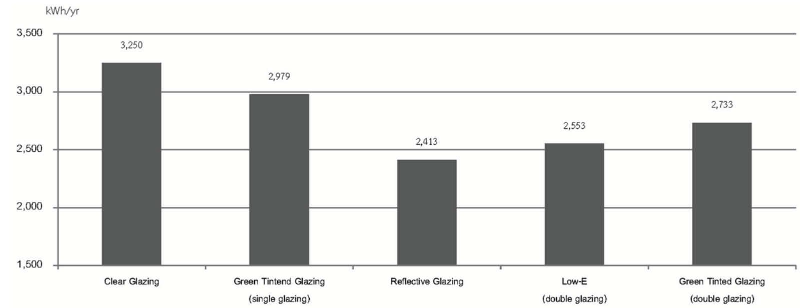


Figure 4. Comparison of energy consumption for the glazing types.

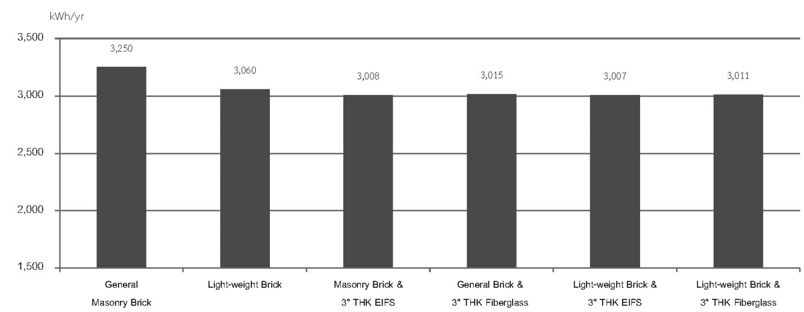


Figure 5. Comparison of energy consumption for the exterior wall's materials.

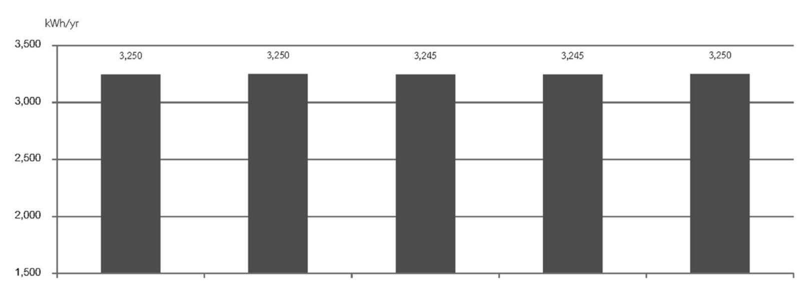


Figure 6. Comparison of energy consumption for the ceiling insulation materials.

From the analysis of improving the building envelope by three techniques, the results confirm that using high-performance glass considerably improves energy efficiency when compared to the improvement of the exterior wall's thermal resistance. However, ceiling insulation provides a slight effect on energy savings.

3.2 Design implementation

The energy-saving performance from 29 design scenarios is used to assess financial feasibility, including NPV, IRR, and PB values. This study can classify the energy-saving performance that corresponded to that investment cost into four groups, as presented in Figure 7. The relationship between energy-saving performance and its construction cost when applied to different building materials is presented in Table 2.

High-Efficiency Class

This group performs at the highest energy performance representing 41-48% in energy savings with 111–236% increase in the construction cost. The financial feasibility determined that the calculated NPV is less than zero, IRR is 1%, and the PB is 19 years. The recommended materials for the best performance are using reflective glazing as windows and generic masonry brick with 3 inches fiberglass for the exterior walls.

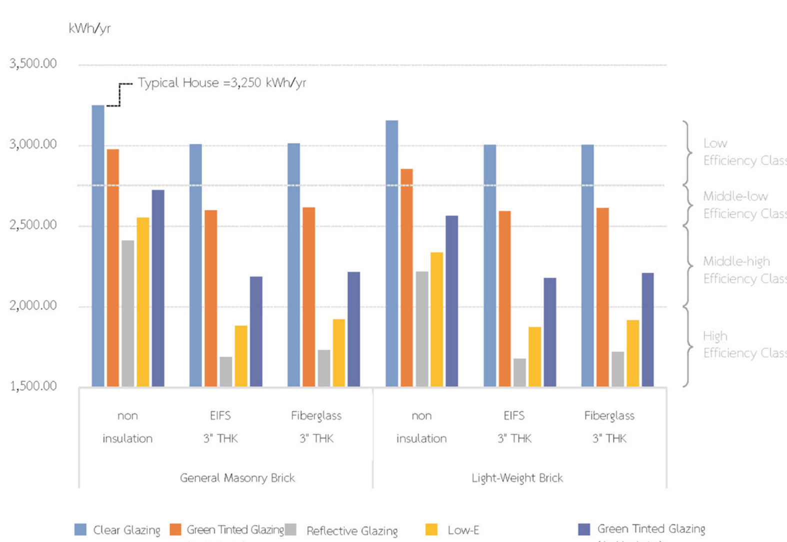


Figure 7. Classifications of the energy performance of studied houses with improvements to different envelope materials

Middle-high Efficiency Class

This group performs at the upper level in energy-saving performance, which provides 26-33% energy savings with 34–212% increase in the construction cost. The financial feasibility determines that NPV is 16,200 baht, IRR shows 7%, and the PB is 11 years. The recommended materials for the best performance of this group are using reflective glazing as windows and generic masonry brick for the exterior walls.

Middle-low Efficiency Class

This group performs at the middle-low level in energy-saving performance, which offers 5-136% in energy savings with 70–141% increase in the construction cost. The financial feasibility determined that NPV and IRR are less than zero. The payback period is expected to be more than 30 years, which is higher than the recommended building operational lifetime. This group is not appropriate for practical use.

Low-Efficiency Class

This group performs at the lowest level in energy-saving performance, which shows 3-12% in energy savings with 5–136% increase in the construction cost. The financial feasibility determined that NPV is 12,130 baht, IRR is 21%, and the payback period is 5 years. The recommended materials for the best performance of this group are using the green-tinted glass (single glazing) as windows and generic masonry brick for the exterior walls.

A previous study (Sreshthaputra, & Sirithumpiti, 2017) showed that the investment cost of building materials increases by up to 73% to achieve the highest energy performance following the Ecovillage's assessment framework. This result confirms the hypothesis that the high thermal-performance materials such as green-tinted glazing (single glazing) and reflective glazing can improve the detached houses more energy efficiency with acceptable construction investment for improving R-value of the building envelope.

Table 2. The data analysis on the improvement of energy savings in the studied houses and the cost of investment.

Class	Scenario		Energy Consumes		Financial Feasibility			
	Glazing Types	Materials of Wall Types	kWh/yr	Saving	Cost Plus (%)	Payback Period (year)	Net Present Value (NPV: Baht)	Internal Rate of Return (IRR: %)
Sample Case	Clear Glazing : (Typical house)	General Masonry Brick : (Typical house)	3,250.00	-				
High-Efficiency Class	Reflective Glazing	Light-Weight Brick & 3"EIFS	1,677.30	-48%	170%	25.14	-69,431.74	-2%
		Masonry Brick & 3"EIFS	1,688.90	-48%	153%	27.71	-87,395.14	-3%
		Light-Weight Brick & 3"Fiberglass	1,722.30	-47%	128%	21.41	-43,234.36	-1%
		Masonry Brick & 3"Fiberglass	1,731.30	-47%	111%	18.69	-25,103.58	1%
	Low-E (double glazing)	Light-Weight Brick & 3"EIFS	1,873.50	-42%	236%	44.02	-173,767.55	-7%
		Masonry Brick & 3"EIFS	1,884.40	-42%	219%	41.21	-155,759.21	-6%
		Light-Weight Brick & 3" Fiberglass	1,916.00	-41%	194%	37.28	-129,445.94	-5%
		Masonry Brick & 3"Fiberglass	1,924.40	-41%	177%	34.26	-111,276.33	-5%
Middle-high Efficiency Class	Green Tinted Glazing (double glazing)	Light-Weight Brick & 3"EIFS	2,180.10	-33%	212%	50.76	-166,304.86	-8%
		Masonry Brick & 3"EIFS	2,187.70	-33%	195%	47.06	-148,083.62	-7%
		Light-Weight Brick & 3"Fiberglass	2,209.90	-32%	169%	41.77	-121,164.39	-6%
		Masonry Brick & 3"Fiberglass	2,215.90	-32%	153%	37.84	-102,840.20	-5%
	Reflective Glazing	Light-Weight Brick	2,217.20	-32%	68%	16.80	-8,603.96	2%
	Low-E (double glazing)	Light-Weight Brick	2,336.60	-28%	134%	37.63	-90,026.49	-5%
	Reflective Glazing	Masonry Brick	2,412.90	-26%	34%	10.41	16,204.62	7%
	Low-E (double glazing)	Masonry Brick	2,553.20	-21%	100%	41.09	-77,613.76	-6%
Middle-low Efficiency Class	Green Tinted Glazing (double glazing)	Light-Weight Brick	2,566.40	-21%	109%	36.93	-66,564.91	-5%
	Green Tinted Glazing (single glazing)	Light-Weight Brick & 3"EIFS	2,594.80	-20%	141%	39.60	-68,237.03	-6%
		Masonry Brick & 3"EIFS	2,599.30	-20%	124%	55.10	-114,144.28	-8%
		Light-Weight Brick & 3"Fiberglass	2,612.70	-20%	98%	48.84	-95,723.24	-7%
		Masonry Brick & 3"Fiberglass	2,616.40	-19%	82%	33.01	-49,764.51	-4%
	Green Tinted Glazing (double glazing)	Masonry Brick	2,723.20	-16%	76%	36.92	-50,297.88	-5%
Low-Efficiency Class	Green Tinted Glazing (single glazing)	Light-Weight Brick	2,855.00	-12%	38%	25.00	-17,325.62	-2%
		Masonry Brick	2,978.60	-8%	5%	4.56	12,129.94	21%
	Clear Glazing (single glazing)	Light-Weight Brick & 3"EIFS	3,006.80	-7%	136%	83.69	-70,086.29	-11%
		Light-Weight Brick & 3"Fiberglass	3,006.80	-7%	94%	98.70	-88,281.64	-12%
		Masonry Brick & 3"EIFS	3,008.30	-7%	119%	126.19	-116,702.31	-13%
		Masonry Brick & 3"Fiberglass	3,014.80	-7%	77%	143.39	-135,342.64	-14%
		Light-Weight Brick	3,156.20	-3%	34%	92.19	-31,382.79	-12%

4. Conclusion

The establishment of energy-saving building assessment frameworks of Thailand aims at contributing decrease the energy consumption in Thai houses. The design of detached houses achieving high energy performance as defined by that assessment frameworks mainly invests high construction cost. As a consequence, this strategy might not successfully convince consumers/ homeowners to improve their houses. With this obstruction, this research investigates the relationship between energy savings and financial feasibility obtained from the envelope design using different materials. The results show there is a potential to design the detached house more energy efficiency with the low investment cost. The relationship study can classify the energy-saving performance and its financial return into 4 classes. The low-efficiency class seems to be the most feasible option since it provides 5 year PB, 12,000 baht NPV, and 12% IRR. To achieve the highest energy-saving performance with 40% energy savings, it needs 1.1 times more investment cost, and the PB is 19 years with negative NPV and only 1% IRR.

5. Acknowledgment

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