The 8th TSME International Conference on Mechanical Engineering
12-15 December 2017
Bangkok, Thailand

ETM0006

Optimum building performance scores when applying different ECM sorting schemes

Thosapon Katejanekarn*, Narong Promsorn
Building Energy Systems Laboratory, Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University, Nakhon Pathom 73000, Thailand

* Corresponding Author: Email: thosaponk@hotmail.com, Tel: (+66) 34 259025, Fax: (+66) 34 219367

Abstract. There are many ways to sort energy conservation measures (ECMs) in order when ones want to earn building performance scores according to building standards or codes. For example, zero and low investment ECMs would be implemented first followed by higher investment ECMs to gain incremental scores. Basically, ones may sort by energy cost saving (descending order), investment cost (ascending order), or earning scores (descending order). From financial aspect, ones may sort by simple payback period (ascending order), net present value (NPV, descending order), or internal rate of return (IRR, descending order). No matter which of the six sorting schemes was applied, there would be an optimum point where it is not worth investing in doing ECMs further because the performance scores would not be increased significantly. It was of interest to see whether the optimum building performance scores would be about the same if different sorting schemes were applied. In this work, a 12,567-m^2 office building, an 8,280-m^2 department store, and an 11,448-m^2 hotel were selected to be sample buildings. The same set of 11 ECMs such as using low-e glasses, installing insulation on the walls, etc. was applied to all three buildings. ASHRAE's Building Energy Quotient (Building EQ) was chosen to be the building performance scoring system. The optimum building performance scores were considered to be the point where the next ECM caused the scores to change by no more than 5%. The results showed that the six different sorting schemes mentioned above yielded about the same optimum performance scores. For the office building, the optimum scores were within the range of 109.29-111.15 where the investment cost per scoring point differed by 23.10%. For the department store building, the optimum scores were within the range of 45.21-47.02 where the investment cost per scoring point differed by only 7.85%. For the hotel building, the optimum scores were within the range of 236.19-241.20 where the investment cost per scoring point differed by only 6.50%. The results implied that whichever sorting scheme was applied the optimum building performance scores would be about the same.

1. Introduction

Electrical consumption in Thailand has been increasing every year. In the first four months of 2017, the electrical consumption was increased by 1.05% compared with that of the same period in 2016 [1]. The building sector contributes as high as 48% of the electrical energy use of the country. Therefore, if the building energy use can be saved, it will cause a significant impact on the whole country.

Energy saving in buildings can be achieved by various kinds of energy conservation measures (ECMs). Some examples are listed in Table 1. If ECMs are categorized by the purpose, they might be grouped as measures aimed to save energy and measures aimed to increase energy efficiency, for instance, shutting down equipment during lunch break [2], using high-performance building envelope [3], using electronic ballasts instead of magnetic ballasts [2, 4], applying dehumidification systems with conventional air conditioning systems [2]. If the magnitude of the investment cost is considered, ECMs may be categorized into 3 groups, i.e., housekeeping (e.g., adjusting thermostat setpoint up by 1ºC [5]), minor change (e.g., installing variable speed drives or VSDs at motors [5, 6], and major change (e.g., replacing chillers with higher efficiency ones [7]). If ECMs are classified according to building systems, they can be divided into 5 groups comprising building envelope (e.g., insulating roofs and walls [2]), lighting system (e.g., replacing incandescent lamps with compact fluorescent lamps [2]), equipment (e.g., using high efficiency equipment [7]), air conditioning system (e.g., using variable air volume or VAV systems [2]), and others (e.g., installing solar water heaters [8]).

Table 1. Examples of energy conservation measures (ECMs) in buildings.

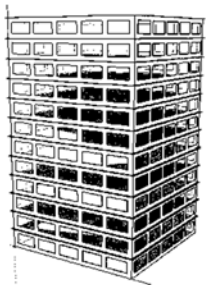
ECM	Building application	Energy saving
Film coating on window glazing [2]	Office	7.12%
Double glazing and internal blinds [2]	Hotel	5.71%
High efficiency envelope and shadings [3]	Office	0.23%
Installing air gap and gypsum boards on the walls [2]	Office	3.65%
1-in fiberglass insulation on the walls [2]	Office	7.11%
Using dehumidification systems with conventional air conditioning systems [2]	Hospital	11.6%
Variable speed split-type air conditioning systems [5]	Office	7.70%
Turning off lighting systems during lunch break [2]	Office	0.82%
Using compact fluorescent lamps instead of incandescent lamps [2]	Office	0.51%
Dimmer control for daylighting utilization [3]	Office	2.25%
Timer control for lighting systems [8]	Fire station	2.07%
Motion sensors for lighting systems [8]	Fire station	0.72%
Solar water heaters [8]	Fire station	9.34%
Ice storage system [3]	Office	0.76%
Solar photovoltaic system [5]	Office	13.67%

When ones want to implement ECMs in a building, they have to define some criteria to sort which ECMs should be done first and which ones should be next. A group of previous researchers that studied on financially optimum green building label [9-12] sorted ECMs by considering investment and return in terms of energy saving. They implemented ECMs in this order: ECMs with no investment and with energy saving, ECMs with no investment and with no energy saving, ECMs with investment and with energy saving, and ECMs with investment and with no energy saving. It was found that by applying this sorting scheme the financially optimum green building label was the 'gold' label. However, there are many ways to sort ECMs in order, for example, implementing ECMs from low to high investment, from high to low saving, or from short to long payback period. There has not been a specific paper discussing about the impact from different ECM sorting schemes. It is curious to see if different ECM sorting schemes would lead to the same optimum green building label or not.

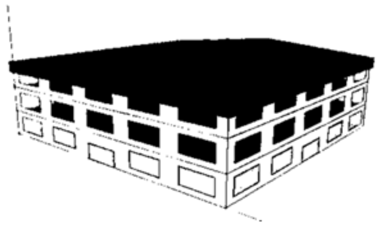
This paper reports the study on optimum building performance scores when applying different ECM sorting schemes. Six sorting schemes were investigated by dividing into 2 groups which are 1) primary sorting schemes considering energy saving, investment, and scores, and 2) secondary sorting schemes considering payback period, net present value (NPV), and internal rate of return (IRR). Three building types were chosen to be sample buildings, i.e., office, department store, and hotel. ASHRAE's Building Energy Quotient (Building EQ) was selected to be the building performance scoring system. It was assumed that the buildings used only electrical energy.

2. Methodology

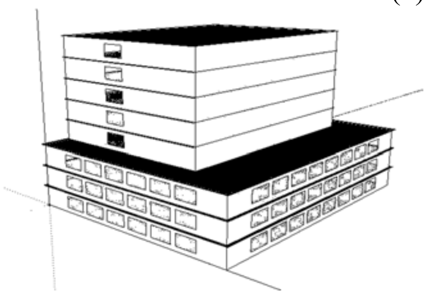
Three sample buildings were chosen in this study comprising a 12,567-m^2 office building, an 8,280-m^2 department store, and an 11,448-m^2 hotel [2]. Figure 1 shows the sketches of the three buildings and their details are summarized in Table 2 [2, 7, 13]. The EnergyPlus software was used to simulate the energy consumption of the buildings.



(a)



(b)



(c)

Figure 1. Illustrations of three sample buildings: (a) office (b) department store (c) hotel.

Table 2. Detail summary of three sample buildings.

Detail	Office	Department store	Hotel
Structure			
Wall area (m^2)	6,934.00	3,304.52	4,319.00
Window area (m^2)	3,051.00	1,208.00	733.93
Window-to-wall ratio	44.00	36.56	16.99
Roof area (m^2)	1,047.25	2,771.22	3,052.80
Total floor area (m^2)	12,567.00	8,280.00	11,448.00
Internal design criteria			
Occupancy level (m^2/per)	14.29	5.00	5.00
Lighting power density (W/m^2)	13.000	14.325	8.710
Equipment power density (W/m^2)	16.460	20.635	8.527
Type of air conditioning system	Central, water-cooled chiller	Central, water-cooled chiller	Central, water-cooled chiller
Thermostat setpoint (ºC)	25	25	25
Infiltration rate (ACH)	0.35	0.35	0.35
Ventilation rate (m^3/s-m^2)	0.000556	0.000556	0.000556
Operating days	Mon-Sat	Mon-Sun	Mon-Sun
Operating hours	08:00-17:00	10:00-21:00	24 hours

In this work, ASHRAE's Building EQ was selected to be the building performance scoring system. To calculate the scores, building energy consumption (site energy) has to be converted to primary energy (source energy) first by applying a conversion factor called a source-site ratio [14]. After that, the source energy use per unit floor area (source EUI) will be compared with the median

EUI, which is the median value the source EUI of the building stock of the same type in the relevant weather zone [15]. For this study, the building stocks of Thailand during 2010-2013 were used to calculate the Building EQ scores. The median EUIs of office, department store, and hotel buildings were found to be 994.08, 2,863.12, and 615.60 MJ/m^2, respectively. Equation (1) expresses how to calculate the Building EQ scores of a building.

$$\text{BuildingEQ} = \frac{\text{SourceEUI}}{\text{MedianEUI}} \text{x} 100 \tag{1}$$

where, source EUI = source energy use per unit floor area (MJ/m^2)
median EUI = median EUI of the building stock of the same type (MJ/m^2).

The Building EQ scores are classified into 7 levels as follows: unsatisfactory (F, > 145), inefficient (D, 116-145), average (C, 86-115), efficient (B, 56-85), very good (A-, 26-55), high performance (A, 1-25), and zero net energy (A+, ≤ 0). It should be noticed that in this scoring system less scores mean higher energy efficiency. Zero or negative scores imply that the building can produce energy equal to or more than it uses [15].

The same set of 11 ECMs was applied to all three sample buildings. Those ECMs are listed in Table 3.

Table 3. ECMs for all three sample buildings.

ECM	Description
S1	Increase thermostat setpoint from 25ºC to 26ºC
S2	Turn off the light during 12:00-13:00
S3	Increase chilled water temperature setpoint from 6.7ºC to 7.2ºC
A1	Install VSDs at pumps
L1	Use electronic ballasts instead of magnetic ballasts
L2	Use LED lamps instead of fluorescent lamps
P1	Install solar photovoltaic panels
E1	Use light-weight bricks instead of conventional bricks
E2	Install 2-in insulation on the roof
E3	Install 2-in insulation on the walls
E4	Use low-e glasses instead of clear glasses

In this study, the impact on the optimum building performance scores when applying different ECM sorting schemes was investigated. The 'optimum' scores in this study were considered to be the point where the next ECM caused the scores to change by no more than 5%. It implies that it is not worth investing in ECMs beyond this point since the scores received in return would not be attractive enough. Six sorting schemes listed as follows were investigated: (a) energy cost saving (descending order), (b) investment cost (ascending order), (c) earning scores (descending order), (d) simple payback period (ascending order), (e) NPV (descending order), and (f) IRR (descending order). In order to see whether the different sorting schemes lead to approximately the same optimum scores or not, the difference in maximum and minimum scores as well as the difference in maximum and minimum investment cost per scoring point at the optimum scores among the six schemes were considered. If the differences were small then it can be said that different sorting schemes have no significant effect on the optimum scores, particularly from the financial point of view.

3. Results and Discussion

3.1. *Energy saving, scores, and financial return from ECMs*

Tables 4 to 6 show the results on the energy saving, investment cost, Building EQ scores, and return on investment of all 11 ECMs for the three sample buildings.

Table 4. ECMs assessment results for the sample office building.

ECM	Energy use (kWh/y)	Energy saving kWh/y	Energy saving Bath/y	Energy saving %	Investment (Baht)	Building EQ scores	Payback period (y)	NPV (Baht)	IRR (%)
Baseline	2,043,809.23	-	-	-	-	162.20	-	-	-
S1	2,016,238.88	27,570.35	84,689.32	1.35	-	160.01	-	815,383.71	-
S2	1,983,125.61	60,683.62	179,480.35	2.97	-	157.39	-	1,728,026.00	-
S3	2,035,735.77	8,073.46	26,002.88	0.39	-	161.56	-	250,354.15	-
A1	2,008,451.30	35,357.93	99,796.97	1.73	144,760.00	159.40	1.45	816,079.17	0.69
L1	1,900,965.01	142,844.21	441,320.30	6.99	213,120.00	150.87	0.48	3,687,963.53	2.06
L2	1,853,431.92	190,377.31	588,258.44	9.31	859,584.00	147.09	1.46	4,542,914.74	0.68
P1	1,845,906.86	197,902.37	584,308.86	9.68	7,043,299.20	146.50	12.05	-2,038,663.02	0.04
E1	2,040,753.26	3,055.97	8,540.00	0.15	141,341.20	161.96	16.55	-59,118.59	0.02
E2	2,041,594.14	2,215.09	6,148.87	0.11	109,504.75	162.02	17.81	-50,303.82	0.01
E3	2,038,592.46	5,216.77	14,404.17	0.26	405,863.00	161.79	28.18	-267,180.54	-0.03
E4	2,026,807.09	17,002.14	52,223.71	0.84	1,081,832.25	160.85	20.33	-569,397.59	-0.002

Table 5. ECMs assessment results for the sample department store building.

ECM	Energy use (kWh/y)	Energy saving kWh/y	Energy saving Bath/y	Energy saving %	Investment (Baht)	Building EQ scores	Payback period (y)	NPV (Baht)	IRR (%)
Baseline	2,156,533.18	-	-	-	-	90.19	-	-	-
S1	2,132,107.63	24,425.55	74,107.07	1.13	-	89.17	-	713,498.45	-
S2	2,105,251.00	51,282.18	151,294.94	2.38	-	88.04	-	1,456,658.53	-
S3	2,149,106.29	7,426.89	23,347.08	0.34	-	89.88	-	224,784.33	-
A1	2,093,559.59	62,973.59	187,352.50	2.92	124,080.00	87.55	0.66	1,679,738.61	1.510
L1	2,009,210.19	147,322.99	449,627.88	6.83	154,740.00	84.03	0.34	3,921,634.67	2.902
L2	1,959,886.48	196,646.69	600,003.02	9.12	624,118.00	81.96	1.04	4,963,012.42	0.961
P1	1,622,535.72	1,578,606.76	1,578,606.76	24.76	18,334,937.60	67.86	11.61	-4,752,919.61	0.045
E1	2,148,098.39	8,434.79	26,521.99	0.39	76,313.33	89.84	2.88	179,038.83	0.347
E2	2,133,774.24	22,758.94	69,702.16	1.06	289,662.30	89.24	4.16	381,425.89	0.237
E3	2,139,295.86	17,237.32	53,663.93	0.80	219,218.80	89.47	4.09	297,454.31	0.242
E4	2,146,203.94	10,329.23	31,944.79	0.48	428,336.07	89.76	13.41	-120,773.58	0.042

Table 6. ECMs assessment results for the sample hotel building.

ECM	Energy use (kWh/y)	Energy saving kWh/y	Energy saving Bath/y	Energy saving %	Investment (Baht)	Building EQ scores	Payback period (y)	NPV (Baht)	IRR (%)
Baseline	2,420,330.82	-	-	-	-	340.50	-	-	-
S1	2,394,027.35	26,303.47	79,835.14	1.09	-	336.80	-	768,647.90	-
S2	2,410,463.76	9,867.07	29,158.04	0.41	-	339.11	-	280,731.81	-
S3	2,417,949.36	2,381.46	7,424.86	0.10	-	340.16	-	71,486.13	-
A1	2,212,353.25	207,977.57	614,437.06	8.59	57,530.00	311.24	0.09	5,858,233.03	10.680
L1	2,330,993.89	89,336.93	275,077.95	3.69	130,080.00	327.93	0.47	2,305,996.27	2.107
L2	2,301,180.25	119,150.57	366,808.61	4.92	524,656.00	323.73	1.43	2,847,518.00	0.699
P1	2,202,192.84	218,137.98	644,891.75	9.01	7,714,089.60	309.81	11.96	-2,185,313.03	0.041
E1	2,402,166.05	18,164.78	55,833.86	0.75	130,496.55	337.94	2.34	407,068.47	0.428
E2	2,396,132.07	24,198.76	74,648.89	1.00	319,125.00	337.09	4.28	399,590.03	0.230
E3	2,385,969.51	34,361.32	105,989.40	1.42	374,723.05	335.66	3.54	645,736.50	0.281
E4	2,413,743.09	6,587.73	20,267.87	0.27	260,238.99	339.57	12.84	-65,101.12	0.047

3.2. *Impact from different ECM sorting schemes*

By applying 6 sorting schemes as follows: (a) energy cost saving in descending order, (b) investment cost in ascending order, (c) earning scores in descending order, (d) simple payback period in ascending order, (e) NPV in descending order, and (f) IRR in descending order, together with the data from Tables 4 to 6, the ECMs were sorted as shown in Tables 7 to 9. Figures 2 to 4 show the progress of the scores and the accumulative investment cost related to ECMs applied according to the 6 different sorting schemes for all three sample buildings.

Table 7. ECMs in order for the sample office building.

Sorting scheme	ECMs in order[a]										
	1	2	3	4	5	6	7	8	9	10	11
(a) Energy cost saving	P1	L2	L1	S2	A1	S1	E4	S3	E3	E1	E2
(b) Investment cost	S2	S1	S3	E2	E1	A1	L1	E3	L2	E4	P1
(c) Earning scores	P1	L2	L1	S2	A1	S1	E4	S3	E3	E1	E2
(d) Simple payback period	S2	S1	S3	L1	A1	L2	P1	E1	E2	E4	E3
(e) NPV	L2	L1	S2	A1	S1	S3	E2	E1	E3	E4	P1
(f) IRR	S2	S1	S3	L1	A1	L2	P1	E1	E2	E4	E3

[a] Shaded ECMs show the optimum points.

Table 8. ECMs in order for the sample department store building.

Sorting scheme	ECMs in order[a]										
	1	2	3	4	5	6	7	8	9	10	11
(a) Energy cost saving	P1	L2	L1	A1	S2	S1	E2	E3	E4	E1	S3
(b) Investment cost	S2	S1	S3	E1	A1	L1	E3	E2	E4	L2	P1
(c) Earning scores	P1	L2	L1	A1	S2	S1	E2	E3	E4	E1	S3
(d) Simple payback period	S2	S1	S3	L1	A1	L2	E1	E3	E2	P1	E4
(e) NPV	L2	L1	A1	S2	S1	E2	E3	S3	E1	E4	P1
(f) IRR	S2	S1	S3	L1	A1	L2	E1	E3	E2	P1	E4

[a] Shaded ECMs show the optimum points.

Table 9. ECMs in order for the sample hotel building.

Sorting scheme	ECMs in order[a]										
	1	2	3	4	5	6	7	8	9	10	11
(a) Energy cost saving	P1	A1	L2	L1	E3	S1	E2	E1	S2	E4	S3
(b) Investment cost	S1	S2	S3	A1	L1	E1	E4	E2	E3	L2	P1
(c) Earning scores	P1	A1	L2	L1	E3	S1	E2	E1	S2	E4	S3
(d) Simple payback period	S1	S2	S3	A1	L1	L2	E1	E3	E2	E4	P1
(e) NPV	A1	L2	L1	S1	E3	E1	E2	S2	S3	E4	P1
(f) IRR	S1	S2	S3	A1	L1	L2	E1	E3	E2	E4	P1

[a] Shaded ECMs show the optimum points.

From Figure 2, it can be seen that for the sample office building the optimum scores when applying the ECM sorting schemes of energy cost saving, investment cost, earning scores, simple payback period, NPV, and IRR were found to be 110.33, 109.29, 110.33, 111.15, 109.29, and 111.15 points, respectively. The maximum and minimum scores were different by only 1.70%. The Building EQ level of all cases was C. The investment cost per scoring point at the optimum scores were found to be 84,681.80, 91,491.20, 84,681.80, 74,321.72, 91,491.20, and 74,321.72 Baht/point, respectively. The difference between the maximum and minimum investment cost per scoring point was calculated to be 23.10%.

It can be drawn further from Table 7 and Figure 2 that if the sorting schemes were related to money, i.e., investment cost, payback period, NPV, and IRR, the ECMs would be sorted in a similar order and the investment cost would be gradually increased as the ECMs were sequentially implemented as shown in Figures 2(b), 2(c), 2(e), and 2(f). But if the energy saving or performance scores were the priority and needed to gain as much as it could since the beginning, it had to be traded off with high investment cost since the beginning as well which can be seen from Figures 2(a) and 2(d). For the cases in this study, the decisive ECM was P1, the installation of solar photovoltaic panels, which required high investment cost but also yielded high saving.

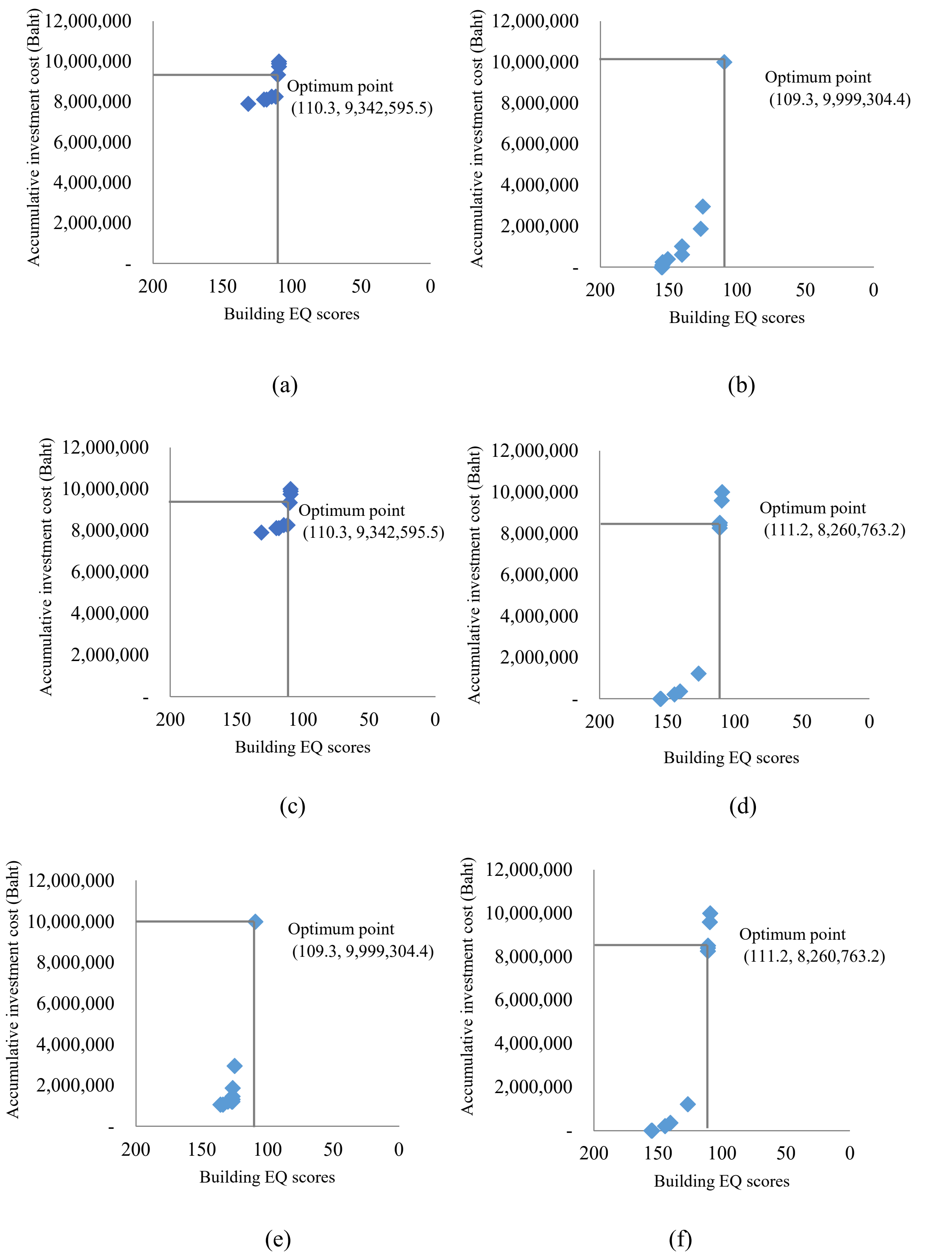


Figure 2. Accumulative investment cost and Building EQ scores from different ECM sorting schemes for the sample office building (a) energy cost saving (b) investment cost (c) earning scores (d) simple payback period (e) NPV (f) IRR.

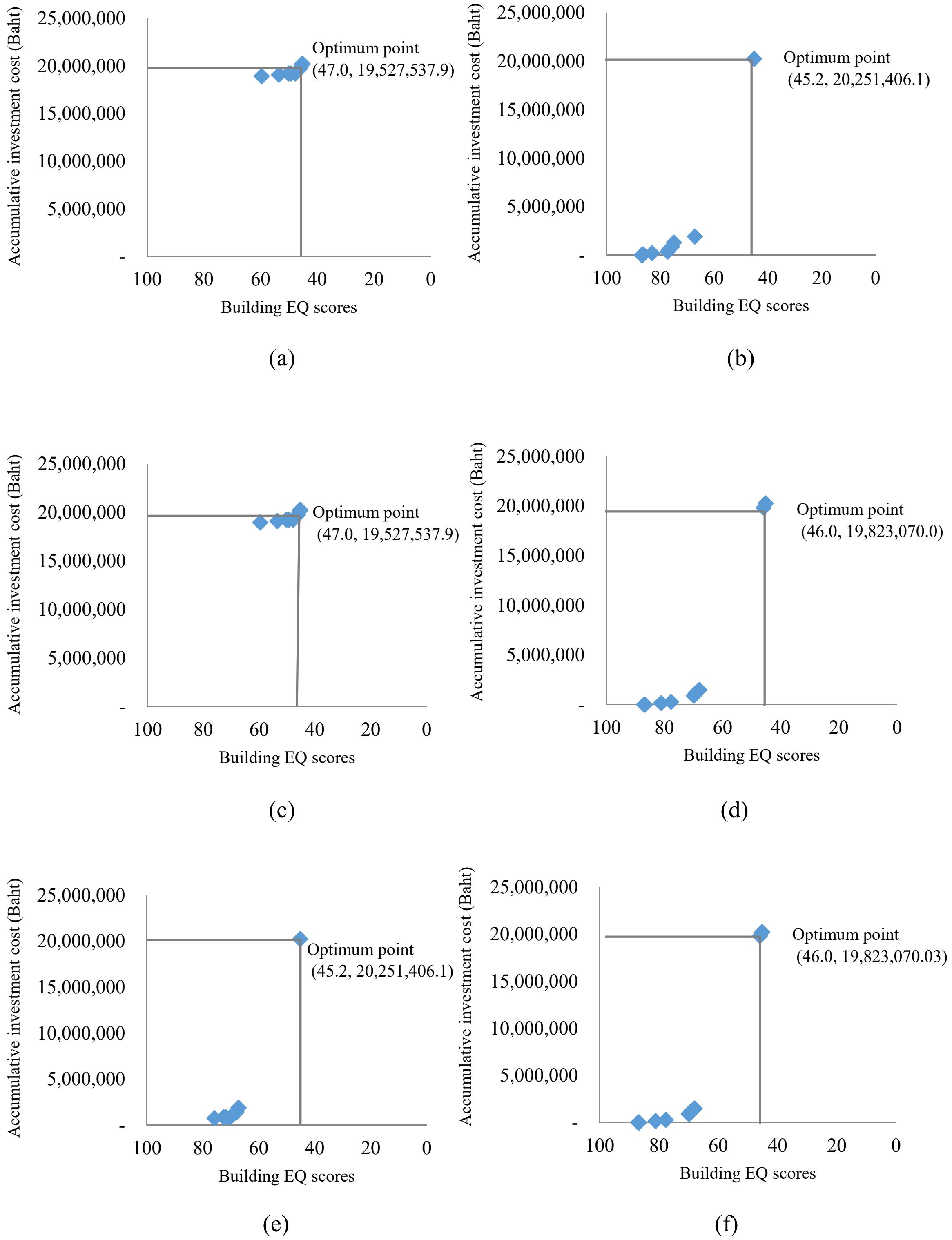


Figure 3. Accumulative investment cost and Building EQ scores from different ECM sorting schemes for the sample department store building (a) energy cost saving (b) investment cost (c) earning scores (d) simple payback period (e) NPV (f) IRR.

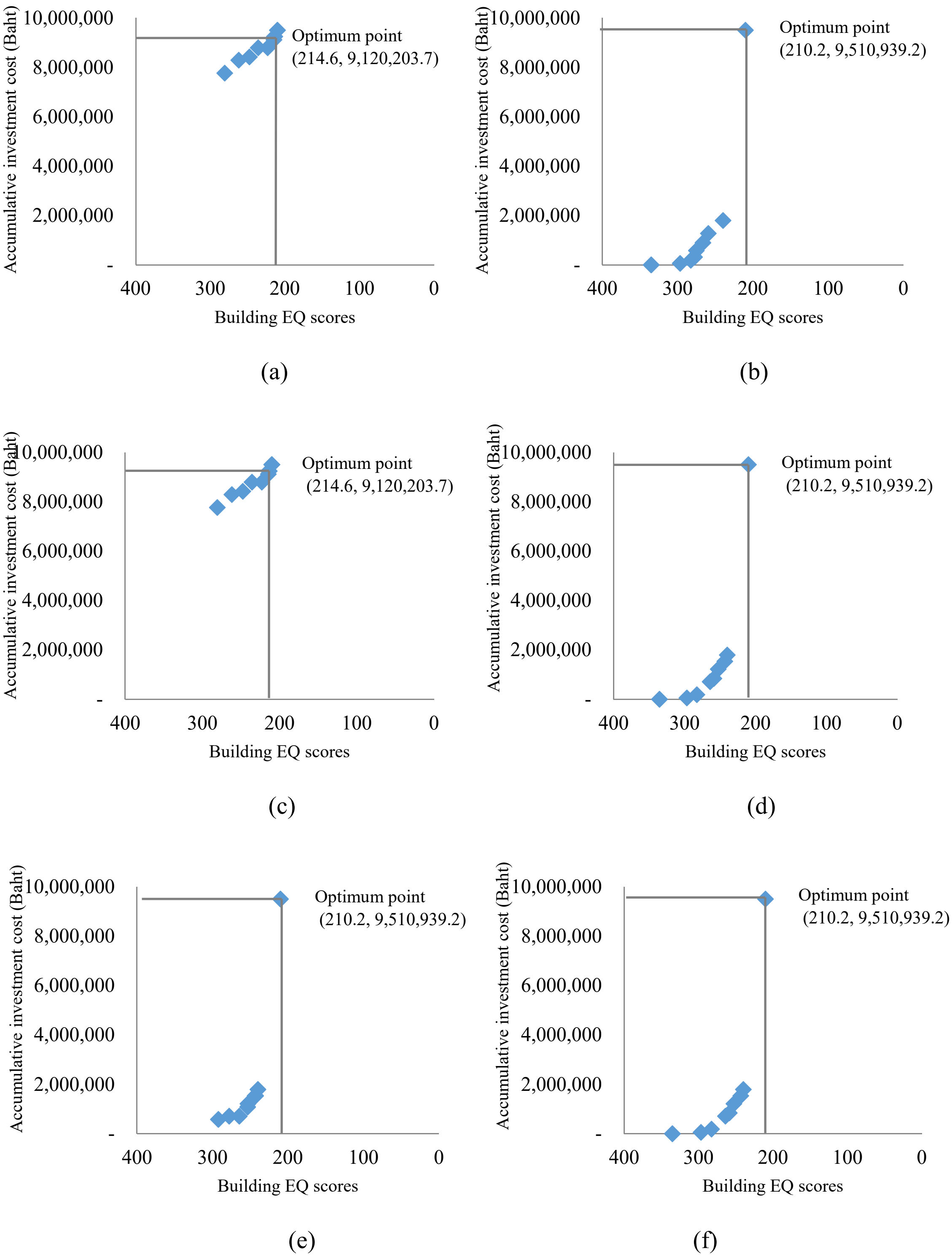


Figure 4. Accumulative investment cost and Building EQ scores from different ECM sorting schemes for the sample hotel building (a) energy cost saving (b) investment cost (c) earning scores (d) simple payback period (e) NPV (f) IRR.

From Table 8 and Figure 3, it can be noticed that for the sample department store building the optimum scores when applying the 6 ECM sorting schemes were found to be 47.02, 45.21, 47.02, 45.96, 45.21, and 45.96 points, respectively. The maximum and minimum scores were different by only 4.00%. The Building EQ level of all cases was A-. The investment cost per scoring point at the optimum scores were found to be 415,328.96, 447,944.29, 415,328.96, 431,330.11, 447,944.29, and 431,330.11 Baht/point, respectively. The difference between the maximum and minimum investment cost per scoring point was found to be only 7.85%. The observations on the trend of the investment cost and the performance scores as the ECMs were implemented one after another were similar to those mentioned for the sample office building.

From Table 9 and Figure 4, it can be seen that for the sample hotel building the optimum scores when applying the 6 ECM sorting schemes were found to be 214.63, 210.17, 214.63, 210.17, 210.17, and 210.17 points, respectively. The maximum and minimum scores were different by only 2.12%. The Building EQ level of all cases was F. The investment cost per scoring point at the optimum scores were found to be 37,811.99, 40,268.78, 37,811.99, 40,268.78, 40,268.78, and 40,268.78 Baht/point, respectively. The difference between the maximum and minimum investment cost per scoring point was found to be only 6.50%. The observations on the trend of the investment cost and the performance scores as the ECMs were implemented one after another were similar to those mentioned for the sample office building and the sample department store building.

When considering the results from all 3 sample buildings, it was found that the optimum building performance scores were almost the same no matter how the ECMs were sorted in order. This finding is very useful because ones can implement ECMs in any order knowing that at the end the optimum building performance scores would be about the same. Another important finding from this study is that if ones want to implement ECMs to earn high energy saving or high scores since the beginning they have to realize that it requires high investment since the beginning in return.

4. Conclusion

In this study, the optimum building performance scores when applying different ECM sorting schemes were investigated to see if they would be about the same or not. Six sorting schemes, which are energy cost saving (descending order), investment cost (ascending order), earning scores (descending order), simple payback period (ascending order), NPV (descending order), and IRR (descending order), were tested. An office building, a department store building, and a hotel building were chosen to be the sample buildings. ASHRAE’s Building EQ was selected to be the building performance scoring system. It was found that ECMs could be sorted with any sorting schemes up to the priority set by the building owner, the optimum performance scores would finally be about the same. Moreover, it was found that if high energy saving or high scores are needed from the beginning, high investment is also needed from the beginning in exchange as well.

Acknowledgment

The authors would like to thank the Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University for all supports to complete this work.

References

[1] Energy Policy and Planning Office 2017 *Energy Consumption in Jan to Apr 2017* (Bangkok: Energy Forecast and Information Technology Center)
[2] Chirarattananon S and Taweekun J 2003 *Energy Conversion and Management* **44** 743
[3] Pan Y, Yin R and Huang Z 2008 *Energy and Buildings* **40** 1145
[4] Katejanekarn T, Jaruyanon P, Mettanant V, Chomchuen P and Kesornthong P 2007 *The 21st Conference on Mechanical Engineering Network of Thailand* (Pattaya: Royal Thai Air Force Academy) p 60
[5] Pinpiti W 2016 *Feasibility Study of Constructing Office Buildings to Comply with Green Building Standards* (Nakhon Pathom: Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University)

[6] Prakongjai J and Kittiwannachot N 2012 *Evaluation of Constructing a Building to Conform to Thailand's Green Building Standard* (Nakhon Pathom: Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University)
[7] Yungchareon V and Limmeechokchai B 2004 *International Conference on Sustainable Energy and Environment* (Hua Hin: JGSEE-CEE)
[8] Montgomery R and Wentz T G 2014 *ASHRAE Journal* **56** 62
[9] Hirunyakarn N and Tangwichai L 2012 *Feasibility Analysis for a Construction of a Green Building* (Nakhon Pathom: Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University)
[10] Samutsopakul S and Lakboon A 2016 *Comparison of Financially Optimum Green Building Label between LEED 2009 and LEED v.4* (Nakhon Pathom: Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University)
[11] Chantrasawang T and Ounwised M 2016 *Financially Optimum Green Building Level for an Office Building* (Nakhon Pathom: Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University)
[12] Mettanant V and Katejanekarn T 2014 *International Conference and Utility Exhibition on Green Energy for Sustainable Development* (Pattaya: Asian Institute of Technology) p 57
[13] Chirarattananon S and Limmeechokchai B 1994 *Energy* **19** 269
[14] Energy Star 2009 *Methodology for Incorporating Source Energy Use* (United States: Energy Star)
[15] ASHRAE 2015 *Building Energy Quotient (bEQ)*, http://www.buildingenergyquotient.org, access on 28/04/2017