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Optimum Design of Retail and Wholesale Building for Minimum Energy Consumption and Total Cost

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ABSTRACT

The electric consumption in the building shares the highest portion in all user sectors. Therefore, energy conservation in building is important to get higher energy standard in the country. Retail and wholesale building consume high electricity. Energy consumption ratio in this building type is 40% Air conditioning, 28% Refrigeration, 12% lighting and 20% from the other. Those element need to be focused. This research is an optimization of air conditioning design and building envelope with operation schedule, refrigeration and lighting system. The objective is to find out optimization design to minimize total cost. The design criteria is to maintain requirement at day time whereas to response refrigeration system at all night. The developed designed is interacted between building system and building envelop. Case study is retail and wholesale building in Thailand. The design with life time of the machine, replacement cost and energy consumption of each option will be used to evaluate total life cycle cost. This study results in the total life cycle cost of new model of 1,014.14 M Baht comparing with 1,207.91 M Baht of conventional design. It has been saved 193.76 M Baht or 16% for 30 years. Therefore, the benefit of new improvement is very high and helps building owner to save a huge amount of money.

Keywords: Optimization Design, Retail and Wholesale Building, Energy Saving in Retail and Wholesale Building
JEL Classifications: Q400 Energy, General

1. INTRODUCTION

Within the current rate of population growth and technology trend, the future global economy is likely to consume more energy, especially in the building. At the same time, the tremendous risk of climate change associated with the use of fossil fuels makes supplying this energy increase difficult (Romprasert and Jermsittiparsert, 2019; Allouhi et al., 2015). We not only face the energy crisis, but also confront increased the emission of greenhouse gas (Jermsittiparsert and Chankoson, 2019). According to the electric consumption statistic 10 years ago in Thailand, Commercial and residential sectors consumed electricity 53.4% of all. Industrial sector consumes 45.7% while agricultural sector is 0.2%, and other sector is 0.6% (Energy in the buildings and social development plans national economy, 2019). The most energy consumption is commercial sector. So we have to consider the energy management in commercial sector and commercial building. Retail and wholesale is also considered, because the building need to be operated refrigeration system 24 h (Mylona et al., 2017; Gimeno-Frontera et al., 2018). Energy conscious design is important to improve energy efficiency in those building. Air conditioning system, refrigeration system and lighting system are considered to optimize design (Kosir et al., 2018). We cannot evaluate only energy consumption, we have to concern repair and maintenance cost and long term operation cost.

This paper is an analysis for total cost of energy for retail and wholesale building. This study improves current retail and wholesale building with conventional system in Thailand. Building size is 10,000 sq. m for total area and 7,000 sq. m. for sales area.

This can be classified as a large cold room and refrigeration system. The model is validated against the operation& maintenance cost, energy cost and investment cost of those three parts.

2. CASE STUDY BUILDING

The case study building for experimental research is retail and wholesale buildings in Bangkok Thailand. Building area is 10,000 sq. m. Sale area is 7,000 sq. m. The data parameter comparison is actual consumption and energy cost comparison. The trading hour is 6.00 till 22.00 every day. Energy consumption proportion are 40% of air conditioning system, 28% refrigeration system, 12% of lighting system, 6% of bakery system, 4% Sanitary system and 10% of other [Figure 1]. This building size is more than the one of 50 buildings in Thailand retail and wholesale building. It represents retail and wholesale building in this country.

2.1. Lighting System

Lighting system consumes 12% of total energy in the building. The conventional luminaires type comprise of T8 fluorescent (36 W) for fresh food area, racking area and office area, HID 150 W for general lighting in sale area and HID 250 W and 400 W for external lighting. Lighting luminance criteria is shown in Table 1.

2.2. Refrigeration System

Refrigeration system comprise of refrigerator and all cold room. It need more power and cooling load so remote condensing unite has been decided to use in the building. Refrigeration system consumes 28% of the total energy in the building. Remote condensing units have typical refrigerating capacities and are composed of one (and sometimes two or three) compressor(s), one condenser, and one receiver assembling into a single unit. This normally located externally nearby the sales area. The condenser (and often other parts of the system) is located outside the space or area cooled by the evaporator, typically ejecting heat to the outdoor ambient environment. In direct systems, the refrigerant circulates from the machinery room to the sales area, where it evaporates in display-case heat exchangers. Then returns in vapor phase to the suction headers of the compressor racks.

2.3. Air Conditioning System

The air conditioning system for this case is central water cool chiller system. It is a major energy consumption in the building. The air conditioning energy is 40% load of total building load. Water-cooled chiller is more efficient than air cool chiller one. This research study is to consider chiller selection of water cool system.

This system consists several essential components including cooling towers, condenser water pumps, chilled water pumps and chillers. This research considers RT refrigeration tons (BTU/h) selection. Chiller consumes 52% of air conditioning system. It means that 21.45% is chiller consumption out of 100% of the whole energy consumption in the building as Figure 2.

2.4. Building Envelope

This building is designed for active cooling. Their form and envelop are designed to minimize heat gain. Building size is 110 meters width and 80 meters long as floor plan shown in Figure 3. The building has two brick wall 150 mm thickness and 100 mm thickness for above 6.00 m. height providing high level of thermal mass. The roof material is metal sheet. Its thickness is 0.47 mm. with 3 inch insulation one. Its overall thermal transfer value (OTTV) and roof thermal transfer value (RTTV) are 16.22 BTU/sq. m. and 5.38 BTU/sq. m.

Figure 1: This is an energy consumption percentage by each system of case study building

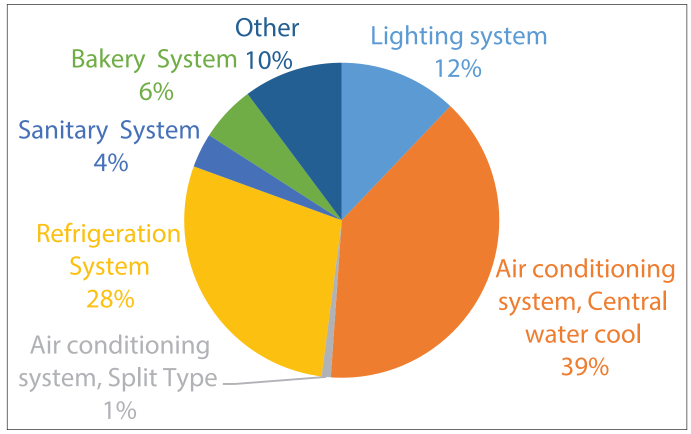


Figure 2: This is energy consumption percentage of air conditioning system by each machine of building study case

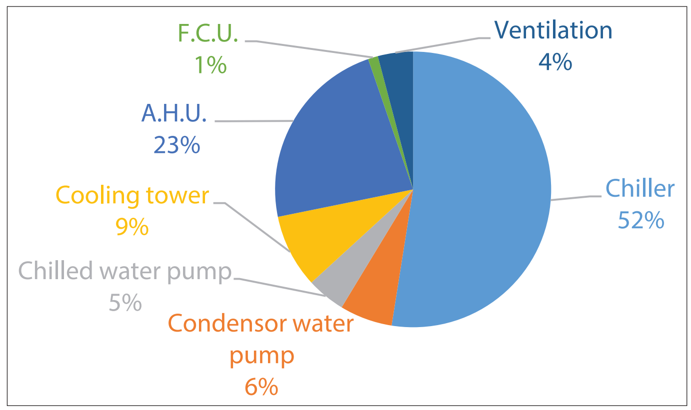


Table 1: Lighting criteria

Area	Luminance (*Lux*)
General sale area	500
Sale area, fresh food area	500
Sale area, high rack area	250
Office	500
Toilet	150
Storage, Warehouse	200
Office corridor	200
Plant room	200
Loading area	150
External	20

3. MATERIALS AND METHODS

3.1. Objective

This research objective is to find out the design solution for minimum total investment, energy and repair and maintenance cost of Retail and whole sale building.

Figure 3: This is architectural drawing for this case study building: (a) Site lay out, (b) Ground floor plan

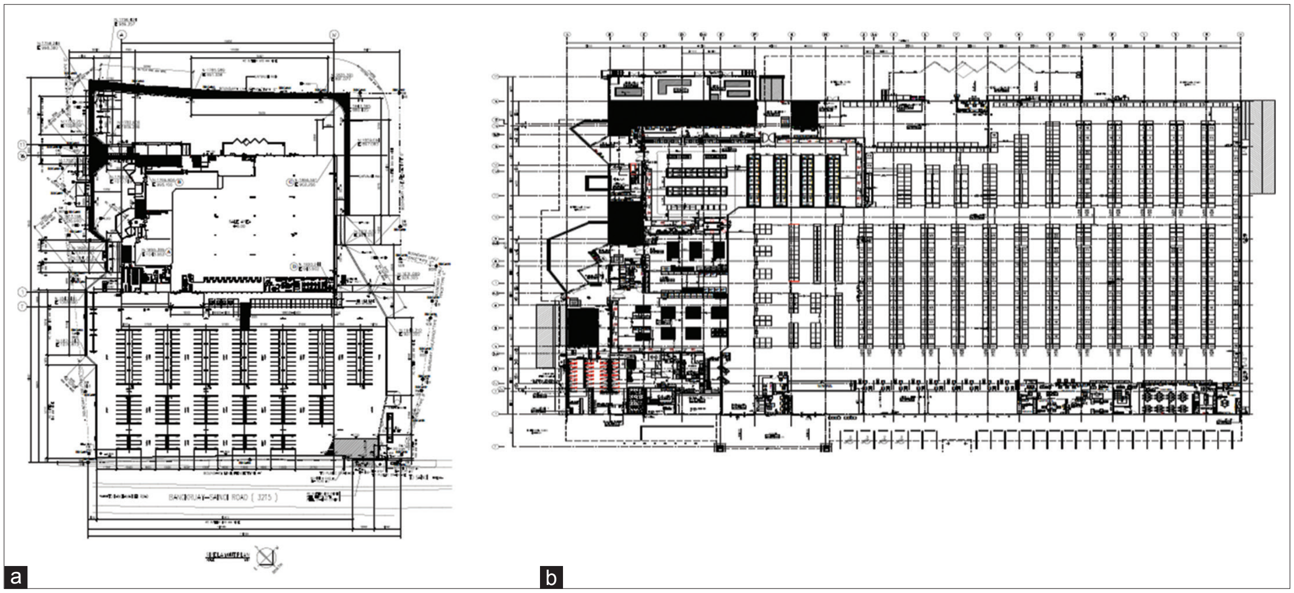
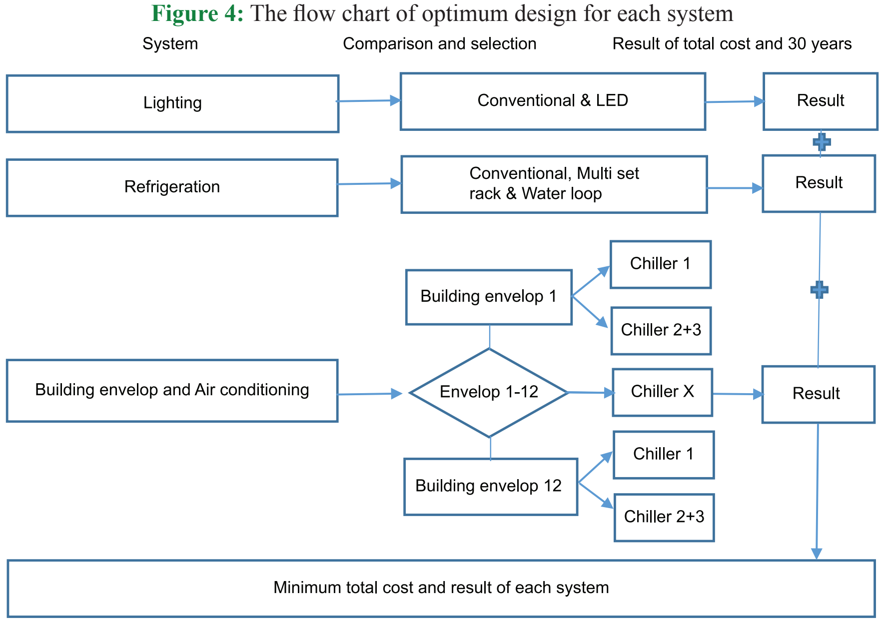


Figure 4: The flow chart of optimum design for each system



3.2. Scope of Research

The case study building for experimental research is retail and wholesale building in Bangkok, Thailand. Building area is 10,000 sq. m. Sale area is 7,000 sq. m. The data parameter comparison is energy cost, investment cost and maintenance cost during the whole building life of 30 years.

3.3. Research Methodology

Main design system in the building are lighting, refrigeration, building envelop and air conditioning. Lighting and refrigeration system are considered by each system to find an optimum design for minimum total cost. Building envelope and air conditioning system are direct related for investment and energy cost optimization. Both system are considered to find optimization together. Lighting and refrigeration system are not directly related to energy consumption of air conditioning system. It can be separately considered. The result of lighting and refrigeration system will be put in the factor of calculation for cooling load of air conditioning system (Wang et al., 2012).

The present study was divided into three stages. First stage is lighting design. Second one is refrigeration system. The last one is the combination design between building envelop and air conditioning system. Base on the proposed methods which are introduced above, the result of each one is presented as following sub-sections. Lighting system, refrigeration system, building envelop and air conditioning system design method chart is shown in Figure 4.

Referring the consumption of each system, it leads to 30 years expense calculation cost. The 30 years is building aging according to accounting. Total cost expenses include energy cost, investment cost and maintenance cost (Karasek et al., 2018). Those are used to calculate 30 years present worth.

3.3.1. Lighting system optimum design

Lighting design is one system to be considered for high efficiency of energy management in the building. LED lighting is high efficiency with high investment cost. On the other hand, conventional lamp is normal efficiency with low investment cost. Conventional lamp includes fluorescent and high intensity pressure discharge lamp (Watcharapongvinij and Therdyothin, 2017).

This research one is to follow the case study building condition with two material of lighting system. First system is conventional and second is LED. DIA LUX is a tool to find quantity of lamp with the lighting condition according to the number in Table 2 and lighting plan shown in Figure 5. Two numbers of difference lamp will be analyzed in the next step.

According to the Table 2, two type of lighting system is different in the number, energy use (kW), replacement of the light bulb and accessory investment cost. Total cost comparison is from 1st year to 30th year. To meet life time of building, firstly, Energy consumption has to be presented in actual load with all energy loss from ballast and diver. Researcher takes all lamps to measure actual consumption in all type of lamp. Then the energy consumption is yearly recorded. The energy cost was 3.816 baht/kWh from 2018 so it will be increased by 1.9% per year (Hirunwong and Singhasane, 2015). Actual cost from the starting year to the 30th year represents cost each year, then the real cost has to be in present worth. The equation is as below.

$$P = F/(1*i)^n \qquad \text{(a)}$$

P = Present worth,
F = Future worth, and
I = Interest.

Lighting design results in 556,580 kWh yearly energy consumption of conventional lamp, and 330,304 kWh for LED lamp. According to the graph in Figure 6, The 30 years expense calculation result are 341.7 M Baht for conventional and 277.2 M Baht for LED

3.3.2. Refrigeration system optimum design

Fresh food area of retail and wholesale building temperature need to be controlled to maintain quality of product. Refrigeration system display consists multi-deck cabinet for 0-8°C (Degree Celsius) temperature, freezer cabinet for −20-18°C temperature, receiving area for 20°C temperature, freezer cold room for −20°C and chiller cold room for −5°C temperature.

For conventional system, all cabinet and cold room get refrigerant supply from multi set compressor rack with air cooled system. The current development is water cool system and separate freezer cabinet to be plugged in freezer cabinet. It also combines cooling tower with air conditioning system.

Figure 5: Those are comparison of high bay result of design: (a) Conventional lamp, (b) LED lamp

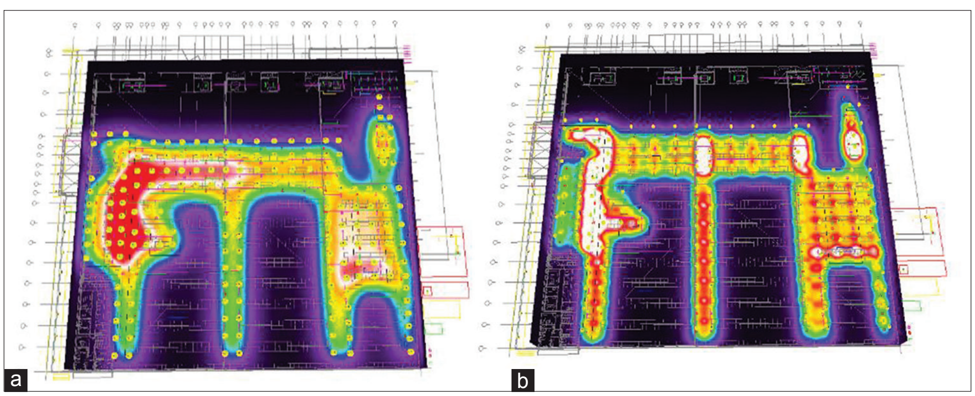


Table 2: Lighting quantity of each system from the design

Lamp description	Area	Luminaire (*lux*)	Quantity of conventional (*set*)	Quantity of LED (*set*)
D-5 High bay	Sale area	500	190	160
E-1 External flood light	Bill board	400	12	12
E-2/1 External flood light	General	20	18	18
E-2/2 External flood light	Street	400	16	13
F-8 External street light	Street	20	31	31
A-1/1 Internal (Fluorescent)	Good receiving	500	620	620
A-1/2 Internal (Fluorescent)	Butchery	500	30	30
A-2 Internal (Fluorescent)	Cold room	400	10	10
A-5 External (Fluorescent)	Parking	50	90	90
A-10 Internal (Fluorescent)	Racking	250	450	450
A-13 Internal (Fluorescent)	Cashier	500	10	10
B-2 Internal (Fluorescent)	Office	500	120	120
B-7 Internal (Fluorescent)	Toilet	150	20	20

Figure 6: Energy consumption comparison between conventional lamp and LED lamp

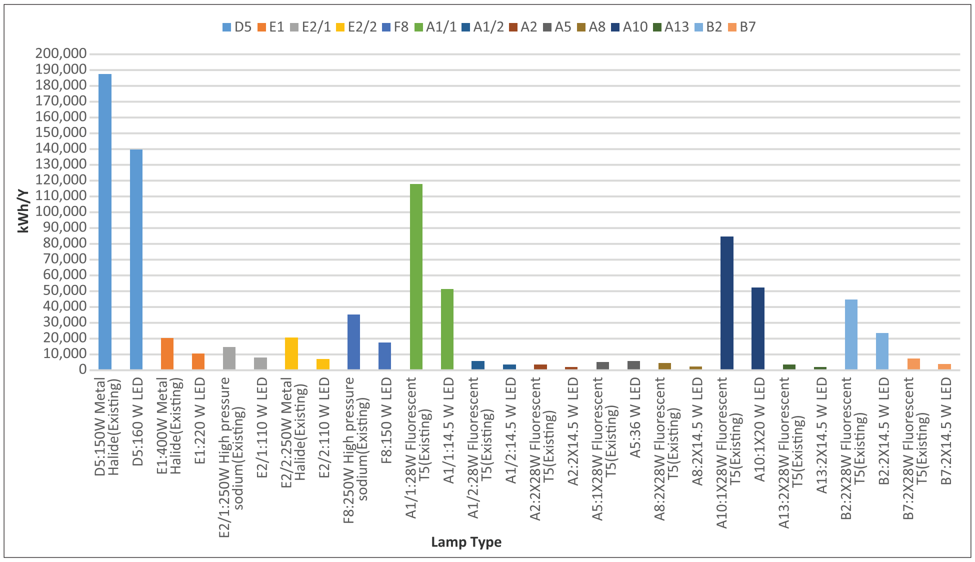
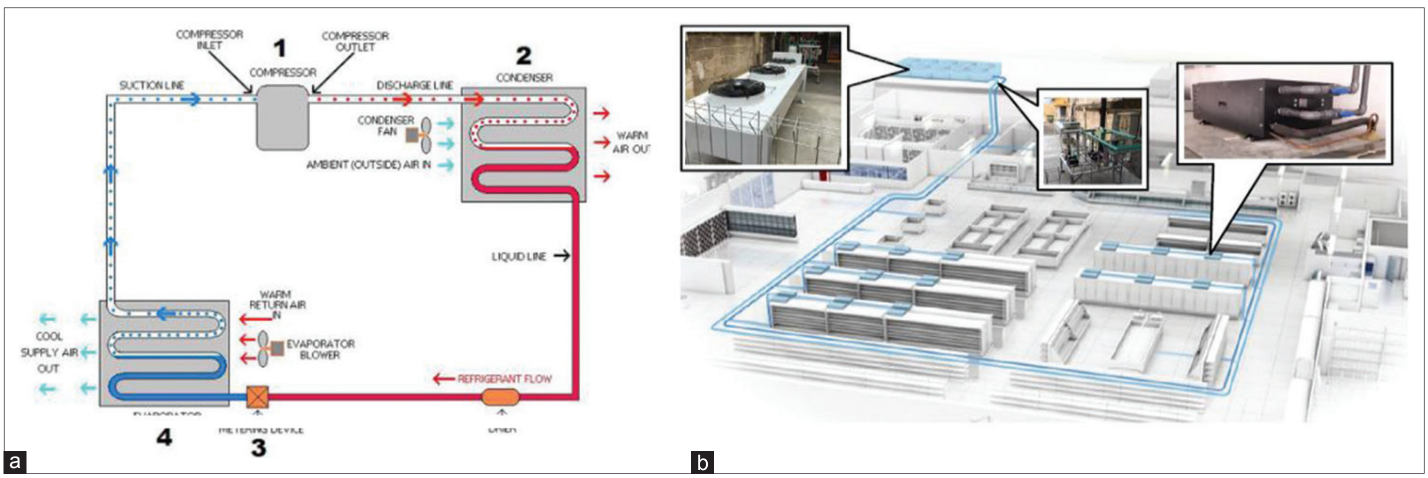


Figure 7: Those are diagram of two type of refrigeration system: (a) Multi set rack with remote system, (b) Water loop system



The refrigeration system with multi set compressor rack can be air cool or water cool system. Water cool system is more efficiency than air cool. The conventional system of this building research is water cool system and separated freezer cabinet. High efficiency plug in freezer cabinet is selected to replace island freezer cabinet remote system for total energy consumption saving and repair and maintenance.

Multi set compressor rack system has efficient performance to manage refrigerant from central rack as diagram shown in Figure 7a. On the other hand, the quantity of refrigerant and piping should be considered for investment cost, temperature leakage also refilling of refrigeration during repair and maintenance. The new development trend is water loop system. Water loop system is considered to compare with multi set rack for minimum total cost of retail and whole sale building as diagram shown in Figure 7b.

The last few years, a new system has been discussed in the commercial refrigeration market, involving a water loop with variable speed compressors. This system represents a change in approach comparing to conventional systems. Conventional systems are centralized, with compressor racks - generally installed in equipment rooms or on the roof of the building - that supply refrigerant to the evaporating units (showcases and cold rooms inside the store) via long copper pipes. The water loop solution, on the other hand, is the distributed system: the refrigeration units feature small water-cooled condensing units fitted with compressors. A simple water circuit is used to carry away the heat or transfer it to the outside via a dry cooler. Water loop system is considered to reduce energy lose and leakage from central multi set rack to each cabinet and evaporator. It has a lot of benefit such as fast installation, low maintenance cost, low initial refrigerant cost and reduction of refrigerant charge and less leaks (Five advantages of the water loop system for refrigeration in supermarkets, 2019).

This experimental research is to find out the actual result from energy measurement of 2 sites with same load demand as shown in Figure 8. First is conventional multi set compressor rack and second is water loop system. The first stage is a design of conventional system by calculation sheet in Figures 9 and 10. Then water loop design sheet is in Figures 11 and 12.

This research study is not only calculation design comparison but also experimental result. It is a final stage to measure actual consumption as show in Table 3.

Figure 8: Those are elements of 2 types of refrigeration system: (a) Conventional multi set rack (b) Water loop system

Figure 9: This is calculation sheet of chiller system for conventional multi set rack

CHILLER RANGE

Item No.	Cabinets Modle	Description	Dimentions 1250	1875	2500	3750		Shelf	EC90°	Connected Load (kW.)/Uni Defr.heater	Fra.heater	Fans	Lighting	Load Max	Temp.(°C)	Evap.(°C)	Ref.Capacity(kW)	Electric Load(kW)	Orific No.
1	MENDOS LUD 375	Fruit & Vegetable	-	-	-	7	-	4	-	-	0.10	0.10	0.30	0.50	+4/+6	-5.5	29.83	3.49	
2	MENDOS LUM 375	Dairy	-	-	-	5	-	4	-	-	0.10	0.11	0.30	0.52	+0/+2	-6	26.36	2.59	
3	MENDOS LUM 250	Dairy	-	-	6	-	-	4	-	-	0.07	0.08	0.20	0.35	+0/+2	-6	21.20	2.07	
4	ZK ASAR 37 SS	Service Counter	-	-	-	6	-	-	-	0.49	0.17	0.09	-	0.26	+0/+2	-10	8.10	1.55	
5	ZK ASAR 25 SS	Service Counter	-	-	2	-	-	-	-	0.70	0.13	0.06	-	0.19	+0/+2	-10	1.80	0.38	
6	ZK-ASAR9ESS	Service Counter	-	-	-	-	-	-	1	0.23	0.07	0.03	-	0.33	+0/+2	-10	0.60	0.33	
			0	0	8	18	0		1						Total		87.89	10.41	

Item No.	Area	eigl ubic mporator Mo	QTY	Temp.(°C)	Evap.(°C)	Ref.Capacity(kW)	Electric Load(kW)	Orific No.
7	Fruit & Veg Chiller Room(Small)	SPB042D	1	+4/+6	-4	4.73		
8	Fruit & Veg Chiller Room	SPB052D	1	+4/+6	-4	8.70		
9	Dairy Chiller Room	SPBE062D	1	+1/+3	-8	10.80		
10	Meat Chiller Room	SPBE062D	1	+1/+3	-8	10.80		
11	Poultry Chiller Room	SPBE043D	1	+1/+3	-8	7.04		
12	Fish Chiller Room	SPBE043D	1	+1/+3	-8	7.20		
13	Ante Room	SPBE031D	1	+1/+3	-8	1.14		
14	Meat Prep.	SPA031D	1	+15	+5	2.88		
15	Fish Sale Area	DFB063C	2	+15	+5	15.92		
16	FV. Sale Area	DFB063C	4	+15	+5	31.84		
17	F&V Receiving	SPB043D	1	+15	+5	9.62		
18	Meat Receiving	SPB043D	1	+15	+5	9.62		
19	Dairy Receiving	SPB042D	1	+15	+5	8.00		
20	Fish Receiving	SPB042D	1	+15	+5	8.00		
		Total	18	Total		136.29	0.00	

*Compressor : 6MID-40X + 6MI-40X + (4MK-35X x 2) (249.4kW)
(68.1+68.7+(56.3x2))kW
Heat Reject : 371.3kW

Total Ref.Capacity Load Item 1-20 224.18 (kW.)
Spare 11% 24.66 (kW.)
Grand total 248.84 (kW.)

Condenser :
Condition : Evaporator Temp. (to) = −11°C
Condenser Temp. (tc) = +40°C
Ambient Temp. (ta) = +37 °C
**R407F

Table 3: Refrigeration system comparison between conventional racking system and water loop system

	Calculation power, Energy consumption	Measurement energy consumption
Conventional	169 kW, 668,230 kWh/y	674,898 kWh/y
Water loop	215 kW, 735,241 kWh/y	1,004,230 kWh/y

Table 4: Refrigerant comparison between conventional racking system and water loop system

	Refrigerant charge (kg)	Annual leakage (kg)	GHG (ton CO^2)
Conventional	600	60	109
Water loop	300	30	55

The refrigerant is one factor to be evaluated life cycle cost. The refrigerant of water loop is 300 kg. but conventional is 600 kg. According to 50 building average record in Thailand, There is the leakage of refrigerant around 10% per year. It means that the annual leakage of water loop can be reduced 30 kg., 11,850 baht/year and 50% saving. On the other hand, GHG emission of water loop is lower than conventional 54 ton co_2 eq. as shown in Table 4.

The result of energy consumption, Conventional system is 674,898 kWh/year and water loop is 1,004,230 kWh/y. Those data come from measurement from the same load and building size also same date as shown in Figure 13.

To consider total cost of 30 years of building life. Initial cost, energy cost and repair and Maintenance cost of water loop system is 609.7 M Baht and conventional system is 446.9 Baht.

3.3.3. Building envelope and air conditioning system optimum design

This is the integrated design approach for building envelope with appropriate consideration to optimize roof insulation and heat

Figure 10: This is calculation sheet of freezer system for conventional multi set rack

FREEZER RANGE

Item No.	Cabinets Modle	Description	Dimentions: 2 Door	3 Door	4 Door	5 Door		Shelf	EC 90°	Connected Load (kW.)/Unit: Defr. heater	Fra. heater	Fans	Lighting	Load Max	Temp.(°C)	Evap.(°C)	Ref.Capacity(kW)	Electric Load(kW)	Orific No.
1	AGBT80-4Door	Frozen Cabinet	-	-	1	-	-	4	-	3.20	1.18	0.23	0.41	5.02	-25/-23	-33	2.05	5.02	
2	AGBT80-2Door	Frozen Cabinet	1	-	-	-	-	4	-	1.60	0.59	0.11	0.21	2.51	-25/-23	-33	1.05	2.51	
															Total		3.10	2.51	

Item No.		Area	eigl	ubic m	vaporator Mode	QTY.	Temp.(°C)	Evap.(°C)	Ref.Capacity(kW)	Electric Load(kW)	Orific No.
2	Bakery Freezer Room				SPBE042D	1	-25/-23	-33	2.51		
3	Dairy Freezer Room				SPBE042D	2	-25/-23	-33	10.39		
4	Meat Freezer Room				SPBE042D	2	-25/-23	-33	8.26		
5	Fish Freezer Room				SPBE042D	2	-25/-23	-33	8.22		
					Total	7	Total		29.38	0.00	

*Compressor : ZF41KQE x 3 (35.7kW)
(11.9 x 3)kW
Heat Reject : 65.19 kW

Total Ref.Capacity Load Item 1-6	32.48	(kW.)
Spare 9%	2.92	(kW.)
Grand total	35.40	(kW.)

Condenser :
Condition : Evaporator Temp. (to) = -35°C
Condenser Temp. (tc) = +40°C
Ambient Temp. (ta) = +37 °C
**R 407F

Figure 11: This is calculation sheet of showcase cabinet for water loop system

Cooling Load summary

ITEM.	DESCRIPTION	MODEL	DIMENSION	Q,TY	LOAD KW	WATER COOLED CONDENSING UNIT R-407F: NO	MODEL	CAPACITY (W)	BUFFER CAPACITY	HEAT REJECT CAPACITY (W)	ZONE 1 HEAT REJECT CAPACITY (W)	ZONE 2 HEAT REJECT CAPACITY (W)
Cab No.1	Frozen	AGBT80-4Door	4 Door	1	2,050	1	LR640FR1	5600W	36%	6,720	6,720	-
Cab No.23	Frozen	AGBT80-2Door	2 Door	1	1,050							
					3,100							
Cab No.2	Produce	MEHdooLUD375	3750	1	4,261	2	LR420CH1	4850W	14.0%	5,820	5,820	-
					4,261							
Cab No.3	Produce	MEHdooLUD375	3750	1	4,261	3	LR420CH1	4850W	14.0%	5,820	5,820	-
					4,261							
Cab No.4	Produce	MEHdooLUD375	3750	1	4,261	4	LR420CH1	4850W	14.0%	5,820	5,820	-
					4,261							
Cab No.5	Produce	MEHdooLUD375	3750	1	4,261	5	LR420CH1	4850W	14.0%	5,820	5,820	-
					4,261							
Cab No.6	Produce	MEHdooLUD375	3750	1	4,261	6	LR420CH1	4850W	14.0%	5,820	5,820	-
					4,261							
Cab No.7	Produce	MEHdooLUD375	3750	1	4,261	7	LR420CH1	4850W	14.0%	5,820	5,820	-
					4,261							
Cab No.8	Produce	MEHdooLUD375	3750	1	4,261	8	LR420CH1	4850W	14.0%	5,820	5,820	-
					4,261							
Cab No.9	Dry Fish	MEHdooLUM250	2500	1	4,940	44	LR725CH1	7250W	12.0%	8,700	8,700	-
Cab No.10	Fish Fillet	2K-ASAR25 SS	2500	1	900							
Cab No.11	Fish Fillet	2K-ASAR3E SS	90°	1	600							
					6,440							
Cab No.12	Dairy	MEHdooLUM375	3750	1	7,030	10	LR650CH1	7850W	12.0%	9,420	-	9,420
					7,030							
Cab No.13	Dairy	MEHdooLUM375	3750	1	7,030	11	LR650CH1	7850W	12.0%	9,420	-	9,420
					7,030							
Cab No.14	Dairy	MEHdooLUM375	3750	1	7,030	12	LR650CH1	7850W	12.0%	9,420	-	9,420
					7,030							
Cab No.15	Dairy	MEHdooLUM375	3750	1	7,030	13	LR650CH1	7850W	12.0%	9,420	-	9,420
					7,030							
Cab No.16	Dairy	MEHdooLUM250	2500	1	4,940	14	LR650CH1	7850W	58.0%	9,420	-	9,420
					4,940							
Cab No.17	Dairy	MEHdooLUM250	2500	1	4,940	15	LR650CH1	7850W	58.0%	9,420	-	9,420
					4,940							
Cab No.18	Dairy	MEHdooLUM250	2500	1	4,940	16	LR650CH1	7850W	58.0%	9,420	-	9,420
					4,940							
Cab No.19	Dairy	MEHdooLUM375	3750	1	7,030	17	LR650CH1	7850W	12.0%	9,420	-	9,420
					7,030							
Cab No.20	Poultry	2K-ASAR37 SS	3750	1	1,350	18	LR725CH1	7250W	8.0%	8,700	-	8,700
Cab No.21	Poultry	2K-ASAR37 SS	3750	1	1,350							
Cab No.22	Poultry	2K-ASAR25 SS	2500	1	900							
Cab No.23	Beef	2K-ASAR37 SS	3750	1	1,350							
Cab No.24	Pork	2K-ASAR37 SS	3750	1	1,350							
					6,300							
Cab No.25	Pork	2K-ASAR37 SS	3750	1	1,350	9	LR340CH1	3450W	11.0%	4,140	-	4,140
Cab No.26	Pork	2K-ASAR37 SS	3750	1	1,350							
					2,700							
Cab No.27	Dairy	MEHdooLUM250	2500	1	4,940	45	LR420CH1	4850W	0.0%	5,820	-	5,820
					4,940							
Cab No.28	Dairy	MEHdooLUM250	2500	1	4,940	46	LR420CH1	4850W	0.0%	5,820	-	5,820
					4,940							

Figure 12: This is calculation sheet of cold room for water loop system

Cold Room ITEMs	DESCRIPTION	MODEL	DIMENSION	Q,TY	LOAD KW	WATER COOLED CONDENSING UNIT R-407F: NO	MODEL	CAPACITY (W)	BUFFER CAPACITY	HEAT REJECT CAPACITY (W)	HEAT REJECT CAPACITY (W)	HEAT REJECT CAPACITY (W)
1	Fruit & Veg Chiller Roo	SPB042D		1	4,730	19	LR420CH1	5150W	9%	5,820	5,820	-
2	Fruit & Veg Chiller Roo	SPB052D		1	8,700	20	LR725CH1	9350W	7%	8,700	8,700	-
3	Dairy Chiller Room	SPBE062D		1	10,800	21	LR101CH1	12650W	17%	15,180	-	15,180
4	Meat Chiller Room	SPBE062D		1	10,800	22	LR101CH1	12650W	17%	15,180	-	15,180
5	Poultry Chiller Room	SPBE043D		1	7,040	23	LR725CH1	7900W	12%	8,700	-	8,700
6	Fish Chiller Room	SPBE043D		1	7,200	24	LR725CH1	7900W	10%	8,700	8,700	-
7	Ante Room	SPBE031D		1	1,140	25	LR130CH1	1450W	27%	1,740	1,740	-
8	Bakery Freezer	SPBE042D		1	2,510	26	LR350FR1	3070W	22%	3,684	3,684	-
9-1	Dairy Freezer	SPBE042D		1	5,195	27	LR640FR1	5600W	8%	6,720	-	6,720
9-2	Dairy Freezer	SPBE042D		1	5,195	28	LR640FR1	5600W	8%	6,720	-	6,720
10-1	Meat Freezer	SPBE042D		1	4,130	29	LR640FR1	5600W	35%	6,720	-	6,720
10-2	Meat Freezer	SPBE042D		1	4,130	30	LR640FR1	5600W	35%	6,720	-	6,720
11-1	Fish Freezer	SPBE042D		1	4,110	31	LR290FR1	2530W	12.0%	3,036	3,036	-
11-2	Fish Freezer	SPBE042D		1	4,110	32	LR640FR1	5600W	36%	6,720	6,720	-
12-1	Fish Sale Area	DFB063C		1	7,960	33	LR550CH1	10350W	30%	12,420	12,420	-
12-2	Fish Sale Area	DFB063C		1	7,960	34	LR550CH1	10350W	30%	12,420	12,420	-
13-1	FV. Sale Area	DFB063C		1	7,960	35	LR550CH1	10350W	30%	12,420	12,420	-
13-2	FV. Sale Area	DFB063C		1	7,960	36	LR550CH1	10350W	30%	12,420	12,420	-
13-3	FV. Sale Area	DFB063C		1	7,960	37	LR550CH1	10350W	30%	12,420	12,420	-
13-4	FV. Sale Area	DFB063C		1	7,960	38	LR550CH1	10350W	30%	12,420	12,420	-
14	FV. Receiving	SPB043D		1	9,620	39	LR550CH1	10350W	8%	12,420	12,420	-
15	Meat Receiving	SPB043D		1	9,620	40	LR550CH1	10350W	8%	12,420	-	12,420
16	Dairy Receiving	SPB042D		1	8,000	41	LR550CH1	10350W	29%	12,420	-	12,420
17	Fish Receiving	SPB042D		1	8,000	42	LR550CH1	10350W	29%	12,420	12,420	-
18	Meat Prep.	SPA031D		1	2,880	43	LR180CH1	3200W	11%	3,840	-	3,840
									Total	388,380	193,920	194,460

transfer performance of wall. The insulation quality of building envelope affects to heat gain and cooling load so that building envelope and air conditioning system should be considered for designing together of optimum design. On the other hand high quality insulation building envelope will be high investment cost. Those are the key point of consideration for optimization (Rysanek and Choudhary, 2013; Sohrabi et al., 2018).

Building envelope design, Current situation of case study building is a bench mark. The wall and roof material of current building envelop are shown in Table 5.

The heat gain of building case study mainly comes from 2 parts. The first part is heat gain through wall which is mainly opaque wall. The second is heat gain through roof. Heat gain condition which is a quality of wall and roof. The total heat gain in to the building depends on a thermal resistant of wall and roof. Researcher selects 12 combinations of the appropriate wall and roof with additional insulation quality to compare with convention building as shown in Table 6.

Table 5: Building envelope of existing condition

	Material	U value
Wall	Brick wall 10 and 15 cm.	2.889, 2.279
Roof	Metal sheet thk. 0.47 with insulation 3”	0.397

The method of building envelop and air conditioning system optimum design can be simplified into 6 steps.

1. 12 appropriate building envelops are set.
2. Using 12 thermal property combination to design cooling load results in hourly cooling load calculation of total building. Cooling load calculation factor of each combination is as following.
    - Heat gain from external:
      It is 12 month of weather pattern. Each month includes 17 pattern according to 6.00 am-10 pm of operation hour.
    - The customer pattern:
      People numbers that used to calculate can be divided into 2 patterns which are working day and holiday. The people number from whole year actual customer is used to find average people number. Those in each day are calculated from the whole year information of customer bill. The actual customer bill represents people in the building. Customers during weekend are higher than the ones in weekday. The cooling load of each month can be calculated by 34 times of operating and 2 sets of Monday-Friday and Saturday-Sunday as show in Figure 14.
    - Equipment in the building:
    - Lighting:
      Researcher uses the LED lighting from the previous method to calculate.

Table 6: Building envelop 12 combinations

Envelop	Wall	U value	Roof	U value
Envelop 1	Brick wall 15 and 10 cm.	2.88,2.28	Metal sheet thk. 0.47mm. with insulation 3”	0.39
Envelop 2	Metal sheet thk. 0.47 mm. with PU foam 50 mm.	0.41	Metal sheet thk. 0.47mm. with insulation 3”	0.39
Envelop 3	Metal sheet thk. 0.47 mm. with PU foam 80 mm.	0.27	Metal sheet thk. 0.47mm. with insulation 3”	0.39
Envelop 4	Metal sheet thk. 0.47 mm. with PU foam 100 mm.	0.22	Metal sheet thk. 0.47mm. with insulation 3”	0.39
Envelop 5	Brick wall 15 and 10 cm.	2.88,2.28	Metal sheet thk. 0.47mm. with insulation 4”	0.31
Envelop 6	Metal sheet thk. 0.47 mm. with PU foam 50 mm.	0.41	Metal sheet thk. 0.47mm. with insulation 4”	0.31
Envelop 7	Metal sheet thk. 0.47 mm. with PU foam 80 mm.	0.27	Metal sheet thk. 0.47mm. with insulation 4”	0.31
Envelop 8	Metal sheet thk. 0.47 mm. with PU foam 100 mm.	0.22	Metal sheet thk. 0.47mm. with insulation 4”	0.31
Envelop 9	Brick wall 15 and 10 cm.	2.88,2.28	Metal sheet thk. 0.47mm. with insulation 3”+ceramic coating	0.39
Envelop 1 0	Metal sheet thk. 0.47 mm. with PU foam 50 mm.	0.41	Metal sheet thk. 0.47mm. with insulation 3”+ceramic coating	0.39
Envelop 1 1	Metal sheet thk. 0.47 mm. with PU foam 80 mm.	0.27	Metal sheet thk. 0.47mm. with insulation 3”+ceramic coating	0.39
Envelop 1 2	Metal sheet thk. 0.47 mm. with PU foam 100 mm.	0.22	Metal sheet thk. 0.47mm. with insulation 3”+ceramic coating	0.39

Figure 13: Performance load comparison graph between conventional multi-set rack and water loop system (kW) comparison

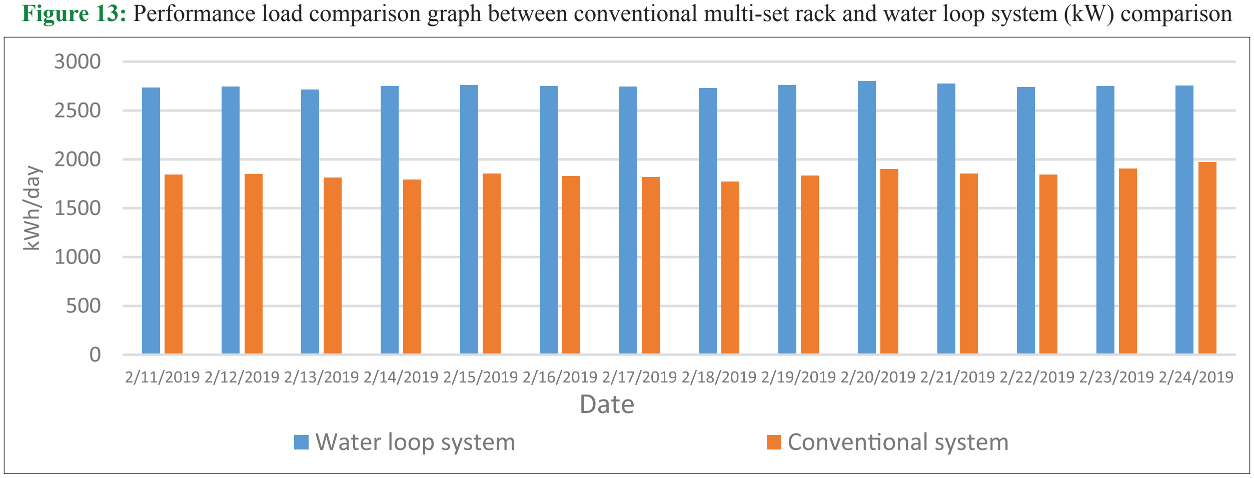


Table 7: Selected chiller of each building envelope

Material	Max. cooling load		Selection chiller								
Schedule			Single chiller			Separate chiller (B+C)					
Building envelop	Week end	Week day	Chiller A	Model	Chiller A	Chiller B	Chiller C	Model	Model	Chiller B	Chiller C
type	(RT)	(RT)	(RT)	Chiller A	(kW/RT)	(RT)	(RT)	Chiller B	Chiller C	(kW/RT)	(kW/RT)
1	247	246	250	CRTHD-C2E1F1(VSD)	0.6323	150	150	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6628	0.6628
2	244	222	225	CRTHD-C1E1F1(VSD)	0.6452	150	150	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6628	0.6628
3	218	216	225	CRTHD-C1E1F1(VSD)	0.6452	135	135	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6598	0.6598
4	215	213	225	CRTHD-C1E1F1(VSD)	0.6452	135	135	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6598	0.6598
5	238	236	250	CRTHD-C2E1F1(VSD)	0.6323	150	150	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6628	0.6628
6	218	216	225	CRTHD-C1E1F1(VSD)	0.6452	135	135	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6598	0.6598
7	211	209	225	CRTHD-C1E1F1(VSD)	0.6452	135	135	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6598	0.6598
8	209	207	210	CRTHD-C1E1F1(VSD)	0.6447	135	135	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6598	0.6598
9	240	237	250	CRTHD-C2E1F1(VSD)	0.6323	150	150	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6628	0.6628
10	218	215	225	CRTHD-C1E1F1(VSD)	0.6452	135	135	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6598	0.6598
11	212	210	225	CRTHD-C1E1F1(VSD)	0.6452	135	135	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6598	0.6598
12	209	207	210	CRTHD-C1E1F1(VSD)	0.6447	135	135	CRTHD-B1C1D1(VSD)	CRTHD-B1D1(VSD)	0.6598	0.6598

- Infiltration and ventilation:
  408 cooling loads are result of each building envelope from January to December of total year. After that the suitable chiller of that building envelope can be selected. Researcher repeats this method for the remaining of building envelope. 4496 cooling load is a total result for all building envelop to consider chiller machine.

3. The maximum cooling load of each combination is used to select the capacity of chiller.
   The difference of maximum cooling load is applied to select the difference chiller size. Moreover, Researcher selects 2 types of chiller. Firstly chiller is one machine and secondly are two chillers for each building envelope as shown in Table 7.
4. The total electricity consumption is calculated by each building envelop and each chiller.
   Then kWh of each chiller is calculated to follow COP of chiller specification. Its consumption can be converted to energy cost in the final stage.
5. Total cost is calculated from energy cost from energy consumption in item 4, investment cost and repair & maintenance cost also chiller replacement on 21st year.

Finally, this stage of building envelope and air conditioning system are a total 30 year cost. It consists Initial cost, energy cost and maintenance cost. The optimum cost of envelope and chiller type will be the output of those method. Building envelop and air conditioning system design method are shown in Figure 14.

The building envelop 12 with 210 ton of chiller is a lowest cost. Its total cost is 339.9 M Baht. The conventional total cost is 419.2 M Baht. 79.2 M Baht is total 30 years being saved from optimum building envelop and chiller.

4. RESULTS

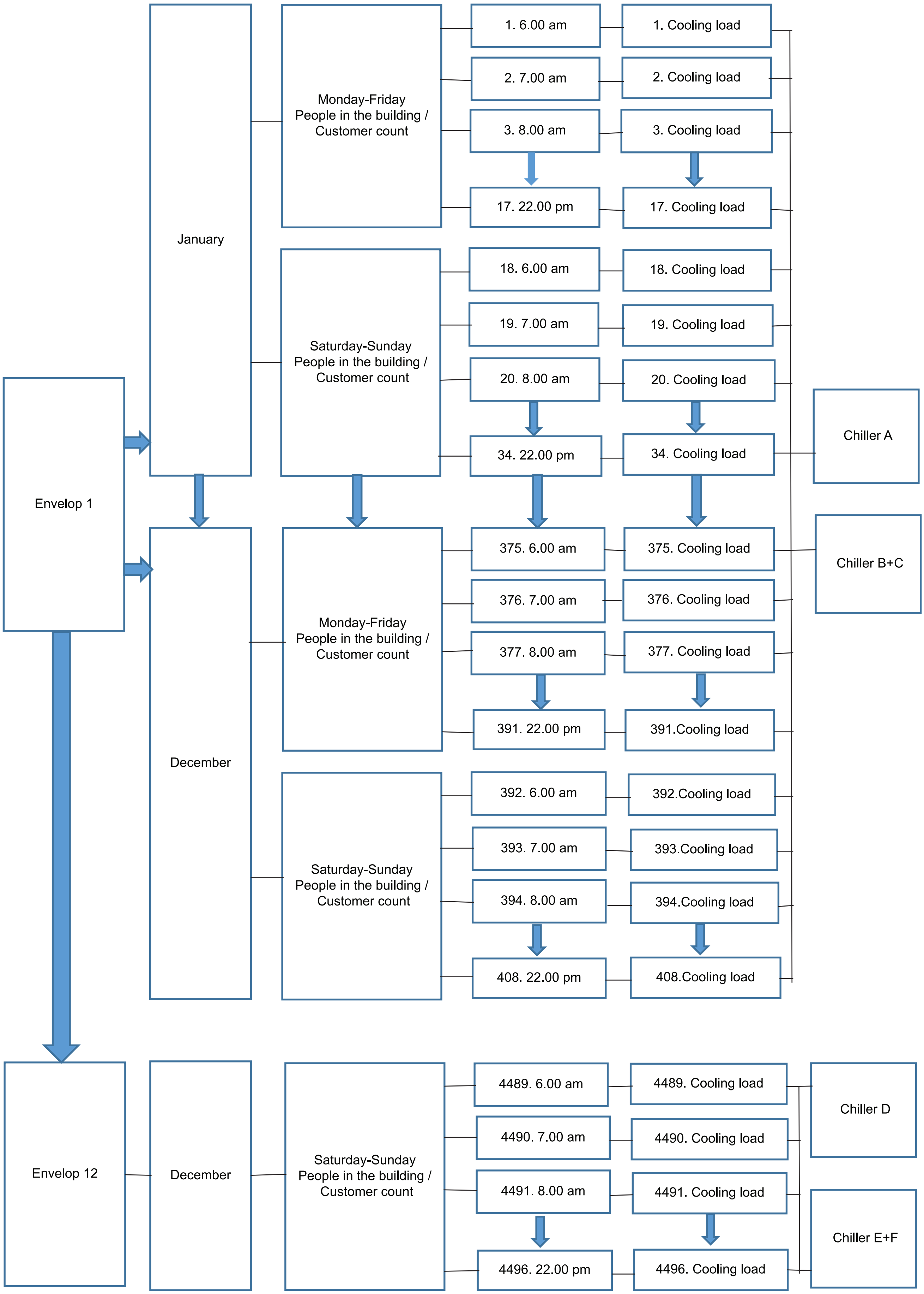
4.1. Energy Use

The building annual energy use from January 2017 to December 2018 is 2,945,000 kWh and 2,945 kWh/m^2 for whole building area, 420.71 kWh/m^2 for sale area. Total consumption saving is 20.3% out of total consumption of lighting, refrigeration and air conditioning system as shown in Table 8. This percentage saving can be calculated to be total building saving by using energy consumption ratio in Figures 1 and 2. 11.86% consumption saving is a simulation of total building. It means that the final optimum design prediction is 2,595,723 kWh/year and 259.5 kWh/m^2 for whole building area and 370.8 kWh/m^2 for sale area. 11.86 % is an energy consumption saving from the total solution of this research.

4.2. Lighting System

556,580 kWh is yearly energy consumption of conventional lamp, and 330,304 kWh is for LED lamp. LED lamp consumes energy lower than conventional lamp of 226,076 kWh/year or 40.6% saving. Total life cycle cost (present worth) is 341.8 M Baht for conventional lamp, and 227.3 M Baht for LED lamp. All concerned factors for this research are investment cost, energy cost, spare part and light bulb replacement. Life cycle evaluation of LED lighting for retail and whole sale building, reflect that life cycle cost of LED lighting being lower than current one or equal to 114.5 M Baht or 33.5% saving as show in Figure 15.

Figure 14: The flow chart of building envelop and air conditioning optimization.



4.3. Refrigeration System

Conventional multi set rack system yearly consumes 674,898 kWh and 1,004,230 kWh for water loop system. Conventional system saves 329,332 kWh/year or 32.7%. Total life cycle costs (present worth) is 446.9 M Baht for conventional multi-set rack system, and 609.7 M Baht for water loop system. Total 30 years cost of conventional multi-set rack can save 162.8 M Baht as show in Figure 16.

4.4. Building Envelope and Air Conditioning System

The integrated and efficient building envelope with appropriate roof and wall material are result of this stage. This study is a method to transform the existing building into appropriate energy efficient building and to improve the energy performance by optimization. From this optimization, the lowest energy consumption is envelop 12. 209 ton is a maximum load of holiday whereas 207 ton is a maximum load of normal day. That has not been the final solution for this stage yet. The minimum total 30 years cost is end result for building envelop and air conditional system. Building envelop 12 with chiller 210 ton is an optimum design solution. 339,974,670 Baht is total cost as shown in Figure 17.

Existing building envelope with current chiller is 419,246,690 Baht total cost. The optimum design envelop 12 with 210 tons of chiller is 339,974,670 total cost. 79,272,020 Baht or 18.9 % is saving cost as shown in Table 9.

4.5. Total Life Cycle Cost of Optimization

The total life cycle of energy costs is initial cost and 30 year operation cost from 3 parts. This study found the saving from optimum design. It can save 16% or 193.7 M Baht as shown in Table 10.

5. DISCUSSION

The result of this study is the guideline of a system design for retail and wholesale building design for minimum total cost during 30 years of building life in Thailand. The case study is in Thailand. The optimization model gives the opportunity to design the building system to reduce energy and total operation cost.

5.1. Lighting System

LED lighting is high investment, low consumption and long life time. The exact number of benefit of replacement need to be known for the decision of commercial building. The long term comparison can be proved optimum solution with spare part replacement, yearly energy cost. LED lighting can save 114.5 M. baht/30 years or 33.5%.

Table 8: Summary of yearly energy consumption comparison by each system of conventional system and optimum system

Systems	Conventional new design (kWh/y)		Optimum design (kWh/y)
Lighting	556.580	330,304	330,304 (LED)
Refrigeration	674,898	1,004,230	674,898 (Multi set)
Building envelope and air conditioning	736,537	563,828	563,898 (new design)
Total use	1,968,015		1,569,100
Total energy saving			398,915 (20.3%saving)

Table 9: Summary of yearly energy consumption by each system comparison between conventional system and optimum system

Building envelop	Cooling load holiday (Ton)	Cooling load normal day (Ton)	Initial cost (Baht)	Energy cost (Baht)/30y	O&M cost (Baht)/30y	Total cost (Baht)/30y
Existing envelop	247	246	10,806,646	112,252,960	2,289,060	419,246,690
Envelop 12	209	207	13,921,670	85,931,048	2,289,060	339,974,670

Figure 15: Life cycle cost comparison between conventional lamp and LED lamp

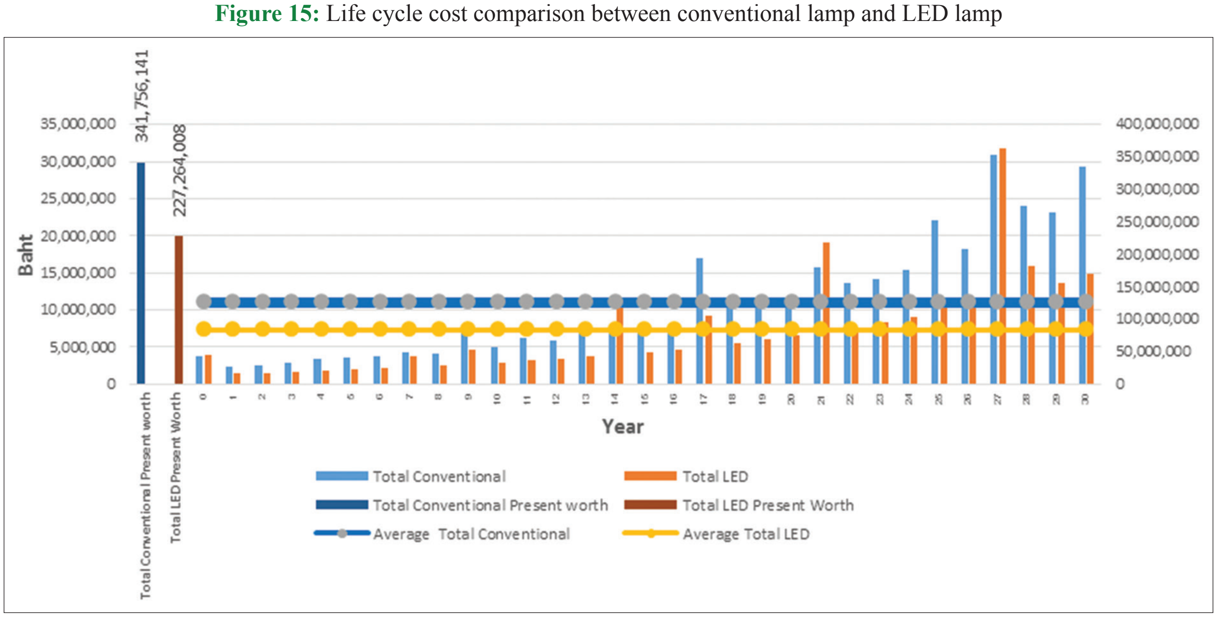


Figure 16: Life cycle comparison between conventional multi set rack and water loop system. (The whole replacement system is 16th year)

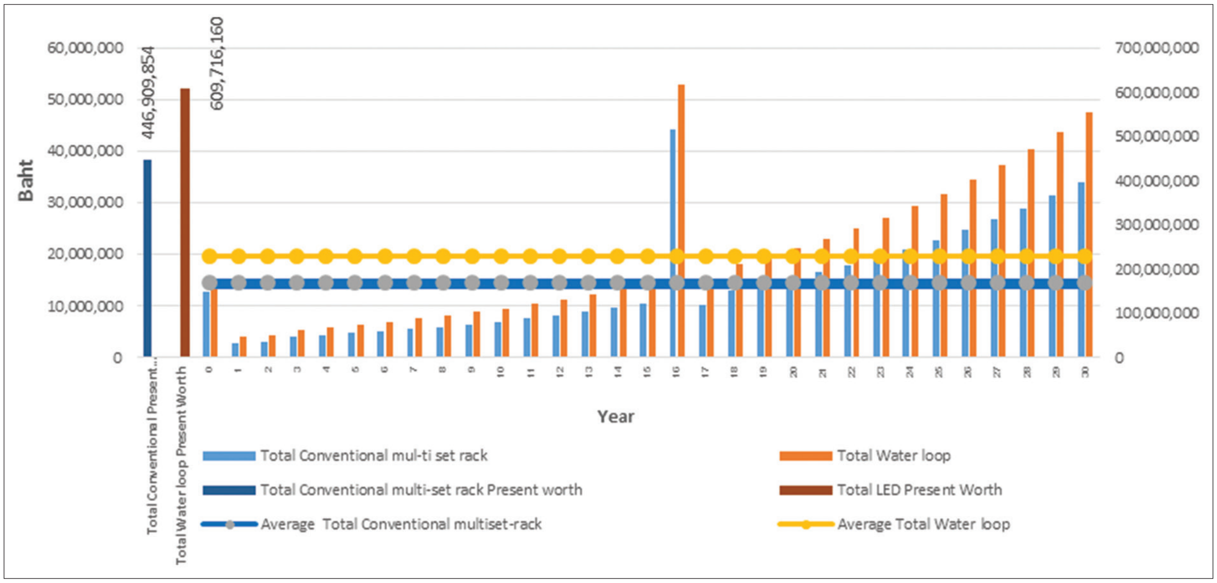


Figure 17: Life cycle cost comparison between existing building envelop with current 150 ton*2 sets chiller and optimum design building envelop with 210 ton chiller. (The whole replacement is 21st year)

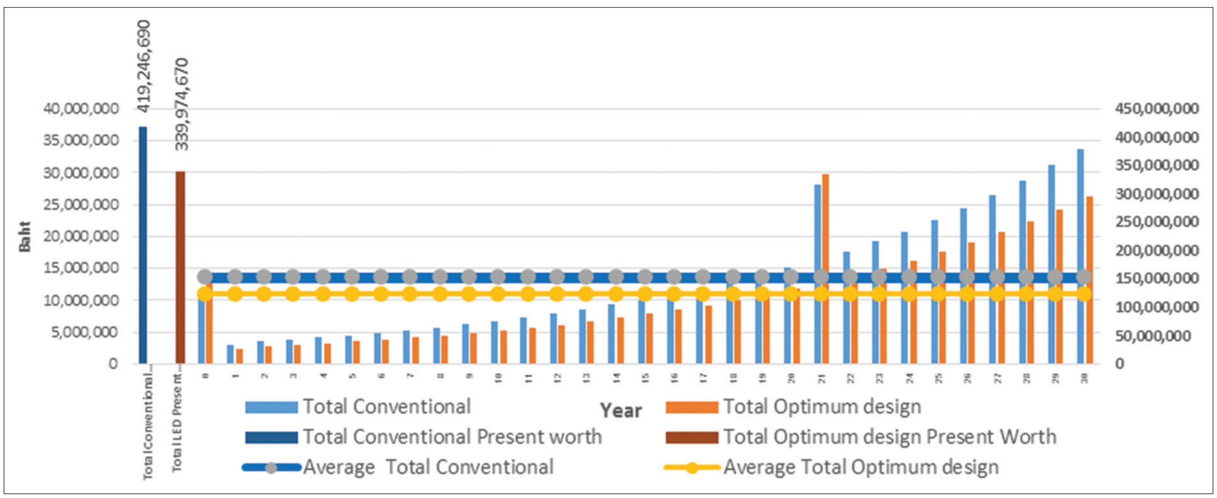


Table 10: 30 years summary of total cost by each system comparison between conventional system and optimum system

Systems	Conventional (M Baht)	New design (M Baht)	Optimum design (M Baht)
Lighting	341.8	227.3	227.3
Refrigeration	446.9	609.7	446.9
Building envelope and air conditioning	419.2	339.9	339.9
Total cost	1,207.9	1,176.9	1,014.1
Total cost saving			193.7 (16% saving)

5.2. Refrigeration System

According to the other research for conventional system and water loop system comparison, Bagarella, Lazzarin and Noro study in supermarkets. Energy consumption of water loop can save 15.8% and is expected to require a higher initial investment. It is expected to require lower operation cost (Bagarella et al., 2014). This research found the difference. A yearly consumption of water loop is higher than conventional one. Whereas the operation cost is lower than the conventional one. Finally, Long term total cost of water loop is 609.7 M Baht and conventional is 446.9 M Baht. Conventional can save 162.8 M Baht/30 years or 26.7 %. It means that conventional multi-set rack is still be optimum design for this building. Anyway the water loop system is a challenge to be considered to get benefit from low quantity of refrigerant and maintenance cost including the greenhouse gas emission. This research study on the big scale of refrigeration system. The water loop may suitable for smaller scale.

5.3. Building Envelope and Air Conditioning System

The high efficiency of building envelop and high performance of chiller are not a result of this stage. The optimum is considered the total life cycle 30 year cost. Those are initial cost, energy cost,

Table 11: 30 year summary of total cost by each system comparison between conventional system and optimum system

System	Energy consumption					Total cost of 30 years				
	Current	New design	Optimum	Saving		Current	New design	Optimum	Saving	
	kWh/y	kWh/y	kWh/y	kWh/y	%	Baht	Baht	Baht	Baht	%
Lighting	556,580	330,304	330,304	(226,276)	(40.65)	341,756,141	227,264,008	227,264,008	(114,492,133)	(33.50)
Refrigeration	674,898	1,004,230	674,898	-	-	446,909,854	609,716,160	446,909,854	-	-
Building envelop and air conditioning	736,537	563,828	563,828	(172,709)	(23.45)	419,246,690	339,974,670	339,974,670	(79,272,020)	(18.91)
Total	1,968,015	1,898,362	1,569,031	(398,985)	(20.27)	1,207,912,685	1,176,954,838	1,014,148,532	(193,764,154)	(16.04)

operation and maintenance cost. Regarding energy conservation technology, It is always high investment and high energy saving. This research finds the optimization solution for this case study building. The solution is building envelop 12 with chiller 210 ton. It is an optimum total cost. 339,974,670 Baht is a total cost, and 563,828 kWh is a yearly energy consumption. The existing condition of building envelop with current chiller are 419,246,690 Baht for total cost, and 736,537 kWh is a yearly energy consumption. It means that the optimization solution can be saved 79,272,020 Baht for total 30 year life cycle cost. For further air conditioning system improvement and sustainability, the system commissioning and operation& maintenance are important process. Optimizing of chiller sequence control, set point, chiller water pump, approach temperature monitoring are considered.

6. CONCLUSION

This paper has developed a quantitative and cost-benefit analysis of the newly proposed retail and large size wholesale building in Thailand. The new development and experimental research method influence the performance of lighting system, refrigeration system and combination between building envelop and air conditioning system. In the experimental study, Researcher propose the optimum design for retail and wholesale building to be 3 sectors.

6.1. Lighting

Lighting design solution is LED. Its total 30 year present worth cost is lower than the current conventional system (T8 fluorescent 36 W) for fresh food area, racking area and office area, HID 150 W for general lighting in sale area and HID 250 W and 400 W for external lighting). All LED lighting in the whole building can be performed the same quality of conventional lighting, but the total life cycle 30 year cost can be save 114.5 m baht. Total life cycle cost is 341.8 m baht for conventional lamp, and 227.3 m baht for LED lamp.

6.2. Refrigeration System

Refrigeration system solution is convention multi-set rack system. This system is still strong in energy saving and minimum life cycle cost. 446.9 M Baht is a total cost of conventional multi-set rack system and 609.7 M Baht is a total cost of water loop system. Total cost of conventional multi-set rack is lower than water loop system cost of 162.8 M Baht.

6.3. Building Envelop and Air Conditioning System

Optimum building envelop design comprises as following,

- 0.47 mm thickness metal sheet wall with 100 mm PU foam.
- 0.47 mm thickness metal sheet roof with insulation 3”and ceramic coating roof.
- 210 ton chiller selection.

It life cycle cost is 339.9 M baht. 79.2 M Baht is a difference cost of current building envelop and chiller. 419.2 M baht is a total cost of current condition. 79.2 M Baht is a saving or 18.9%.

6.4. Total Optimum Design

In summary, Optimum design of retail and wholesale building for minimum cost comprise of as following:

1. LED lighting system.
2. Conventional multi-set rack refrigeration system.
3. Building envelop with 210 ton chiller.
   3.1 0.47 mm thickness Metal sheet with PU 100 mm wall.
   3.2 0.47 mm thickness Metal sheet with 3”insulation roof plus ceramic coating.

All of 3 appropriate parts model can be saved 193.7 M Baht for 30 years or 16% as shown in Table 11. The total yearly energy consumption is 11.86% saving.

7. ACKNOWLEDGMENTS

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REFERENCES

Allouhi, A., Fouih, Y.E., Kousksou, T., Jamil, A., Zeraouli, Y., Mourad, Y. (2015), Energy consumption and efficiency in the buildings: Current status and future trends. Journal of Cleaner Production, 109, 118-130.

Bagarella, G., Lazzarin, R., Noro, M. (2014), Annual energy analysis of water-loop self-contained refrigeration plant and comparison with multiplex systems in supermarkets. International Journal of Refrigeration, 45, 55-63.

Energy in the Buildings and Social Development Plans National Economy. (2019), Available from: http://www.2ebuilding.com/article.php?cat=knowledge&id=215. [Last accessed on 2019 Jan 06].

Five Advantages of the Water Loop System for Refrigeration in Supermarkets. (2019), Available from: https://www.carel.com/blog/-/blogs/five-advantages-of-the-water-loop-system-for-refrigeration-in-supermarkets. [Last accessed on 2019 Feb 03].

Gimeno-Frontera, B., Mainar-Toledo, M.D., de Guinoa, A.S., Zambrana-Vasquez, D., Zabalza-Bribian, I. (2018), Sustainability of non-residential buildings and relevance of main environmental impact contributors’ variability. A case study of food retail store building. Renewable and Sustainable Energy Reviews, 94, 669-681.

Hirunwong, P., Singhasane, S. (2015), Future electricity energy in Thailand Enough but Risk. FAQ Focused and Quick; 2015.

Jermsittiparsert, K., Chankoson, T. (2019), Behavior of tourism industry under the situation of environmental threats and carbon emission: Time series analysis from Thailand. International Journal of Energy Economics and Policy, 9 (In Press).

Karasek, J., Pojar, J., Kalocai, L., Heralova, R.S. (2018), Cost optimum calculation of energy efficiency measures in the Czech Republic. Energy Policy, 123, 155-166.

Kosir, M., Lglic, N., Kunic, R. (2018), Optimisation of heating, cooling and lighting energy performance of modular buildings in respect to location’s climatic specifics. Renewable Energy, 129, 527-539.

Mylona, Z., Kolokotroni, M., Tassou, S.A. (2017), Frozen food retail: Measuring and modeling energy use and space environmental systems in an operational supermarket. Energy and Buildings, 144, 129-143.

Natephra, W., Yabuki, N. (2018), Optimizing the evaluation of building envelope design for thermal performance using a BIM-based overall thermal transfer value calculation. Building and Environment, 136, 128-145.

Nguyen, T.A., Aiello, M. (2013), Energy intelligent buildings based on user activity: A survey. Energy and Building, 56, 244-257.

Papineau, M. (2017), Setting the standard? A framework for evaluating the cost-effectiveness of building energy standard. Energy Economics, 64, 63-76.

Romprasert, S., Jermsittiparsert, K. (2019), Energy risk management and cost of economic production biodiesel project. International Journal of Energy Economics and Policy, 9, 269-275.

Rysanek, A.M., Choudhary, R. (2013), Optimum building retrofits under technical and economic uncertainly. Energy and Buildings, 57, 324-337.

Sanchez, D., Llopis, R., Cabello, R., Catalan-Gil, J., Nebot-Andres, L. (2017), Conversion of a direct to an indirect commercial (HFC134a/CO_2) cascade refrigeration system: Energy impact analysis. International Journal of Refrigeration, 73, 183-199.

Sghiouri, H., Mezrhab, A., Karkri, M., Naji, H. (2018), Shading devices optimization to enhance thermal comfort and energy performance of a residential building in Morocco. Journal of building Engineering, 18, 292-302.

Sohrabi, F., Nazari-Heris, M., Mohammadi-Ivatloo, B., Asadi, S. (2018), Optimal chiller loading for saving energy by exchange market algorithm. Energy and Buildings, 169, 245-253.

Wang, S., Yan, C., Xiao, F. (2012), Quantitative energy performance assessment methods for existing buildings. Energy and Buildings, 55, 873-888.

Watcharapongvinij, A. Therdyothin A. (2019), Life Cycle Evaluation of LED Lighting in the Retail and Wholesale Building. I-SEEC 2017 Proceeding, No. 8. p216-219.

Zhang, X., Wang, F. (2016), Hybrid input-output analysis for life cycle energy consumption and carbon emissions of China’s building sector. Building and Energy, 104, 188-197.

Zhao, H., Yuan, T., Gao, J., Wang, X., Yan, J. (2019), Conventional and advanced energy analysis of parallel and series compression-ejection hybrid refrigeration system for household refrigeration system for household refrigerator with R290. Energy, 166, 845-861.

Zhao, S., Feng, W., Zhang, S., Hou, J., Zhou, N., Levine, M. (2015), Energy saving and cost-benefit analysis of the new commercial building standard in China. Procedia Engineering, 121, 317-324.

Zhao, S.Y., Chen, Q. (2016), Design criteria of different heat exchangers for the optimal thermodynamic performance of regenerative refrigeration systems. Applied Thermal Engineering, 93, 1164-1174.