



**Provision of Services Related to Enabling Readiness for Up
Scaling Investments in Building Energy Efficiency for
Achieving NDC Goals in Thailand**

Contract No.: UNEP/2020/252 (4700019197)

**PROGRESS REPORT 4:
REPORT ON FINANCIAL ASSESSMENT FOR NEW
BUILDINGS WITHIN BEC FRAMEWORK**

Prepared for

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Leading the Transition to Clean Energy

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Acronyms

BEC	-	Building Energy Code
BESM	-	Building Energy Simulation Model
CBEEC	-	Commercial Building Energy Efficiency Information Center
CC	-	Cooling Capacity
COP	-	Coefficient of Performance
CTCN	-	Climate Technology Centre and Network
DEDE	-	Department of Alternative Energy Development and Efficiency
DPT	-	Department of Public Works and Town and Country Planning
ECON	-	Economic Building
EEP	-	Energy Efficiency Plan
EER	-	Energy Efficiency Ratio
EIA	-	Environment Impact Assessment
ENCON Act	-	Energy Conservation and Promotion Act
EnPI	-	Energy Performance Indicator
EPPO	-	Energy Policy and Planning Office (EPPO)
EUI	-	Energy Use Indicator
GGGI	-	Global Green Growth Institute
HEPS	-	High Energy Performance Standard
IIEC	-	International Institute for Energy Conservation
INDC	-	Intended Nationally Determined Contributions
KMUTT	-	King Mongkut University of Technology Thonburi
LAOs	-	Local Administration Organizations
LED	-	Lighting Emitting Diode
LPD	-	Lighting Power Density
MOE	-	Ministry of Energy
MOI	-	Ministry of Interior
MRV	-	Measurement, Report and Verification
NAMA	-	Nationally Appropriate Mitigation Actions
NCCC	-	National Committee on Climate Change Policy
NDC	-	Nationally Determined Contributions
NXPO	-	Office of National Higher Education Science Research and Innovation Policy Council
ONEP	-	Office of Natural Resources and Environmental Policy and Planning
OTTV	-	Overall Thermal Transfer Value
PEECB	-	Promoting Energy Efficiency in Commercial Buildings



RTTV	-	Roof Thermal Transfer Value
SEER	-	Seasonal Energy Efficiency Ratio
TBEED	-	Thailand Building Energy Efficiency Disclosures
TGO	-	Thailand Greenhouse Gas Management Organization
UNFCC	-	UN Framework Convention on Climate Change
UNEP	-	United Nations Environment Programme
ZEB	-	Zero Energy Building



EXECUTIVE SUMMARY

This report summarizes progress of the Contract No: UNEP/2020/252 (4700019197) for the provision of Services Related to Enabling Readiness for Up Scaling Investments in Building Energy Efficiency for Achieving NDC Goals in Thailand. The progress report specifically presents the completed project activities in the fourth reporting period of the project (September to October 2021).

This progress report shows the completed deliverable result of Task 3, activity 3.1 and 3.2, which are continued from Task 2 in the previous report. The second stakeholder consultation workshop was organized to disseminate the outcomes of Task 2 (activity 2.3) and Task 3 (activity 3.3) to the relevant stakeholders was completed on October 2021 through an online virtual conference, and it was separately reported.

Key outcomes from the implementation of the project activities during the reporting period are as follows.

Activity 3.1: Energy Performance Simulation for Five building Types

From the list of prioritized technology list in Task 2, energy performance simulation and financial assessment are conducted for the most potential technologies to enhance the BEC implementation.

List of high potential technologies for each BEC component

Item	BEC Technology	Baseline Technology	Priority
Component 1: Building Envelope			
	<u>Opaque Wall</u>		
1-1	Light weight concrete blocks (AAC)	Concrete, concrete block or brick.	A
1-2	Wall insulation with fiber glass, mineral wool	Walls with no insulation.	A
1-3	Composite insulated panels with polyurethane, PIR, Rockwool	Walls with no insulation.	B
	<u>Transparent Wall and Window</u>		
1-4	Energy efficient coated glass: reflective glass, low-e film	Clear or tinted float or laminated glass.	A
1-5	Insulating glass: low-e multi-glazing	Clear or tinted float or laminated glass.	A
1-6	Window shading devices	Windows with no shading devices	A
	<u>Roof</u>		
1-7	Roof insulation with fiber glass, mineral wool or foams	Concrete or metal sheet roof without insulation.	A
1-8	High solar reflective paint	Normal roof material.	A
Component 2: Lighting System			
2-1	High efficiency LED lamps (200 lm/W)	Fluorescent lamps, normal LED lamps with efficiency less than 150 lumen/Watt.	A
Component 3: Air Conditioning System			
3-1	High efficiency Inverter split-type air conditioners with label no.5 3-star	Fixed speed or standard inverter split-type air conditioners.	A
3-2	VRF/VRV air conditioning system	Split-type, packaged unit air conditioner or air-cooled chillers.	B
3-3	High efficiency chillers/Oil-free magnetic bearing chillers	Standard air-cooled or water-cooled electric chillers.	A
Component 4: Hot Water Generation			
4-1	Heat pump hot water generation	Electric or fuel hot water boiler.	A
Component 5: Renewable Energy Utilization			
5-1	Rooftop solar PV without grid selling and battery system	100% use of on-grid electricity.	A
Component 6: Whole Building Energy Performance			
	None		

Remark: Priority groups: A = high, B= medium, C= low.



The simulation models are developed to estimate savings from the implementation of these BEC technologies. Baseline scenarios representing existing technology deployed and operating parameters of the BEC buildings are assumed based on 10-year BEC database, available building design and BEC project publications.

Component 1 building envelope technology is integrated to the same analytic model for simulate the impacts of opaque wall, transparent wall and window, roof and insulation materials to cooling loads and air conditioning consumption. Technologies in component 2 to 5 the analysis is conducted on the individual basis to estimate energy savings from lighting, air conditioning, hot water generation and renewable energy systems.

Five types BEC buildings under three groups of operating hours are covered.

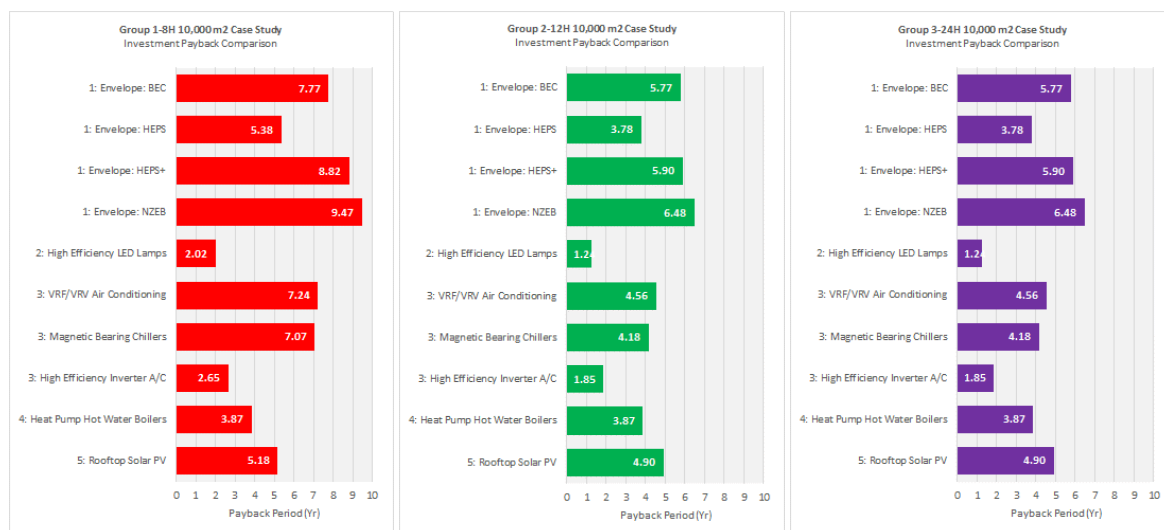
- Group 1-8Hr: offices with 8 operating hours per day during 08:00-17:00 hour weekdays (Monday to Friday)
- Group 2-12Hr: department stores with 12 operating hours every day during 10:00-22:00 hour
- Group 3-24Hr: hotels, hospitals and condominiums with 24 operating hours every day

Activity 3.2: Assessment of Financial Aspects of Technology

The financial assessment analyzes the scale of investment and economic return on investment for each of the key BEC technologies listed in the previous section. Capital investment on the implementation of technology and the impacts on the energy and building cost savings are input to the financial model to calculate simple payback period of the technology. The analysis of financial return are based on the net additional investment and the net operating cost savings of the technology over baseline scenario.

The financial assessment result show good savings with moderate to high return on investment from the identified technologies. Technologies on independent building systems of component 2 to component 5 can potentially provide short payback periods less than five years for buildings in Group 2-12Hr and Group 3-24Hr which have high operating hours. The payback on building envelope technologies of component 1 could be a little longer due to higher investment and complication but would generate savings in a long term throughout the building life time.

Comparison of return on investment for potential technologies in different BEC components



The project is progressing to recover the delayed activities due to the widespread of COVID-19 pandemic. With the definite project completion deadline of 31 December 2021, the alternative work plans has been taken into action following the consultation to key project stakeholders (DEDE, KMUTT, NDE and NDA). The summary of current status and proposed work plan are as follows:

-
- The combined workshop on outcomes of Task 2: Technology Assessment and Task 3: Financial Assessment was completed on October 2021 through an online virtual conference.
 - Energy audit activities of Task 4 were completed in October 2021. Remote interview and data gathering were deployed for the sites with unallowable access. Alternative sources of information from DEDE and network BEC assessors were used to fulfil some missing data.
 - Reporting of Task 4 results and conduct of Task 5 are on progressing.

The project team is still taking best effort to complete the tasks within the definite deadline. CTCN and all stakeholders will be continually notified on any update and progress results.



1 SUMMARY OF ACTIVITIES

This report summarizes the project's progress from September to October 2021 and deliverables under Task 3 (activity 3.1 and 3.2). The activities undertaken by the IIEC project team during this reporting period are summarized as follows.

- From the result of Task 2 in the previous progress report, the IIEC project team conducts energy performance simulation and financial assessment for the most potential technologies identified in each BEC component.
- The simulation models are developed to estimate savings from the implementation of these BEC technologies. Baseline scenarios representing existing technology deployed. Operating parameters of the BEC buildings are assumed based on 10-year BEC database, available building design and BEC project publications.
- The integrated analytic model is used for simulate the impact of building envelope technology to cooling loads and air conditioning consumption.
- For technologies in component 2 to 5 the analysis is conducted on the individual basis to estimate energy savings from lighting, air conditioning, hot water generation and renewable energy systems.
- Continued from energy performance simulation, the financial assessment analyzes the scale of investment and economic return on investment for each of the key BEC technologies.
- The second stakeholder consultation workshop was organized to disseminate the outcomes of Task 2 (Technology Assessment) and Task 3 (Financial Assessment) to the relevant stakeholders was completed on October 2021 through an online virtual conference, and it was separately reported.

Methodologies in conducting activity 3.1 and 3.2 are presented in Chapter 2. The analysis details are provided for reference in the Annex-1 in Chapter 4.



2 PROGRESS BY TASK 3

This report provides the complete result of project task 3: Financial Assessment for New Buildings within the BEC Framework. Key BEC technologies identified by technology assessment in Task 2 are used to simulate the energy performance of five BEC building types. Savings and investment costs are estimated and input to the financial model to indicate the investment magnitude and analyze the return on investment in implementing the technologies under different scenarios. The outcomes of financial assessment in this task 3 together with the result of technology assessment in task 2 lead to the recommendation on possible technology options that can be promoted to achieve the targets set in BEC.

2.1 ACTIVITY 3.1: ENERGY PERFORMANCE SIMULATION FOR FIVE BUILDING TYPES

Technology assessment in Task 2 applied the 7-aspect criteria to screen possible technologies for each BEC component. As a result the prioritized listing of technology is indicated as table 1.

Table 1: List of prioritized BEC technologies

Item	Technology	Baseline Technology	Priority
Component 1: Building Envelope			
	<u>Opaque Wall</u>		
1-1	Light weight concrete blocks (AAC)	Concrete, concrete block or brick.	A
1-2	Wall insulation with fiber glass, mineral wool	Walls with no insulation.	A
1-3	Composite insulated panels with polyurethane, PIR, Rockwool	Walls with no insulation.	B
	<u>Transparent Wall and Window</u>		
1-4	Energy efficient coated glass: reflective glass, low-e film	Clear or tinted float or laminated glass.	A
1-5	Insulating glass: low-e multi-glazing	Clear or tinted float or laminated glass.	A
1-6	Window shading devices	Windows with no shading devices	A
	<u>Roof</u>		
1-7	Roof insulation with fiber glass, mineral wool or foams	Concrete or metal sheet roof without insulation.	A
1-8	High solar reflective paint	Normal roof material.	A
Component 2: Lighting System			
2-1	High efficiency LED lamps (200 lm/W)	Fluorescent lamps, normal LED lamps with efficiency less than 150 lumen/Watt.	A
2-2	Energy efficient luminaires	Normal luminaires with low efficiency reflector.	C
2-3	Lighting controls: occupancy, schedule controls	Basic light on-off switches.	C
2-4	Daylighting devices: light pipe, light shelves	Artificial lighting and natural lighting from windows and openings.	C
Component 3: Air Conditioning System			
3-1	High efficiency Inverter split-type air conditioners with label no.5 3-star	Fixed speed or standard inverter split-type air conditioners.	A
3-2	VRF/VRV air conditioning system	Split-type, packaged unit air conditioner or air-cooled chillers.	B
3-3	High efficiency chillers/Oil-free magnetic bearing chillers	Standard air-cooled or water-cooled electric chillers.	A
3-4	Absorption chillers	Electric chillers.	C
3-5	Energy Recovery Ventilation (ERV)	Normal cool air ventilation with fresh air and AHU.	C
Component 4: Hot Water Generation			
4-1	Heat pump hot water generation	Electric or fuel hot water boiler.	A
Component 5: Renewable Energy Utilization			
5-1	Rooftop solar PV without grid selling and battery system	100% use of on-grid electricity.	A



Item	Technology	Baseline Technology	Priority
5-2	Solar hot water generation system	Electric or fuel hot water boiler.	C
Component 6: Whole Building Energy Performance			
6-1	Building Energy Management Systems (BEMS): integrated building control	Independent or no control of building systems	C
6-2	Combined Heat and Power (CHP)	Separated supply of electricity from on-grid system and generation of heat from boiler.	C

Remark: Priority groups: A = high, B= medium, C= low.

From the prioritized technology list, energy performance simulation and financial assessment in this task 3 will be conducted for technologies in the priority group A (high priority) and B (medium priority), which are most potential technologies to enhance the BEC implementation. The list of these potential technologies are summarized in table 2.

Table 2: List of high potential technologies for BEC

Item	BEC Technology	Baseline Technology	Priority
Component 1: Building Envelope			
	<u>Opaque Wall</u>		
1-1	Light weight concrete blocks (AAC)	Concrete, concrete block or brick.	A
1-2	Wall insulation with fiber glass, mineral wool	Walls with no insulation.	A
1-3	Composite insulated panels with polyurethane, PIR, Rockwool	Walls with no insulation.	B
	<u>Transparent Wall and Window</u>		
1-4	Energy efficient coated glass: reflective glass, low-e film	Clear or tinted float or laminated glass.	A
1-5	Insulating glass: low-e multi-glazing	Clear or tinted float or laminated glass.	A
1-6	Window shading devices	Windows with no shading devices	A
	<u>Roof</u>		
1-7	Roof insulation with fiber glass, mineral wool or foams	Concrete or metal sheet roof without insulation.	A
1-8	High solar reflective paint	Normal roof material.	A
Component 2: Lighting System			
2-1	High efficiency LED lamps (200 lm/W)	Fluorescent lamps, normal LED lamps with efficiency less than 150 lumen/Watt.	A
Component 3: Air Conditioning System			
3-1	High efficiency Inverter split-type air conditioners with label no.5 3-star	Fixed speed or standard inverter split-type air conditioners.	A
3-2	VRF/VRV air conditioning system	Split-type, packaged unit air conditioner or air-cooled chillers.	B
3-3	High efficiency chillers/Oil-free magnetic bearing chillers	Standard air-cooled or water-cooled electric chillers.	A
Component 4: Hot Water Generation			
4-1	Heat pump hot water generation	Electric or fuel hot water boiler.	A
Component 5: Renewable Energy Utilization			
5-1	Rooftop solar PV without grid selling and battery system	100% use of on-grid electricity.	A
Component 6: Whole Building Energy Performance			
	None		

To estimate savings the improved energy efficiency from the implementation of BEC technologies are compared with baseline scenario with conventional technology and operating assumptions. Baseline scenarios representing existing technology deployed and operating parameters of the BEC buildings are assumed from 10-year BEC database, available building design and BEC project publications.

Component 1 building envelope technology is integrated to the same analytic model for simulate the impacts of opaque wall, transparent wall and window, roof and insulation materials to cooling loads and air conditioning consumption. Technologies in component 2 to 5 the analysis is conducted on the individual basis to estimate energy savings from lighting, air conditioning, hot water generation and renewable energy systems.



Assumptions used in energy performance simulation

General assumptions for simulation of energy performance of prioritized BEC technologies are as follows.

Equipment efficiencies

Energy efficiency of BEC technologies are based on the average efficiencies obtained from equipment or material specification available from suppliers. Both full load and part load efficiencies of the equipment such as chillers and air conditioners are incorporated for accurate analysis of energy consumption. Typical specifications and efficiencies of equipment are assumed in simulation of improved energy efficiency of BEC technologies over baseline scenarios.

Operating hours

The operating hours for each types of the BEC buildings under study are referred to DEDE's assumptions on each BEC building categories. These are:

- **Group 1-8Hr: offices**
This group has 8 operating hours per day during 08:00-17:00 hour weekdays (Monday to Friday) with 260 working days per year and total of 2,340 operating hours per year.
- **Group 2-12Hr: department stores**
This group has 12 operating hours every day during 10:00-22:00 hour with 365 working days per year and total of 4,380 operating hours per year.
- **Group 3-24Hr: hotels, hospitals and condominiums**
This group operates 24 hours every day with 365 working days per year and total of 8,760 operating hours per year.

Building cooling load and equipment utilization

Cooling load patterns and equipment utilization factors are simulated using actual measurement data from previous projects with similar building types and operation scenarios.

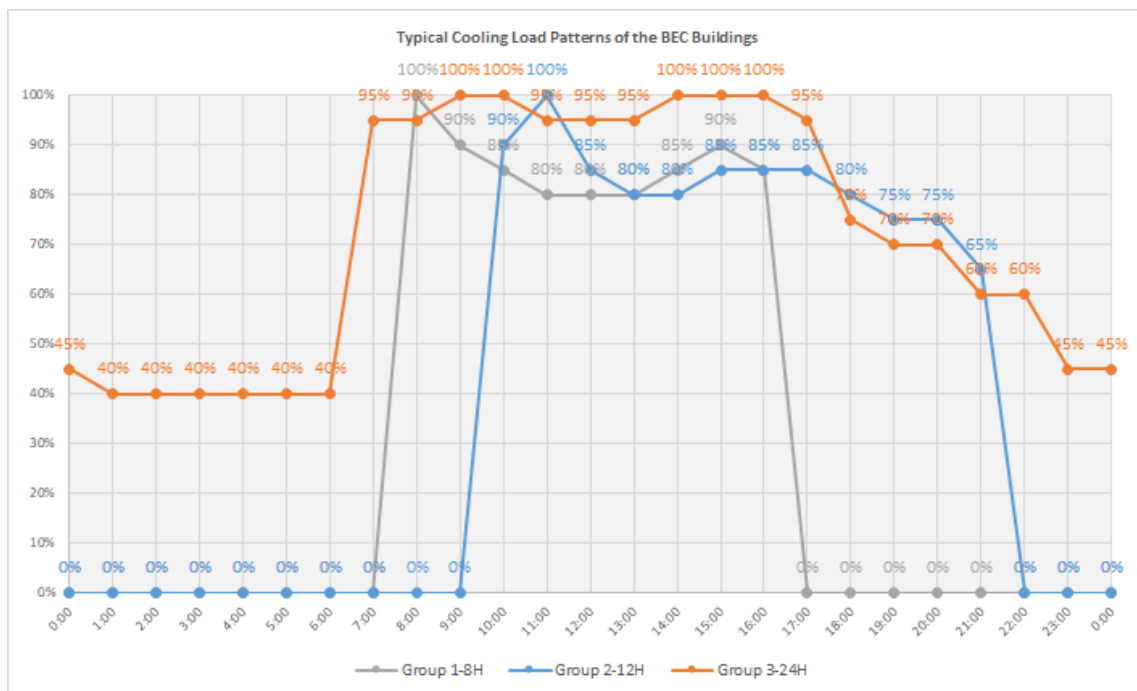


Figure 1: Typical cooling load patterns used in the simulation



2.2 ACTIVITY 3.2: ASSESSMENT OF FINANCIAL ASPECTS OF TECHNOLOGY

The financial assessment analyzes the scale of investment and economic return on investment for each of the key BEC technologies listed in the previous section. Capital investment on the implementation of technology and the impacts on the energy and building cost savings are input to the financial model to calculate simple payback period of the technology. The analysis of financial return are based on the net additional investment and the net operating cost savings of the technology over baseline scenario.

For BEC component 1, 2, 3, 5 and 6, the improved efficiency of the technologies would result in reduction of both electricity consumption and demand and thus energy charges and demand charges on the Time of Use (TOU) tariff. Better efficiency of technology in BEC component 4 would directly reduce fuel consumption costs in hot water generation. For the technology with alternate energy source, energy costs from different types are compared in the calculation of net savings.

Assumptions used in financial assessment

Assumptions on costings and parameters used in the analysis are summarized as below.

Capital investment

Investment including materials and labors of the identified BEC technology are compared with baseline technology. Any investment impacts on building systems, i.e. reduced size from better efficiency or avoided installation from higher output, are also included in the analysis. The costs of materials and labors for installation are based on the average costs obtained from the reliable sources such as Thai government's construction middle prices, previous DEDE projects and case studies on technology implementation, related publications and technology suppliers both local and international.

Operating expenses

The main benefits of the BEC technologies are reduction of building operating costs through reduced energy consumption. The better technologies could save building's operation and maintenance expenses while some technologies might increase operation and maintenance efforts from the additional equipment components. All these costs are considered and included as the net operating expenses savings compared to baseline technology.

Electricity prices

The calculation of electricity costs and savings are based current TOU tariff for MEA and PEA retail consumers, which has been effective since November 2018. The tariff rate of 3.2.2/4.2.2 medium/large general service with 12-24 kV for MEA and 22-33 kV for PEA is assumed for large buildings with area of 10,000 m² or more. The tariff rate of 3.2.3/4.2.3 medium/large general service with <12 kV for MEA and <22 kV for PEA is applied for small buildings with area under 10,000 m². The updated Ft of -0.1532 THB/kWh, for October-December 2021 is applied in the calculation.

Table 3: TOU tariff applied in the financial analysis

Tariff	TOU 3.2.2/4.2.2 MEA:12-24 kV, PEA:22-33 kV	TOU 3.2.3/4.2.3 MEA:<12 kV, PEA:<22 kV
Demand charge On-peak (THB/kW/month)	132.93	210.00
Energy charge On-Peak (THB/kWh)	4.1839	4.3297
Energy charge Off-Peak (THB/kWh)	2.6037	2.6369
Ft (THB/kWh)	-0.1532	-0.1532



Fuel prices

The prices for calculation of fuel costs are referred to the wholesale prices of petroleum products in Bangkok including diesel, fuel oil and LPG, announced by EPPPO. The updated figures as of October 29, 2021 are used for the analysis.

Table 4: Fuel prices used in the financial analysis

Fuel Type	Price (THB per unit)
Fuel oil grade A: low viscosity (FO 600 2%S)	18.3216 THB/liter
Fuel oil grade C: medium viscosity (FO 1500 2%S)	17.5802 THB/liter
LPG	15.3821 THB/kg

Source: www.eppo.go.th, October 29, 2021



2.3 ENERGY PERFORMANCE SIMULATION AND FINANCIAL ASSESSMENT RESULTS

This section presents the analysis and results of the energy performance simulation and financial assessment of the prioritized technologies identified for each BEC component.

2.3.1 Component 1: Building Envelope

Technology 1-1 to 1-8: Material and Insulation Technologies for Building Envelope

Building envelope is the most critical component to energy performance of the building. Envelope with better insulation greatly reduce heat gain and energy consumption of the air conditioning system, which is the most energy consumer of the building. Since the impact of wall, window and roof materials to energy consumption are correlated, it therefore requires integrative approach to simulate the impact of these materials to OTTV, RTTV and energy consumption.

For simulation the conceptual building models are developed as the representative for each BEC building type. The combination of opaque wall, window glass, roof materials and window-to-wall ratio (WWR) are set for each building model. Baseline model represents building with conventional materials with poor insulation and model BEC, HEPS (High Energy Performance Standard), HEPS+ (Higher Energy Performance Standard) and NZEB (Near Zero Energy Building) indicate the progressive increase of heat insulation materials of the building envelope.

Table 5: Representative building models for building envelope simulation

Simulation Case	Baseline	BEC	HEPS	HEPS+	NZEB
Building Information					
Shape	Rectangle				
North-South walls (m)	40				
East-West walls (m)	25				
Floor area (m ²)	1,000				
Number of floors	2 / 5 / 10 / 20				
Total area (m ²) (all areas are air-conditioned)	2,000 / 5,000 / 10,000 / 20,000				
Floor height (m)	4.0				
Roof type	Flat				
Building Envelope Materials					
Wall code	Wall 01	Wall 02	Wall 03	Wall 04	Wall 04
Opaque wall	Pale color Concrete 10 cm	Light color Concrete 10 cm	Light color Light weight concrete 10 cm	Light color Light weight concrete 10 cm Air gap 5 cm Fiberglass 6.5 cm Gypsum 1.2 cm	Light color Light weight concrete 10 cm Air gap 5 cm Fiberglass 6.5 cm Gypsum 1.2 cm
Transparent wall code	Wall 05	Wall 06	Wall 07	Wall 08	Wall 09
Window glass	Ocean green glass 6 mm VT=0.76, SHGC=0.60	Reflective glass 6 mm VT=0.326, SHGC=0.37	Reflective glass 8 mm VT=0.325, SHGC=0.35	Low-e 6-12-6 mm VT=0.6, SHGC=0.39	Heat stop low-e 24 mm VT=0.38, SHGC=0.20
Window to wall ratio (WWR)	50%	50%	37.5%	30%	30%
Roof code	Roof 01	Roof 02	Roof 02	Roof 03	Roof 03
Roof	Light color Concrete 20 cm Air gap 50 cm Gypsum 1.2 cm	Light color Concrete 20 cm Air gap 50 cm Fiberglass 7.5 cm Gypsum 1.2 cm	Light color Concrete 20 cm Air gap 50 cm Fiberglass 7.5 cm Gypsum 1.2 cm	Light color Concrete 20 cm Air gap 50 cm Fiberglass 15 cm Gypsum 1.2 cm	Light color Concrete 20 cm Air gap 50 cm Fiberglass 15 cm Gypsum 1.2 cm



The building models simulate energy consumption and savings from reduced heat gain through improved building envelope for different BEC building groups from small to large sizes (2,000/5,000/10,000/20,000 m²). However only 10,000 m² buildings are selected for illustration in this report.

Table 6: Simulation results of energy consumption and savings from reduced heat gain through improved building envelope of the 10,000 m² building model

Simulation Case	Baseline	BEC	HEPS	HEPS+	NZEB
Building Group 1-8Hr					
Air Conditioning Impact					
Heat gain thru walls (W)	555,066	376,013	257,796	170,829	99,134
Heat gain thru roof (W)	18,482	3,446	3,446	2,114	2,114
Total heat gain thru envelope (W)	573,548	379,459	261,242	172,943	101,248
Total heat gain thru envelope (RT)	163.09	107.90	74.28	49.18	28.79
Cooling load reduction (RT)	0.00	55.19	33.61	25.11	20.39
Air conditioning per area (m ² /RT)	15.00	16.35	17.31	18.09	18.78
Chiller size (RT)	666.7	611.5	577.9	552.8	532.4
Chiller efficiency (kW/RT)	0.65	0.65	0.65	0.65	0.65
Chiller power consumption (kW)	433.3	397.5	375.6	359.3	346.0
Energy savings					
Power saving (kW)	0.00	35.87	57.72	74.04	87.29
Energy saving (kWh/y)	0	83,941	135,069	173,257	204,264
Energy saving percentage (%)	0%	8%	13%	17%	20%
Building Group 2-12Hr					
Air Conditioning Impact					
Heat gain thru walls (W)	447,646	312,718	205,621	128,046	76,335
Heat gain thru roof (W)	19,281	3,716	3,716	2,280	2,280
Total heat gain thru envelope (W)	466,927	316,434	209,337	130,326	78,615
Total heat gain thru envelope (RT)	132.77	89.98	59.52	37.06	22.35
Cooling load reduction (RT)	0.00	42.79	30.45	22.47	14.70
Air conditioning per area (m ² /RT)	15.00	16.03	16.85	17.51	17.98
Chiller size (RT)	666.7	623.9	593.4	571.0	556.3
Chiller efficiency (kW/RT)	0.65	0.65	0.65	0.65	0.65
Chiller power consumption (kW)	433.3	405.5	385.7	371.1	361.6
Energy savings					
Power saving (kW)	0.00	27.81	47.61	62.21	71.77
Energy saving (kWh/y)	0	121,829	208,527	272,489	314,351
Energy saving percentage (%)	0%	6%	11%	14%	17%
Building Group 3-24Hr					
Air Conditioning Impact					
Heat gain thru walls (W)	275,529	192,000	123,644	77,965	46,171
Heat gain thru roof (W)	13,120	2,601	2,601	1,596	1,596
Total heat gain thru envelope (W)	288,649	194,601	126,245	79,561	47,767
Total heat gain thru envelope (RT)	82.08	55.33	35.90	22.62	13.58
Cooling load reduction (RT)	0.00	26.74	19.44	13.27	9.04
Air conditioning per area (m ² /RT)	15.00	15.63	16.12	16.47	16.72
Chiller size (RT)	666.7	639.9	620.5	607.2	598.2
Chiller efficiency (kW/RT)	0.65	0.65	0.65	0.65	0.65
Chiller power consumption (kW)	433.3	416.0	403.3	394.7	388.8
Energy savings					
Power saving (kW)	0.00	17.38	30.02	38.64	44.52
Energy saving (kWh/y)	0	152,269	262,942	338,527	390,002
Energy saving percentage (%)	0%	4%	7%	9%	10%

The simulation results indicate savings of air conditioning consumption of up to 20% for Group 1-8Hr building, 17% for Group 2-12Hr and 10% for Group 3-24Hr. Noting saving percentage for Group 1-8Hr is high because the building operates only during the day causing higher heat gain reduction percentage, while Group 2-12Hr and Group 3-24Hr operate both day and night. The annual energy savings for Group 3-24Hr is the highest and lower on Group 2-12Hr and Group 1-8Hr due to building operating hours.



The following charts summarizes the investment and financial return results for different BEC building groups.

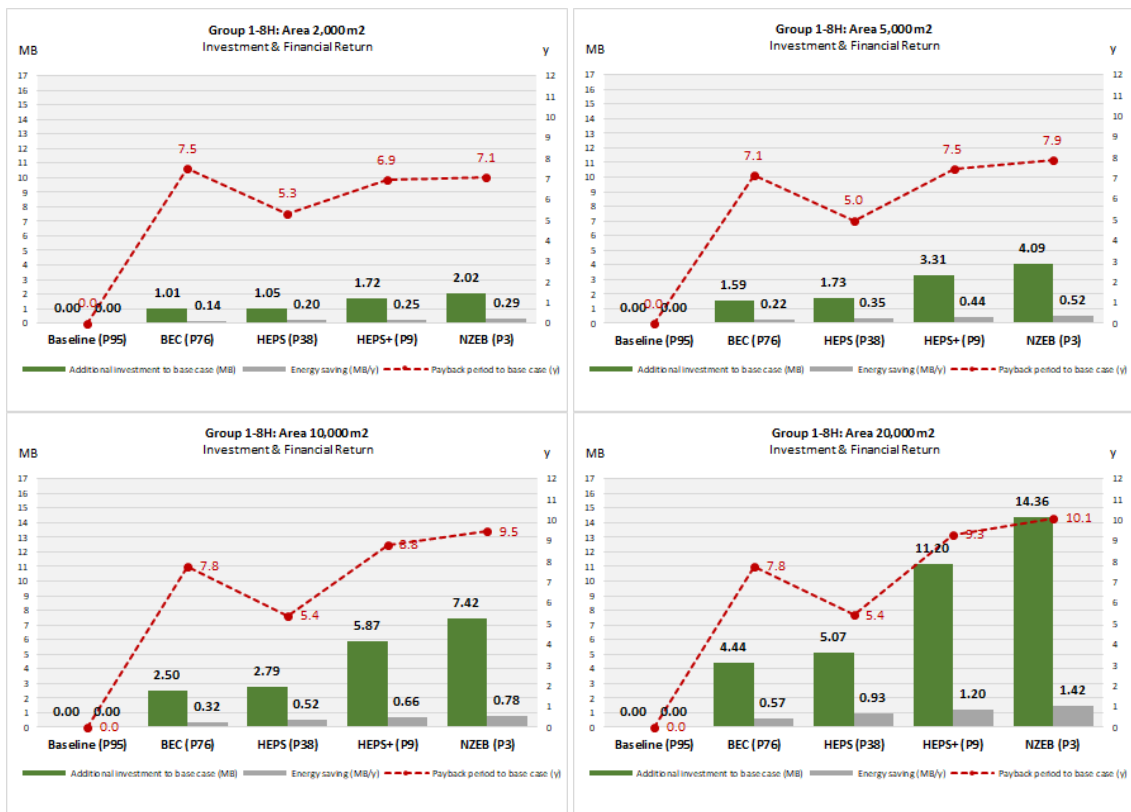


Figure 2: Investment and financial return from building envelope simulation of building Group 1-8Hr



Figure 3: Investment and financial return from building envelope simulation of building Group 2-12Hr





Figure 4: Investment and financial return from building envelope simulation of building Group 3-24Hr

Paybacks on additional investment are range from 5.0 to 10.1 years for Group 1-8Hr, 3.5 to 6.9 years for Group 2-12Hr and 3.1 to 6.0 years for Group 3-24Hr. The simulation indicates the better paybacks on small sized buildings of 2,000 and 5,000 m² as small chillers are less efficient than large chillers resulting in more power savings from reduced cooling loads.

2.3.2 Component 2: Lighting System

Technology 2-1 High efficiency LED lamps (200 lm/W)

High efficiency LED lamps are the new LED technology with higher lumen per Watt than normal LED lamp commonly used in the buildings. Table 7 shows the light output and efficiency comparison between high efficiency tubular LED lamp and normal tubular LED lamps.

Table 7: Light output and efficiency of LED lamps in the simulation

	Baseline Technology	BEC Technology
Lamp Type	Normal 1200 mm Tubular LED Lamp	High Efficiency 1200 mm Tubular LED Lamp
Lamp efficacy (lm/W)	105	200
Luminous flux per lamp (lm)	2,100	3,600
Power per lamp (W)	20	18

Assuming required luminosity of 300 lux average, utilization factor (UF) and maintenance factor (MF) are set as 0.7 and 0.8 for the new and well-maintained building, the number of lamps and lighting energy consumptions can be calculated for each types of BEC building.

Table 8: Energy consumption comparison of LED lamps

Building area (m ²)	2,000	5,000	10,000	20,000
Demand saving (kW)	4.8	12.1	24.2	48.5

Building Group 1-8Hr				
Energy consumption of baseline technology (kWh/y)	23,868	59,717	119,387	238,774
Energy consumption of BEC technology (kWh/y)	12,552	31,337	62,675	125,349
Energy saving (kWh/y)	11,316	28,380	56,712	113,424
Building Group 2-12Hr				
Energy consumption of baseline technology (kWh/y)	44,676	111,778	223,468	446,935
Energy consumption of BEC technology (kWh/y)	23,494	58,657	117,314	234,628
Energy saving (kWh/y)	21,182	53,121	106,154	212,307
Building Group 3-24Hr				
Energy consumption of baseline technology (kWh/y)	89,352	223,555	446,935	893,870
Energy consumption of BEC technology (kWh/y)	46,989	117,314	234,628	469,256
Energy saving (kWh/y)	42,363	106,241	212,307	424,615
Energy saving percentage (%)	47%	48%	48%	48%

The new technology high efficiency LED lamps can save around 48% of energy consumption compared with conventional LED lamps. The simulation confirms the excellent return on investment on very high efficiency LED lamps compared to normal LED lamps. Paybacks are within 2 years in all cases and even less than 1 year on building Group 3-24Hr.



Figure 5: Investment and financial return of high efficiency LED lamps

2.3.3 Component 3: Air Conditioning System

Technology 3-1 High efficiency Inverter split-type air conditioners with label no.5 3-star

Inverter split-type air conditioners with label no.5 3-star rating provide premium efficiency over common label no.5 split type air conditioners. Energy consumption can be calculated and compared for air conditioners with different efficiencies indicated by SEER (Seasonal Energy Efficiency Ratio).

Table 9: Power consumption comparison of split-type air conditioners

Air conditioner size (Btu/h)	12,000	18,000	24,000	30,000	36,000
Baseline Technology	Fixed speed split-type air conditioner with label no.5				
Air conditioner efficiency SEER (Btu/Wh)	12.85	12.85	12.85	12.40	12.40
Power consumption (kW)	0.93	1.40	1.87	2.42	2.90

BEC Technology	Inverter split-type air conditioner with label no.5 3-star				
Air conditioner efficiency SEER (Btu/Wh)	22.50	22.50	22.50	21.50	21.50
Power consumption (kW)	0.53	0.80	1.07	1.40	1.67

Conservatively assuming 40% utilization factor, table 10 compares electricity consumption of the air conditioners at standard cooling capacities for each BEC building category.

Table 10: Energy consumption comparison of split-type air conditioners

Air conditioner size (Btu/h)	12,000	18,000	24,000	30,000	36,000
Building Group 1-8Hr					
Baseline consumption (kWh/y)	874	1,311	1,748	2,265	2,717
BEC technology consumption (kWh/y)	499	749	998	1,306	1,567
Demand saving (kW)	0.40	0.60	0.80	1.02	1.23
Total energy saving (kWh/y)	375	562	750	958	1,150
Building Group 2-12Hr					
Baseline consumption (kWh/y)	1,636	2,454	3,272	4,239	5,086
BEC technology consumption (kWh/y)	934	1,402	1,869	2,445	2,934
Demand saving (kW)	0.40	0.60	0.80	1.02	1.23
Total energy saving (kWh/y)	702	1,053	1,403	1,794	2,153
Building Group 3-24Hr					
Baseline consumption (kWh/y)	3,272	4,908	6,544	8,477	10,173
BEC technology consumption (kWh/y)	1,869	2,803	3,738	4,889	5,867
Demand saving (kW)	0.40	0.60	0.80	1.02	1.23
Total energy saving (kWh/y)	1,403	2,105	2,807	3,588	4,306
Energy saving percentage (%)	43%	43%	43%	42%	42%

With an average price premium of around 40% high efficiency inverter split-type air conditioners with label no.5 3-star provide very good payback less than 4 years over normal fixed speed label no.5 split-type in all cases and should be a common energy efficiency measure applicable to all BEC buildings.

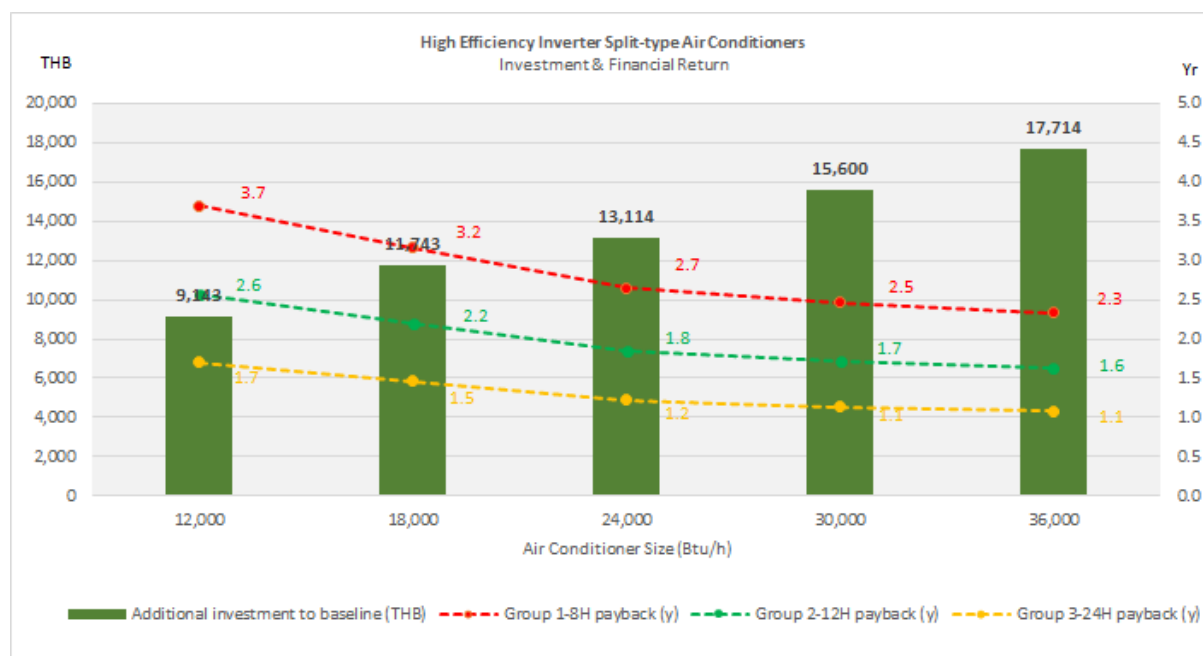


Figure 6: Investment and financial return of high efficiency inverter split-type air conditioners

Technology 3-2 VRF/VRV air conditioning system

VRF or VRV air conditioning system offers high efficiency air conditioning and usage flexibility for small to medium-sized buildings. In the simulation the 40 RT VRF system are compared with the similar sized air-cooled chilled water system. Typical cooling load patterns are used as representatives for BEC building groups. Details of the analysis are summarized as below.

Table 11 and 12 show typical specification and efficiencies of 40 RT VRF system and air-cooled chillers used in the simulation.

Table 11: Typical specification of air-cooled chilled water system and VRF air conditioning system

Baseline Technology	Air-cooled chiller-scroll
Chiller cooling capacity (RT)	40.0
COP	3.15
Chiller power consumption (kW)	44.7
Chiller full load efficiency (kW/RT)	1.12
Chilled water pump consumption (kW)	5.5
Fan coil cooling capacity (Btu/h/unit)	24,000
Fan coil power (kW/unit)	0.17
No. of fan coil unit	20
Total cooling capacity (RT)	40.0
Total fan coil power (kW)	3.4
Total full load power consumption (kW)	53.6
BEC Technology	VRF/VRV air conditioning system
VRV condensing unit cooling capacity (Btu/h)	480,000
VRF condensing unit power (kW)	35.40
VRF full load efficiency (kW/RT)	0.89
VRF fan coil cooling capacity (Btu/h/unit)	24,000
VRF fan coil power (kW/unit)	0.05
No. of VRF fan coil unit	20
Total cooling capacity (RT)	40.0
Total VRF fan coil power (kW)	1.01
Total full load power consumption (kW)	36.4

Table 12: Part load efficiencies of air-cooled chiller and VRF system

% Cooling Load	Air-cooled scroll chiller (kW/RT)	VRF system (kW/RT)
20%	2.50	
30%	2.30	0.45
40%	1.80	0.47
50%	1.55	0.48
60%	1.40	0.53
70%	1.30	0.61
80%	1.20	0.69
90%	1.10	0.78
100%	1.00	0.89

From the simulation of 40 RT cooling capacity, VRF air conditioning system can significantly save around 50% of energy consumption compared with air-cooled chilled water system.

Table 13: Energy saving of VRF air conditioning system over air-cooled chilled water system

	Group 1-8Hr	Group 2-12Hr	Group 3-24Hr
Demand saving (kW)	24	17	17
On-peak energy saving (kWh/y)	52,612	80,258	72,528
Off-peak energy saving (kWh/y)	7,453	38,824	157,587
Total energy saving (kWh/y)	60,065	119,082	230,116
Energy saving percentage (%)	49%	52%	54%



Payback on additional investment are ranged from 3 to 7 years depending on operating hours of the building and cooling load profile of the building. Despite high investment cost VRF system has very attractive investment on high operating hours building Group 3-24Hr.

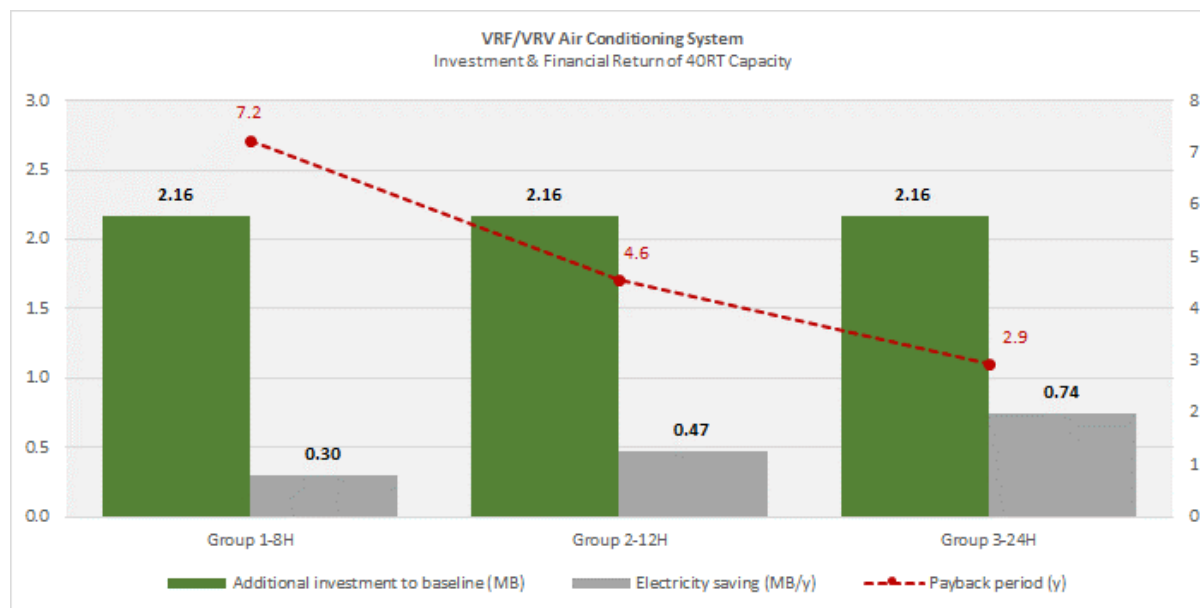


Figure 7: Investment and financial return of VRF/VRV air conditioning system

Technology 3-3 High efficiency chillers/Oil-free magnetic bearing chillers

High efficiency chillers with improved technologies including variable speed centrifugal compressors and magnetic bearing can greatly improve chiller efficiency (COP) and reduce energy consumption. Applying representative cooling load patterns energy consumption and energy performance of high efficiency chillers over conventional chillers can be simulated. Typical specification of chillers for different sizes of buildings are assumed for comparison analysis.

Table 14: Typical specification of chiller models on different building sizes in the simulation

Building area (m ²)	Cooling load (RT) @15 m ² /RT	Baseline Technology		BEC Technology	
		Chiller type	Full load eff (kW/RT)	Chiller type	Full load eff (kW/RT)
2,000	133	Air-cooled screw chiller	1.11	Air-cooled centrifugal magnetic bearing chiller	0.70
5,000	333	Air-cooled screw chiller	1.12	Air-cooled centrifugal magnetic bearing chiller	0.70
10,000	667	Water-cooled centrifugal chiller	0.63	Water-cooled centrifugal magnetic bearing chiller	0.55
20,000	1,333	Water-cooled centrifugal chiller	0.60	Water-cooled centrifugal magnetic bearing chiller	0.55



Table 15: Part-load efficiency factors of different chiller types in the simulation

% Full load	Air-cooled screw	Water-cooled screw	Water-cooled centrifugal	Air-cooled magnetic	Water-cooled magnetic
20%	2.50	1.46	1.16	0.33	0.43
30%	2.30	1.25	1.05	0.37	0.42
40%	1.80	1.12	0.93	0.43	0.42
50%	1.55	1.04	0.83	0.51	0.45
60%	1.40	1.01	0.83	0.58	0.52
70%	1.30	1.00	0.84	0.67	0.63
80%	1.20	1.00	0.90	0.77	0.74
90%	1.10	1.00	0.95	0.88	0.88
100%	1.00	1.00	1.00	1.00	1.00

Table 16 summarizes the result of simulation to compare the energy consumption of baseline chillers and high efficiency magnetic bearing chillers for BEC buildings of different sizes and types.

Table 16: Energy consumption comparison of chillers

Building area (m ²)	2,000	5,000	10,000	20,000
Building Group 1-8Hr				
Energy consumption of baseline technology (kWh/y)	338,335	853,459	846,300	1,612,000
Energy consumption of BEC technology (kWh/y)	158,601	396,502	612,564	1,225,129
Energy saving (kWh/y)	179,735	456,957	233,736	386,871
Energy saving percentage (%)	53%	54%	28%	24%
Building Group 2-12Hr				
Energy consumption of baseline technology (kWh/y)	622,986	1,571,495	1,510,503	2,877,149
Energy consumption of BEC technology (kWh/y)	269,757	674,392	1,033,628	2,067,257
Energy saving (kWh/y)	353,229	897,103	476,875	809,892
Energy saving percentage (%)	57%	57%	32%	28%
Building Group 3-24Hr				
Energy consumption of baseline technology (kWh/y)	1,147,925	2,895,667	2,717,469	5,176,131
Energy consumption of BEC technology (kWh/y)	476,490	1,191,226	1,843,855	3,687,711
Energy saving (kWh/y)	671,435	1,704,441	873,614	1,488,421
Energy saving percentage (%)	58%	59%	32%	29%

The simulation results show significant energy saving of over 50% for small-sized buildings and around 25-30% for larger buildings. The saving percentage for larger buildings are smaller because of smaller differences in chiller efficiencies on large-sized chillers. Returns on investment are high in most cases except for large sized buildings of 10,000 and 20,000 m² and low operating hours of building Group 1-8Hr.

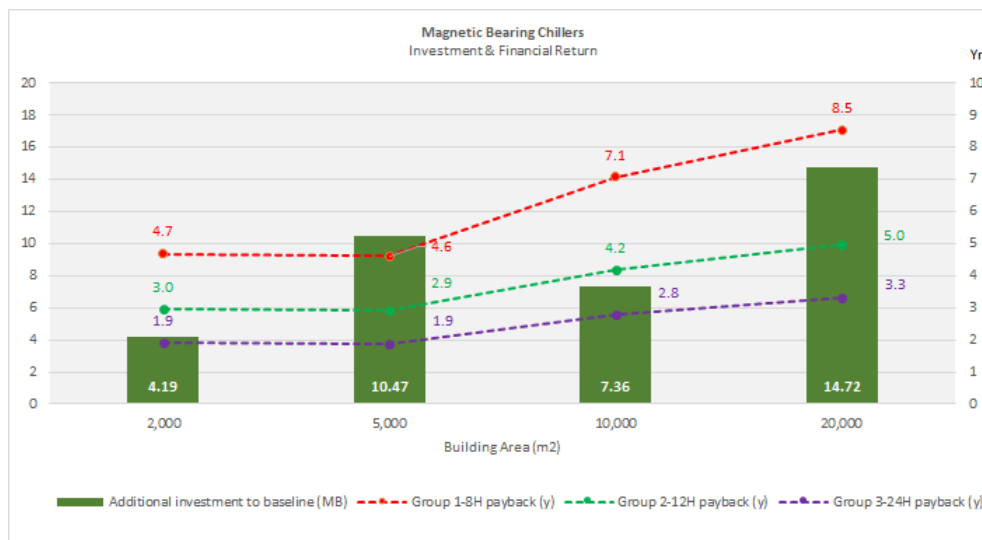


Figure 8: Investment and financial return of high efficiency chillers/Oil-free magnetic bearing chillers



2.3.4 Component 4: Hot Water Generation System

Technology 4-1 Heat pump hot water generation

Heat pump hot water generators can be used in place of fuel hot water boilers in total or partial production of hot water for the buildings. The following calculation illustrates comparison between heat pump system using electricity and fuel oil boiler for hot water production.

Table 17: Comparison of daily energy supply for hot water generation

	Baseline Technology	BEC Technology
Hot Water Generator Type	Fuel Oil Boiler (Grade C)	Air-source heat pump boiler
Efficiency	85%	350% (COP = 3.5)
Energy supply per room (kJ/day)	24,883	6,043
Energy per fuel unit	39,770 kJ/liter	3,600 kJ/kWh
Energy source per room (unit/day)	Fuel oil 0.63 liter/day	Electricity 1.68 kWh/day

Since hot water generation systems are implemented in hotels and hospitals, which are the building Group 3-24Hr, the energy consumption and savings based on 365 day-per-year can be calculated.

Table 18: Energy consumption comparison of hot water generation system

Number of guest rooms	Baseline Technology		BEC Technology				
	Fuel oil consumption (l/y)	Energy consumption (MJ/y)	Electricity Demand (kW)	Electricity consumption (kWh/y)	Energy consumption (MJ/y)	Energy saving (MJ/y)	Energy saving (%)
100	22,837	908,219	47	61,269	220,568	687,652	76%
200	45,674	1,816,439	94	122,538	441,135	1,375,304	76%
500	114,184	4,541,097	236	306,344	1,102,838	3,438,259	76%
1,000	228,368	9,082,194	472	612,688	2,205,676	6,876,519	76%

From the simulation result heat pump hot water system could save 76% of energy consumption compared with fuel oil hot water boiler. Heat pump hot water generation system can offer good savings and return on investment over fuel oil boiler with short payback less than four years in all cases of hotels or hospitals with 100, 200, 500 and 1,000 guest rooms.

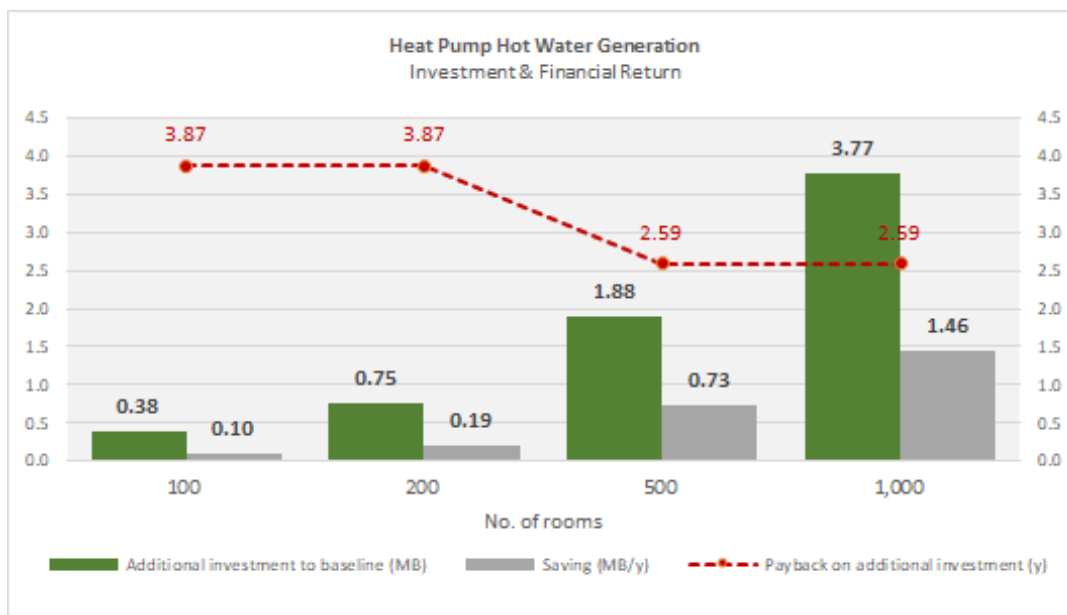


Figure 9: Investment and financial return of heat pump hot water generation

2.3.5 Component 5: Renewable Energy Generation

Technology 5-1 Rooftop solar PV without grid selling and battery system

BEC buildings have great potentials to generate electricity from the free solar energy source. Potential power generation from different capacity of solar rooftop is analyzed and presented in this section. The calculation of power production are based on the solar production profile, normalized from the average of actual energy production of solar PV installed on building roof in Bangkok area.

Table 19: Required roof space and daily energy production of solar PV rooftop

Solar PV installed capacity (kW)	5	10	20	40	100	200	400	1,000
Solar panel rated power (W)	450	450	450	450	450	450	450	450
Number of solar panels	12	23	45	89	223	445	889	2,223
Required space per panel (m ²)	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Total required space (m ²)	26	51	99	196	491	979	1,956	4,891
Inverter size (kW)	5	10	20	20	20	20	20	20
Number of inverters	1	1	1	2	5	10	20	50
Number of string	1	2	4	8	20	40	80	200
Total energy production (kWh/day)	30.7	58.8	114.9	227.3	569.6	1,136.7	2,270.9	5,678.4

By matching of hourly energy production from the solar PV system to the building operating hours, annual energy production to avoided electricity import from the grid can be calculated for BEC building group 1 (8 hours/day: 2,340 hours/year), group 2 (12 hours/day: 4,380 hours) and group 3 (24 hours/day: 8,760 hours/year). Noting that all electricity produced is internally consumed without selling to the grid.

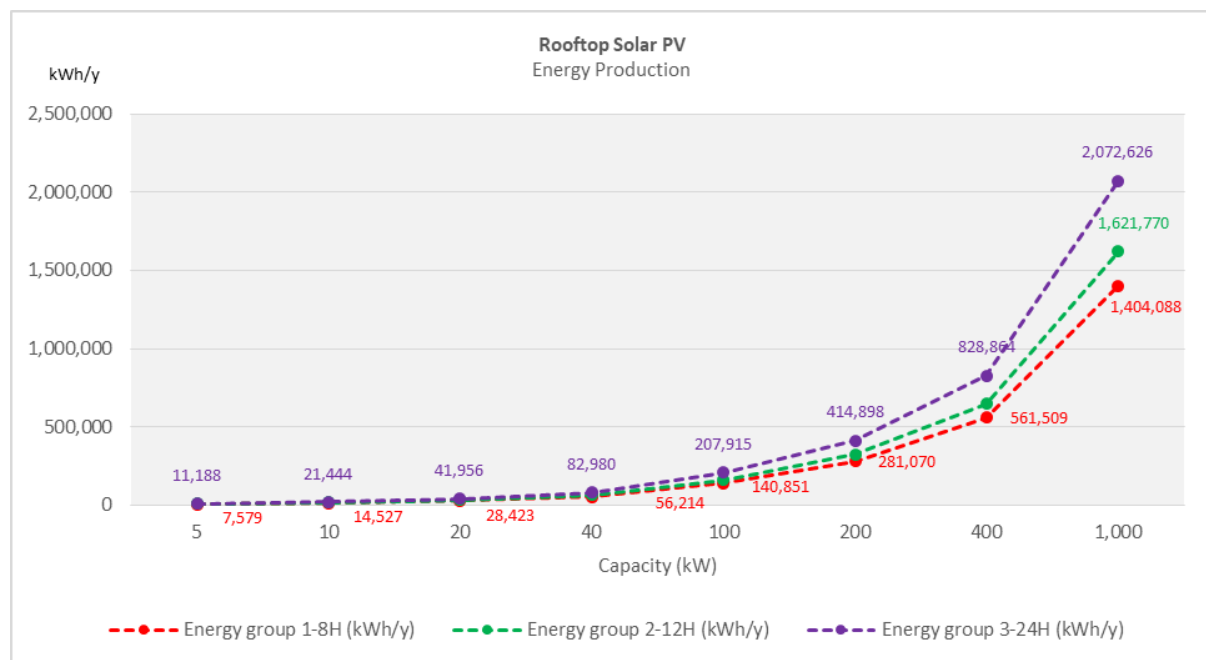


Figure 10: Energy production from rooftop solar PV

Rooftop solar PV system provides savings for BEC buildings with reasonable return on investment within 7 years for Group 1-8Hr buildings and less than 5.5 years for Group 3-24Hr buildings. This is based on assumption that all electricity generated from the PV system is all consumed within the premise. It is therefore important to design the right capacity that matches building electricity profile to maximize return on investment.

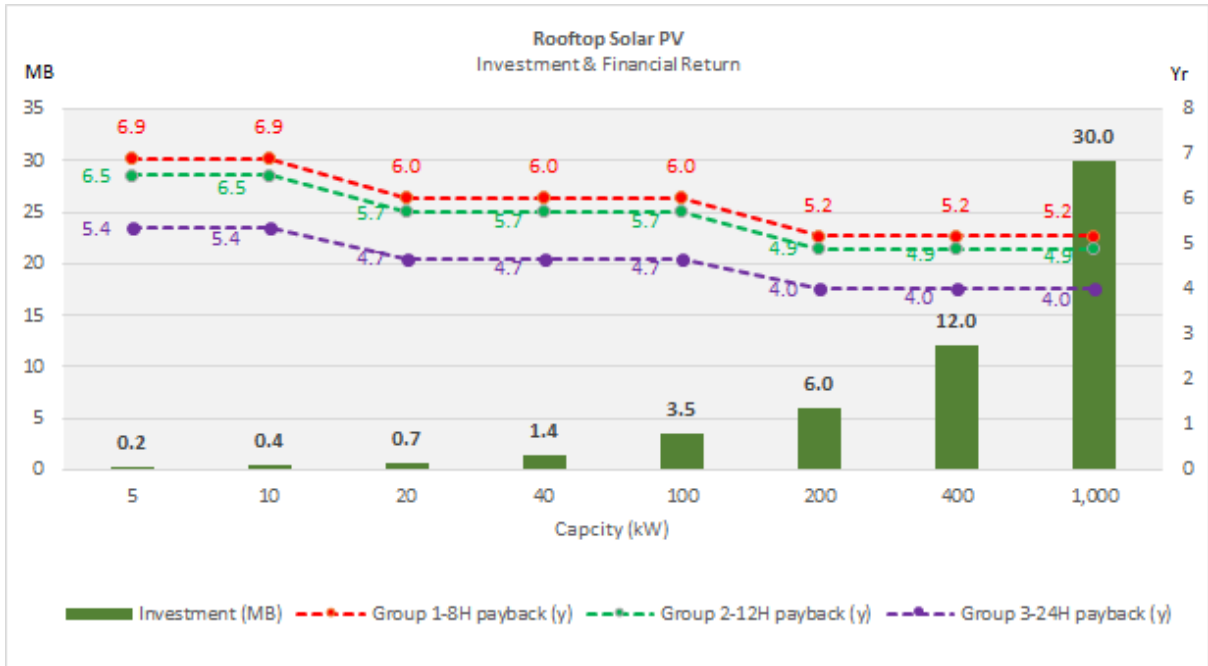


Figure 11: Investment and financial return of rooftop solar PV system

2.3.6 Financial Assessment Conclusion

In conclusion financial assessment of the selected BEC technologies show good savings with moderate to high return on investment. Technologies on independent building systems of component 2 to component 5 potentially provide short payback periods less than five years for buildings in Group 2-12Hr and Group 3-24Hr with high operating hours. The payback on building envelope technologies of component 1 could be a little longer due to higher investment and complication but would generate savings in a long term throughout the building life time.

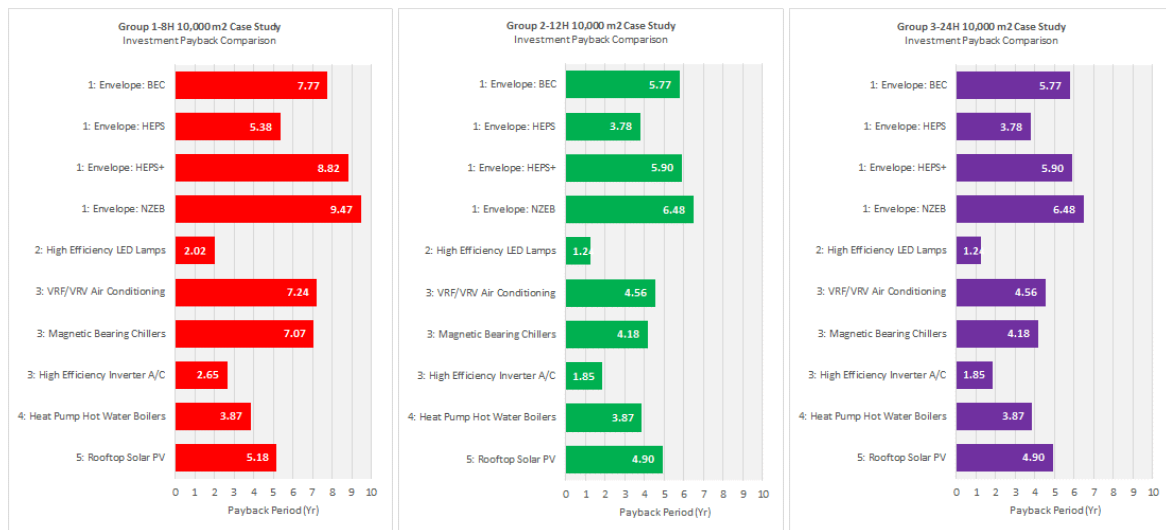


Figure 12: Comparison of return on investment for potential technologies in different BEC components

3 LESSONS LEARNT AND IMPLEMENTATION CHALLENGES

Works on this progress report 4 are on Task 3 to conduct of energy performance simulation and financial assessment of the potential technologies identified in Task 2. The project is running on the fast track mode to recover the delay from the previous activities mainly due to the widespread of COVID-19 pandemic over the past 12 months. The situation tends to be better in the last 2 months and most of the activities involving external parties and data collection are done.

The main challenge faced in this progress still involves the deployment of web-based BEC program to support energy performance simulation. Some calculation features on building energy system are found incorrect so the project team needs to limit its use to building envelope portion and develop the separated calculation models for analysis of technologies on the building systems.

With the definite project completion deadline of 31 December 2021, the alternative work plans has been taken into action following the consultation to key project stakeholders (DEDE, KMUTT, NDE and NDA). The summary of current status and proposed work plan are as follows:

- The combined workshop on outcomes of Task 2: Technology Assessment and Task 3: Financial Assessment was completed on October 2021 through an online virtual conference.
- Energy audit activities of Task 4 were completed in October 2021. Remote interview and data gathering were deployed for the sites with unallowable access. Alternative sources of information from DEDE and network BEC assessors were used to fulfil some missing data.
- Reporting of Task 4 results and conduct of Task 5 are well progressing and running in parallel.
- Handbook of Task 6 has been structured and collectively developed taking the outcomes of the complete tasks

The project team is still taking best effort to complete the tasks within the definite deadline. CTCN and all stakeholders will be continually notified on any update and progress results.



4 ANNEX-1 DETAILS OF ENERGY PERFORMANCE SIMULATION AND FINANCIAL ASSESSMENT OF THE POTENTIAL TECHNOLOGIES FOR EACH BEC COMPONENT

The Annex-1 provides analysis details of the energy performance simulation and financial assessment of the potential technologies for improving energy performance of BEC buildings in each BEC component.

List of high potential technologies for each BEC components

Item	BEC Technology	Baseline Technology	Priority
Component 1: Building Envelope			
	<u>Opaque Wall</u>		
1-1	Light weight concrete blocks (AAC)	Concrete, concrete block or brick.	A
1-2	Wall insulation with fiber glass, mineral wool	Walls with no insulation.	A
1-3	Composite insulated panels with polyurethane, PIR, Rockwool	Walls with no insulation.	B
	<u>Transparent Wall and Window</u>		
1-4	Energy efficient coated glass: reflective glass, low-e film	Clear or tinted float or laminated glass.	A
1-5	Insulating glass: low-e multi-glazing	Clear or tinted float or laminated glass.	A
1-6	Window shading devices	Windows with no shading devices	A
	<u>Roof</u>		
1-7	Roof insulation with fiber glass, mineral wool or foams	Concrete or metal sheet roof without insulation.	A
1-8	High solar reflective paint	Normal roof material.	A
Component 2: Lighting System			
2-1	High efficiency LED lamps (200 lm/W)	Fluorescent lamps, normal LED lamps with efficiency less than 150 lumen/Watt.	A
Component 3: Air Conditioning System			
3-1	High efficiency Inverter split-type air conditioners with label no.5 3-star	Fixed speed or standard inverter split-type air conditioners.	A
3-2	VRF/VRV air conditioning system	Split-type, packaged unit air conditioner or air-cooled chillers.	B
3-3	High efficiency chillers/Oil-free magnetic bearing chillers	Standard air-cooled or water-cooled electric chillers.	A
Component 4: Hot Water Generation			
4-1	Heat pump hot water generation	Electric or fuel hot water boiler.	A
Component 5: Renewable Energy Utilization			
5-1	Rooftop solar PV without grid selling and battery system	100% use of on-grid electricity.	A
Component 6: Whole Building Energy Performance			
	None		



4.1 COMPONENT 1: BUILDING ENVELOPE

4.1.1 Technology 1-1 to 1-8: Material and Insulation Technologies for Building Envelope

Building envelope is the most critical component to energy performance of the building. Envelope with better insulation greatly reduce heat gain and energy consumption of the air conditioning system, which is the most energy consumer of the building. Since the impact of wall, window and roof materials to energy consumption are correlated, it therefore requires integrative approach to simulate the impact of these materials to OTTV, RTTV and energy consumption.

For simulation the conceptual building models are developed as the representative for each BEC building type. The combination of opaque wall, window glass, roof materials and window-to-wall ratio (WWR) are set for each building model. Baseline model represents building with conventional materials with poor insulation and model BEC, HEPS (High Energy Performance Standard), HEPS+ (Higher Energy Performance Standard) and NZEB (Near Zero Energy Building) indicate the progressive increase of heat insulation materials of the building envelope.

Table 20: Representative building models for building envelope simulation

Simulation Case	Baseline	BEC	HEPS	HEPS+	NZEB
Building Information					
Shape	Rectangle				
North-South walls (m)	40				
East-West walls (m)	25				
Floor area (m ²)	1,000				
Number of floors	2 / 5 / 10 / 20				
Total area (m ²) (all areas are air-conditioned)	2,000 / 5,000 / 10,000 / 20,000				
Floor height (m)	4.0				
Roof type	Flat				
Building Envelope Materials					
Wall code	Wall 01	Wall 02	Wall 03	Wall 04	Wall 04
Opaque wall	Pale color Concrete 10 cm	Light color Concrete 10 cm	Light color Light weight concrete 10 cm	Light color Light weight concrete 10 cm Air gap 5 cm Fiberglass 6.5 cm Gypsum 1.2 cm	Light color Light weight concrete 10 cm Air gap 5 cm Fiberglass 6.5 cm Gypsum 1.2 cm
Transparent wall code	Wall 05	Wall 06	Wall 07	Wall 08	Wall 09
Window glass	Ocean green glass 6 mm VT=0.76, SHGC=0.60	Reflective glass 6 mm VT=0.326, SHGC=0.37	Reflective glass 8 mm VT=0.325, SHGC=0.35	Low-e 6-12-6 mm VT=0.6, SHGC=0.39	Heat stop low-e 24 mm VT=0.38, SHGC=0.20
Window to wall ratio (WWR)	50%	50%	37.5%	30%	30%
Roof code	Roof 01	Roof 02	Roof 02	Roof 03	Roof 03
Roof	Light color Concrete 20 cm Air gap 50 cm Gypsum 1.2 cm	Light color Concrete 20 cm Air gap 50 cm Fiberglass 7.5 cm Gypsum 1.2 cm	Light color Concrete 20 cm Air gap 50 cm Fiberglass 7.5 cm Gypsum 1.2 cm	Light color Concrete 20 cm Air gap 50 cm Fiberglass 15 cm Gypsum 1.2 cm	Light color Concrete 20 cm Air gap 50 cm Fiberglass 15 cm Gypsum 1.2 cm

The simulation deploys web-based BEC program for setting material properties and calculate thermal transfer values (OTTV/RTTV) per unit area (W/m²) of each type of envelope and building group.



Table 21: OTTV (W/m^2) on all directions for selected wall and window materials of each building group simulation

Wall Code	OTTV-N	OTTV-S	OTTV-E	OTTV-W	OTTV-Average
Building Group 1-8Hr					
Opaque wall					
Wall_01	39.198	50.472	44.544	51.038	46.313
Wall_02	29.058	35.552	32.121	35.935	33.167
Wall_03	13.511	16.482	15.199	16.302	15.374
Wall_04	3.513	4.286	3.952	4.242	3.998
Window					
Wall_05	139.736	189.146	169.448	175.418	168.437
Wall_06	94.522	124.992	112.845	116.526	112.221
Wall_07	90.521	119.344	107.853	111.336	107.264
Wall_08	82.173	114.290	101.486	105.367	100.829
Wall_09	45.012	61.482	54.916	56.906	54.579
Building Group 2-12Hr					
Opaque wall					
Wall_01	38.815	49.339	45.892	47.623	45.417
Wall_02	29.824	36.135	33.837	35.185	33.745
Wall_03	11.974	14.337	13.827	13.707	13.461
Wall_04	3.121	3.737	3.604	3.574	3.509
Window					
Wall_05	108.812	142.262	133.088	125.924	127.522
Wall_06	75.452	96.080	90.423	86.005	86.990
Wall_07	72.482	91.995	86.643	82.464	83.396
Wall_08	62.073	83.815	77.852	73.196	74.234
Wall_09	34.704	45.854	42.796	40.408	40.941
Building Group 3-24Hr					
Opaque wall					
Wall_01	24.126	30.836	28.921	29.687	28.393
Wall_02	18.581	22.411	21.262	21.645	20.975
Wall_03	6.782	8.125	7.697	7.840	7.611
Wall_04	1.768	2.118	2.006	2.043	1.984
Window					
Wall_05	65.628	86.976	78.936	81.408	78.237
Wall_06	45.482	58.646	53.688	55.213	53.257
Wall_07	43.688	56.141	51.451	52.893	51.043
Wall_08	37.465	51.341	46.115	47.722	45.661
Wall_09	20.936	28.052	25.372	26.196	25.139

Table 22: RTTV (W/m^2) for selected roof materials of each building group simulation

Roof Code	RTTV Group 1-8Hr	RTTV Group 2-12Hr	RTTV Group 3-24Hr
Roof_01	18.482	19.281	13.120
Roof_02	3.446	3.716	2.601
Roof_03	2.114	2.280	1.596

With the wall and roof areas of the building models, total heat gains through building envelope can be calculated and impact to the heat load of the air conditioning system can be estimated.

Calculation of OTTV and RTTV

$$OTTV \text{ North } (W/m^2) = ((1 - WWR_N) \times OTTV_{N_{opaque \text{ wall}}}) + (WWR_N \times OTTV_{N_{window}})$$

$$OTTV \text{ South } (W/m^2) = ((1 - WWR_S) \times OTTV_{S_{opaque \text{ wall}}}) + (WWR_S \times OTTV_{S_{window}})$$

$$OTTV \text{ East } (W/m^2) = ((1 - WWR_E) \times OTTV_{E_{opaque \text{ wall}}}) + (WWR_E \times OTTV_{E_{window}})$$

$$OTTV \text{ West } (W/m^2) = ((1 - WWR_W) \times OTTV_{W_{opaque \text{ wall}}}) + (WWR_W \times OTTV_{W_{window}})$$



$$OTTV (W/m^2) = \frac{\sum_{i=North, South, East, West} (OTTV_i (W/m^2) \times Wall Area i (m^2))}{\sum_{i=North, South, East, West} Wall Area i (m^2)}$$

$$RTTV (W/m^2) = RTTV_{Roof}$$

Calculation of heat gain and reduction of air conditioning load

$$Heat\ gain\ thru\ envelope\ (RT) = \left[\sum_{i=North, South, East, West} (OTTV_i (W/m^2) \times Wall\ area\ i (m^2)) + (RTTV_{Roof} (W/m^2) \times Roof\ area (m^2)) \right] \times \frac{1}{3,516.85}$$

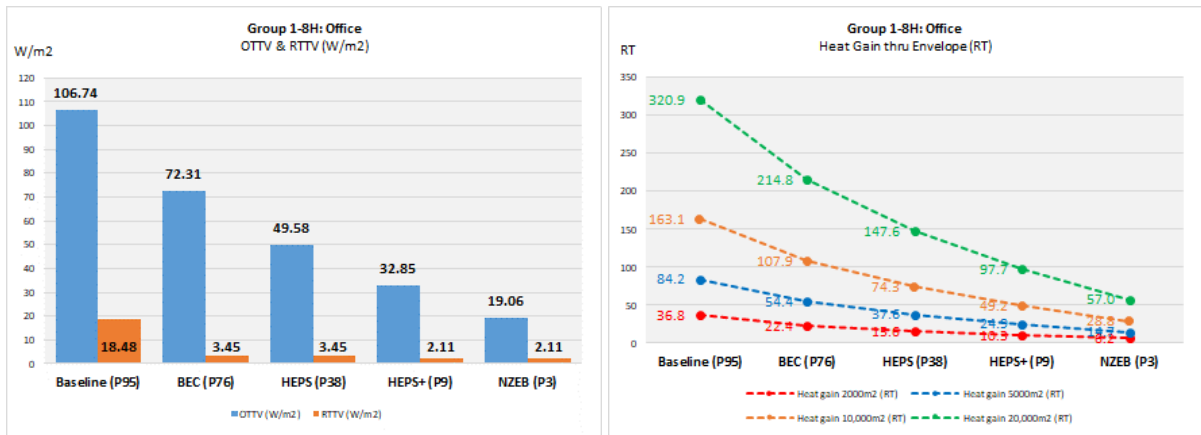


Figure 13: Simulation results on improvement of building envelope from baseline for building Group 1-8Hr

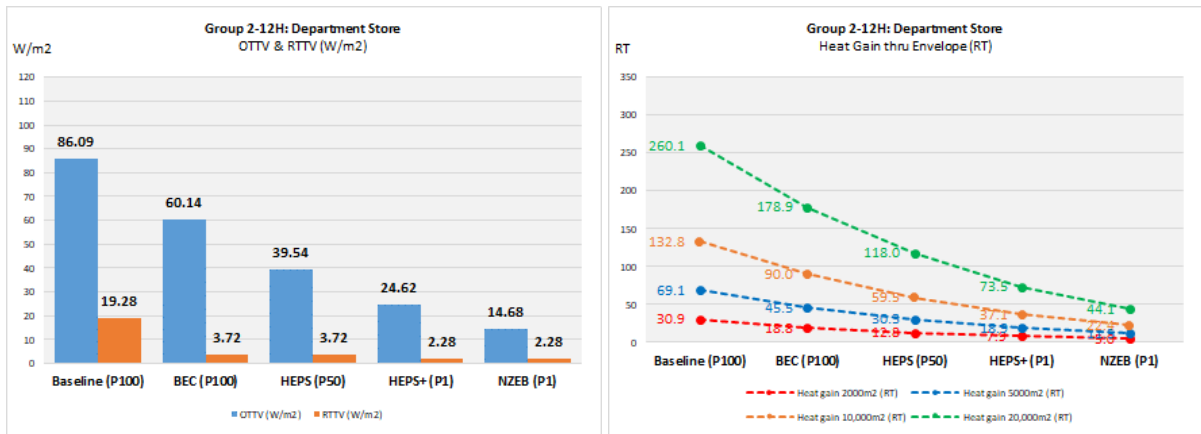


Figure 14: Simulation results on improvement of building envelope from baseline for building Group 2-12Hr



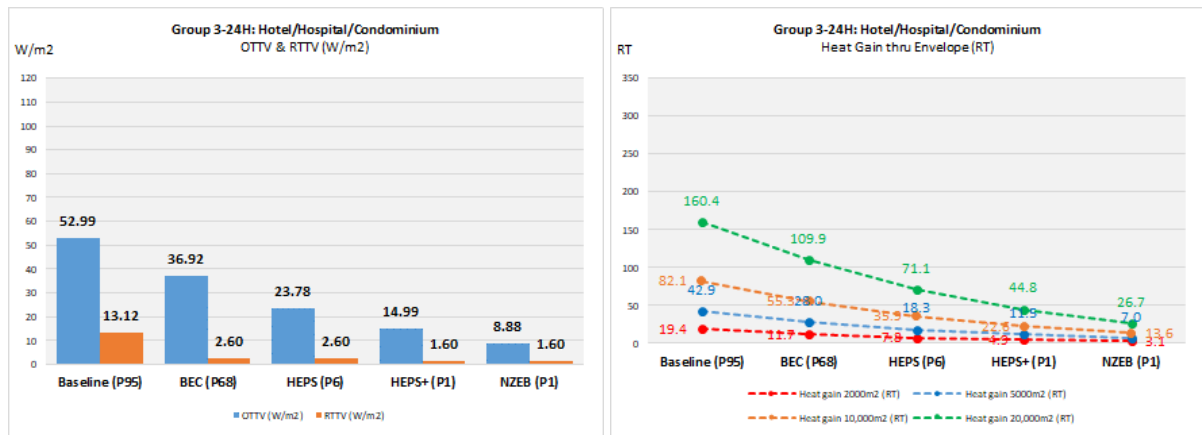


Figure 15: Simulation results on improvement of building envelope from baseline for building Group 3-24Hr

The simulation results show significant reduction of heat gain through each steps of increasing insulation on walls, roof and implementing heat insulating glass. It should be noted that improving RTTV takes much less effort than OTTV. Heat insulating properties of glass for windows or transparent walls and WWR have high impact on OTTV. Despite high-end insulating low-e glass with low solar heat gain (SHGC), heat transfer per unit area (W/m^2) is still high compared to opaque wall.

Knowing efficiency of the air conditioning system, reduced energy consumption from reduced heat gain can be determined by the following formula.

$$\text{Power consumption of air conditioning system from heat gain (kW)} = \text{Heat gain thru envelope (RT)} \times \text{Air conditioning efficiency (kW/RT)}$$

The building models simulate energy consumption and savings from reduced heat gain through improved building envelope for different BEC building groups from small to large sizes (2,000/5,000/10,000/20,000 m^2). However only 10,000 m^2 buildings are selected for illustration in this report.

Table 23: Simulation results of energy consumption and savings from reduced heat gain through improved building envelope of the 10,000 m^2 building model

Simulation Case	Baseline	BEC	HEPS	HEPS+	NZEB
Building Group 1-8Hr					
Air Conditioning Impact					
Heat gain thru walls (W)	555,066	376,013	257,796	170,829	99,134
Heat gain thru roof (W)	18,482	3,446	3,446	2,114	2,114
Total heat gain thru envelope (W)	573,548	379,459	261,242	172,943	101,248
Total heat gain thru envelope (RT)	163.09	107.90	74.28	49.18	28.79
Cooling load reduction (RT)	0.00	55.19	33.61	25.11	20.39
Air conditioning per area (m^2/RT)	15.00	16.35	17.31	18.09	18.78
Chiller size (RT)	666.7	611.5	577.9	552.8	532.4
Chiller efficiency (kW/RT)	0.65	0.65	0.65	0.65	0.65
Chiller power consumption (kW)	433.3	397.5	375.6	359.3	346.0
Energy savings					
Power saving (kW)	0.00	35.87	57.72	74.04	87.29
Energy saving (kWh/y)	0	83,941	135,069	173,257	204,264
Energy saving percentage (%)	0%	8%	13%	17%	20%
Building Group 2-12Hr					
Air Conditioning Impact					
Heat gain thru walls (W)	447,646	312,718	205,621	128,046	76,335
Heat gain thru roof (W)	19,281	3,716	3,716	2,280	2,280
Total heat gain thru envelope (W)	466,927	316,434	209,337	130,326	78,615
Total heat gain thru envelope (RT)	132.77	89.98	59.52	37.06	22.35
Cooling load reduction (RT)	0.00	42.79	30.45	22.47	14.70
Air conditioning per area (m^2/RT)	15.00	16.03	16.85	17.51	17.98

Simulation Case	Baseline	BEC	HEPS	HEPS+	NZEB
Chiller size (RT)	666.7	623.9	593.4	571.0	556.3
Chiller efficiency (kW/RT)	0.65	0.65	0.65	0.65	0.65
Chiller power consumption (kW)	433.3	405.5	385.7	371.1	361.6
Energy savings					
Power saving (kW)	0.00	27.81	47.61	62.21	71.77
Energy saving (kWh/y)	0	121,829	208,527	272,489	314,351
Energy saving percentage (%)	0%	6%	11%	14%	17%
Building Group 3-24Hr					
Air Conditioning Impact					
Heat gain thru walls (W)	275,529	192,000	123,644	77,965	46,171
Heat gain thru roof (W)	13,120	2,601	2,601	1,596	1,596
Total heat gain thru envelope (W)	288,649	194,601	126,245	79,561	47,767
Total heat gain thru envelope (RT)	82.08	55.33	35.90	22.62	13.58
Cooling load reduction (RT)	0.00	26.74	19.44	13.27	9.04
Air conditioning per area (m ² /RT)	15.00	15.63	16.12	16.47	16.72
Chiller size (RT)	666.7	639.9	620.5	607.2	598.2
Chiller efficiency (kW/RT)	0.65	0.65	0.65	0.65	0.65
Chiller power consumption (kW)	433.3	416.0	403.3	394.7	388.8
Energy savings					
Power saving (kW)	0.00	17.38	30.02	38.64	44.52
Energy saving (kWh/y)	0	152,269	262,942	338,527	390,002
Energy saving percentage (%)	0%	4%	7%	9%	10%

The simulation results indicate savings of air conditioning consumption of up to 20% for Group 1-8Hr building, 17% for Group 2-12Hr and 10% for Group 3-24Hr. Noting saving percentage for Group 1-8Hr is high because the building operates only during the day causing higher heat gain reduction percentage, while Group 2-12Hr and Group 3-24Hr operate both day and night. The annual energy savings for Group 3-24Hr is the highest and lower on Group 2-12Hr and Group 1-8Hr due to the number of building operating hours.

Scale of investment, net savings and payback on investment from improved building envelope efficiency (model BEC, HEPS, HEPS+ and NZEB) compared to baseline scenario as table 24. The 10,000 m² building models is selected for presenting in this report.

Table 24: Investment and saving from building envelope simulation of 10,000 m² BEC building models

Simulation Case	Baseline	BEC	HEPS	HEPS+	NZEB
Building Group 1-8Hr					
Energy savings					
Power saving (kW)	0.00	35.87	57.72	74.04	87.29
Energy saving (kWh/y)	0	83,941	135,069	173,257	204,264
Energy saving percentage (%)	0%	8%	13%	17%	20%
Demand charge (THB/kW)	132.93	132.93	132.93	132.93	132.93
Average energy charge (THB/kWh)	3.7795	3.7795	3.7795	3.7795	3.7795
Energy saving (MB/y)	0.00	0.32	0.52	0.66	0.78
Investment and return					
Cost of opaque wall (THB/m ²)	636	739	823	1,279	1,279
Opaque wall cost (THB)	1,652,820	1,920,620	2,674,750	4,653,942	4,653,942
Cost of transparent wall (THB/m ²)	344	1,218	1,625	2,908	4,090
Transparent wall cost (THB)	895,557	3,167,848	3,167,848	4,535,700	6,380,400
Cost of roof (THB/m ²)	592	1,328	1,328	1,411	1,411
Roof cost (THB/m ²)	592,000	1,327,500	1,327,500	1,410,833	1,410,833
Total envelope cost (MB)	3.14	6.42	7.17	10.60	12.45
Cost of chiller (THB/RT)	14,000	14,000	14,000	14,000	14,000
Chiller cost (MB)	9.33	8.56	8.09	7.74	7.45
Total envelope and chiller cost (MB)	12.47	14.98	15.26	18.34	19.90
Additional investment to base case (MB)	0.00	2.50	2.79	5.87	7.42
Payback period to base case (y)	0.00	7.77	5.38	8.82	9.47
Building Group 2-12Hr					



Simulation Case	Baseline	BEC	HEPS	HEPS+	NZEB
Energy savings					
Power saving (kW)	0.00	27.81	47.61	62.21	71.77
Energy saving (kWh/y)	0	121,829	208,527	272,489	314,351
Energy saving percentage (%)	0%	6%	11%	14%	17%
Investment and return					
Cost of opaque wall (THB/m ²)	636	739	823	1,279	1,279
Opaque wall cost (THB)	1,652,820	1,920,620	2,674,750	4,653,942	4,653,942
Cost of transparent wall (THB/m ²)	344	1,218	1,625	2,908	4,090
Transparent wall cost (THB)	895,557	3,167,848	3,167,848	4,535,700	6,380,400
Cost of roof (THB/m ²)	592	1,328	1,328	1,411	1,411
Roof cost (THB/m ²)	592,000	1,327,500	1,327,500	1,410,833	1,410,833
Total envelope cost (MB)	3.14	6.42	7.17	10.60	12.45
Cost of chiller (THB/RT)	14,000	14,000	14,000	14,000	14,000
Chiller cost (MB)	9.33	8.73	8.31	7.99	7.79
Total envelope and chiller cost (MB)	12.47	15.15	15.48	18.59	20.23
Additional investment to base case (MB)	0.00	2.68	3.00	6.12	7.76
Payback period to base case (y)	0.00	5.77	3.78	5.90	6.48
Building Group 3-24Hr					
Energy savings					
Power saving (kW)	0.00	17.38	30.02	38.64	44.52
Energy saving (kWh/y)	0	152,269	262,942	338,527	390,002
Energy saving percentage (%)	0%	4%	7%	9%	10%
Investment and return					
Cost of opaque wall (THB/m ²)	636	739	823	1,279	1,279
Opaque wall cost (THB)	1,652,820	1,920,620	2,674,750	4,653,942	4,653,942
Cost of transparent wall (THB/m ²)	344	1,218	1,625	2,908	4,090
Transparent wall cost (THB)	895,557	3,167,848	3,167,848	4,535,700	6,380,400
Cost of roof (THB/m ²)	592	1,328	1,328	1,411	1,411
Roof cost (THB/m ²)	592,000	1,327,500	1,327,500	1,410,833	1,410,833
Total envelope cost (MB)	3.14	6.42	7.17	10.60	12.45
Cost of chiller (THB/RT)	14,000	14,000	14,000	14,000	14,000
Chiller cost (MB)	9.33	8.96	8.69	8.50	8.37
Total envelope and chiller cost (MB)	12.47	15.37	15.86	19.10	20.82
Additional investment to base case (MB)	0.00	2.90	3.38	6.63	8.35
Payback period to base case (y)	0.00	5.02	3.39	5.16	5.64



The following charts summarizes the investment and financial return results for different BEC building groups and sizes.

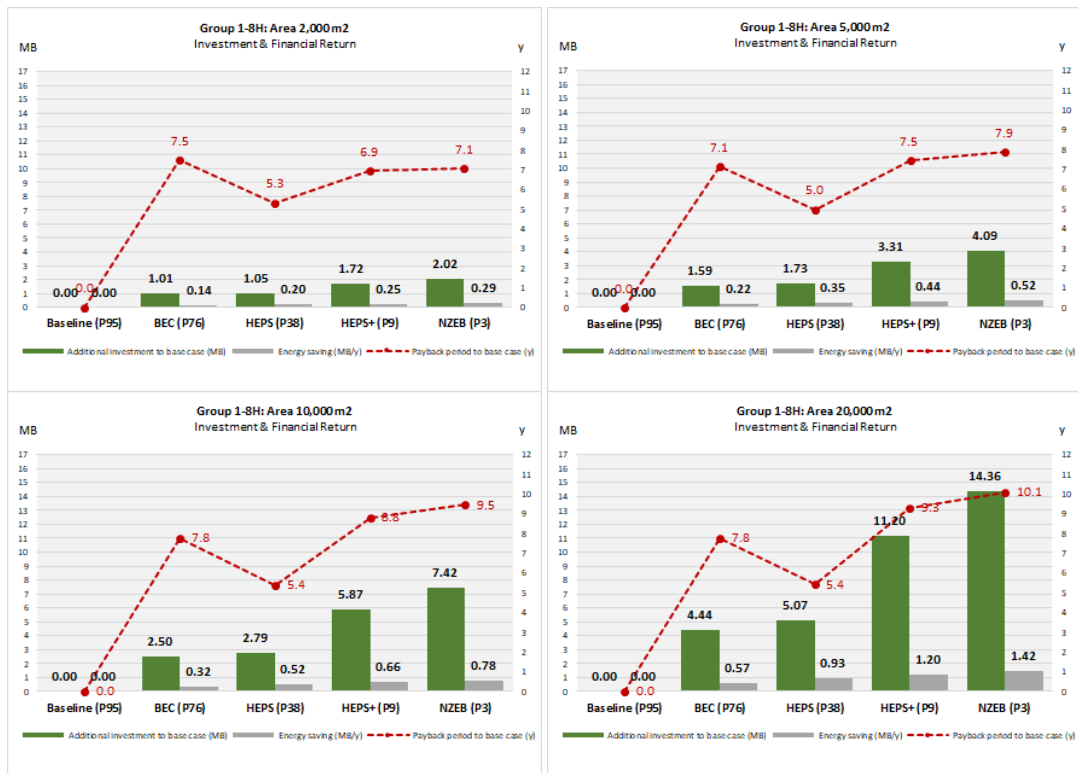


Figure 16: Investment and financial return from building envelope simulation of building Group 1-8Hr

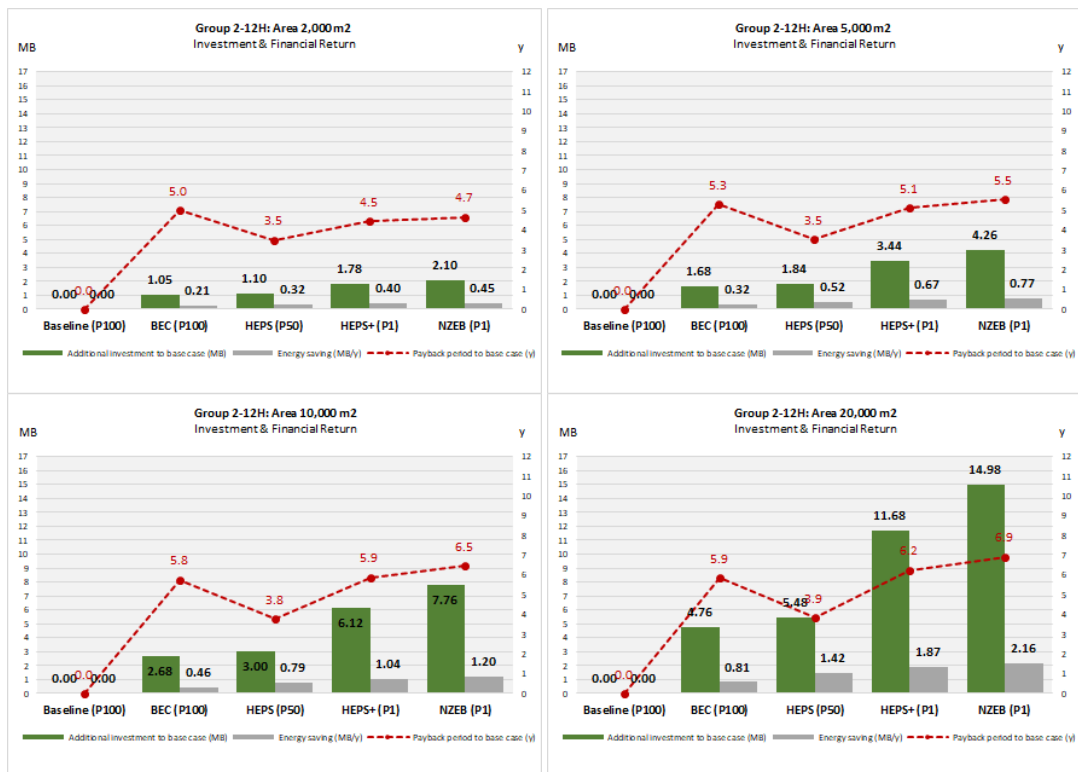


Figure 17: Investment and financial return from building envelope simulation of building Group 2-12Hr



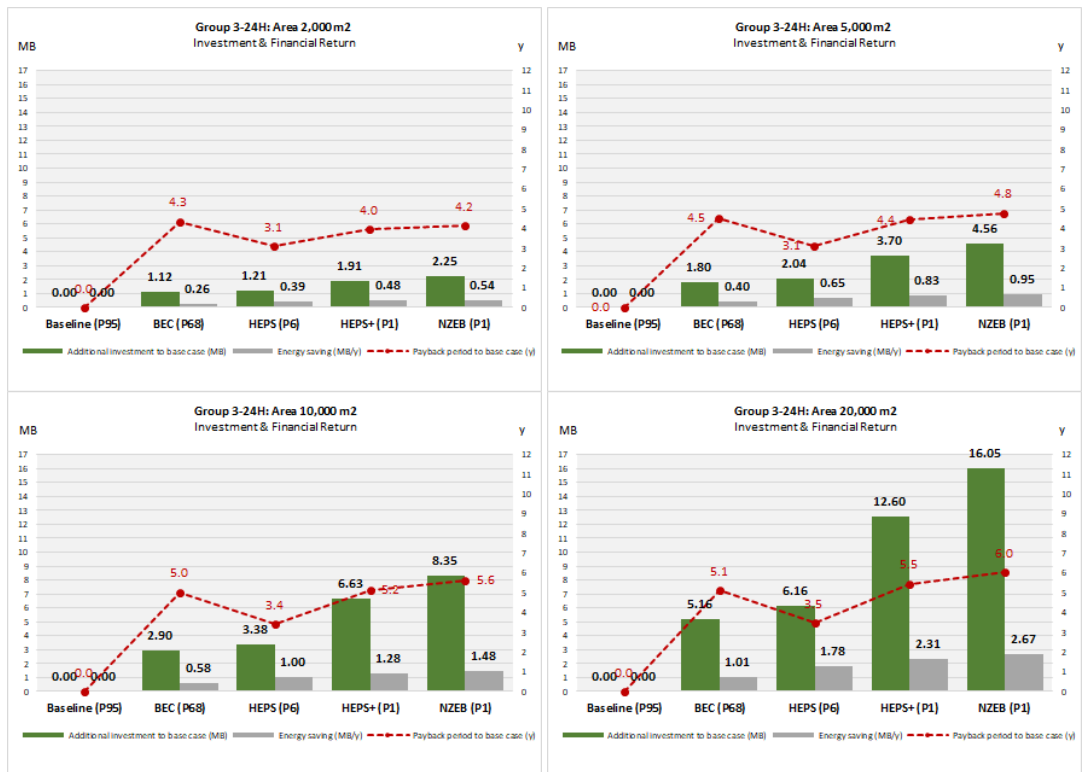


Figure 18: Investment and financial return from building envelope simulation of building Group 3-24Hr

Paybacks on additional investment are range from 5.0 to 10.1 years for Group 1-8Hr, 3.5 to 6.9 years for Group 2-12Hr and 3.1 to 6.0 years for Group 3-24Hr. The simulation indicates the better paybacks on small sized buildings of 2,000 and 5,000 m² as small chillers are less efficient than large chillers resulting in more power savings from reduced cooling loads.



4.2 COMPONENT 2: LIGHTING SYSTEM

4.2.1 Technology 2-1 High efficiency LED lamps (200 lm/W)

High efficiency LED lamps are the new LED technology with higher lumen per Watt than normal LED lamp commonly used in the buildings. Table 25 shows the light output and efficiency comparison between high efficiency tubular LED lamp and normal tubular LED lamps.

Table 25: Light output and efficiency of LED lamps in the simulation

	Baseline Technology	BEC Technology
Lamp Type	Normal 1200 mm Tubular LED Lamp	High Efficiency 1200 mm Tubular LED Lamp
Lamp efficacy (lm/W)	105	200
Luminous flux per lamp (lm)	2,100	3,600
Power per lamp (W)	20	18

The number of lamps and power consumptions are estimated based on the Lumen method formula.

$$\text{Number of lamps} = \frac{\text{Average luminosity (lux)} \times \text{Area (m}^2\text{)}}{\text{Luminous flux per lamp (lm)} \times \text{Utilization factor} \times \text{Maintenance factor}}$$

Assuming required luminosity of 300 lux average, utilization factor (UF) and maintenance factor (MF) are set as 0.7 and 0.8 for the new and well-maintained building, the number of lamps and lighting energy consumptions can be calculated for each types of BEC building.

$$\text{Power consumption (kW)} = \text{Number of lamps} \times \text{Power per lamp (W/lamp)} \times \frac{1}{1,000}$$

$$\text{Energy consumption (kWh/y)} = \text{Power consumption (kW)} \times \text{Operating hours (hr/y)}$$

$$\begin{aligned} \text{Demand saving (kW)} \\ &= \text{Power consumption of baseline technology (kW)} \\ &\quad - \text{Power consumption of BEC technology (kW)} \end{aligned}$$

$$\begin{aligned} \text{Energy saving (kWh/y)} \\ &= \text{Energy consumption of baseline technology (kWh/y)} \\ &\quad - \text{Energy consumption of BEC technology (kWh/y)} \end{aligned}$$

Table 26: Energy consumption comparison of LED lamps

Building area (m ²)	2,000	5,000	10,000	20,000
Demand saving (kW)	4.8	12.1	24.2	48.5
Group 1-8Hr				
Energy consumption of baseline technology (kWh/y)	23,868	59,717	119,387	238,774
Energy consumption of BEC technology (kWh/y)	12,552	31,337	62,675	125,349
Energy saving (kWh/y)	11,316	28,380	56,712	113,424
Group 2-12Hr				
Energy consumption of baseline technology (kWh/y)	44,676	111,778	223,468	446,935
Energy consumption of BEC technology (kWh/y)	23,494	58,657	117,314	234,628
Energy saving (kWh/y)	21,182	53,121	106,154	212,307
Group 3-24Hr				
Energy consumption of baseline technology (kWh/y)	89,352	223,555	446,935	893,870
Energy consumption of BEC technology (kWh/y)	46,989	117,314	234,628	469,256
Energy saving (kWh/y)	42,363	106,241	212,307	424,615
Energy saving percentage (%)	47%	48%	48%	48%



The new technology high efficiency LED lamps can save around 48% of energy consumption compared with conventional LED lamps. Investment and savings from high efficiency LED lamps on all building groups and sizes are summarized as table 27.

Table 27: Investment and saving from simulation of high efficiency LED lamps

Building Area(m ²)	Diff Investment (THB)	Tariff	Demand Saving (THB/y)	Electricity Saving (THB/y)		
				Group 1-8Hr	Group 2-12Hr	Group 3-24Hr
2,000	102,600	TOU 3.2.3/4.2.3	12,187	44,217	76,775	131,398
5,000	254,800	TOU 3.2.3/4.2.3	30,563	110,890	192,541	329,527
10,000	510,100	TOU 3.2.2/4.2.2	38,660	214,343	373,184	642,735
20,000	1,020,200	TOU 3.2.2/4.2.2	77,321	428,687	746,369	1,285,471

Figure 19 shows scale of additional investment and payback period compared to baseline scenario.

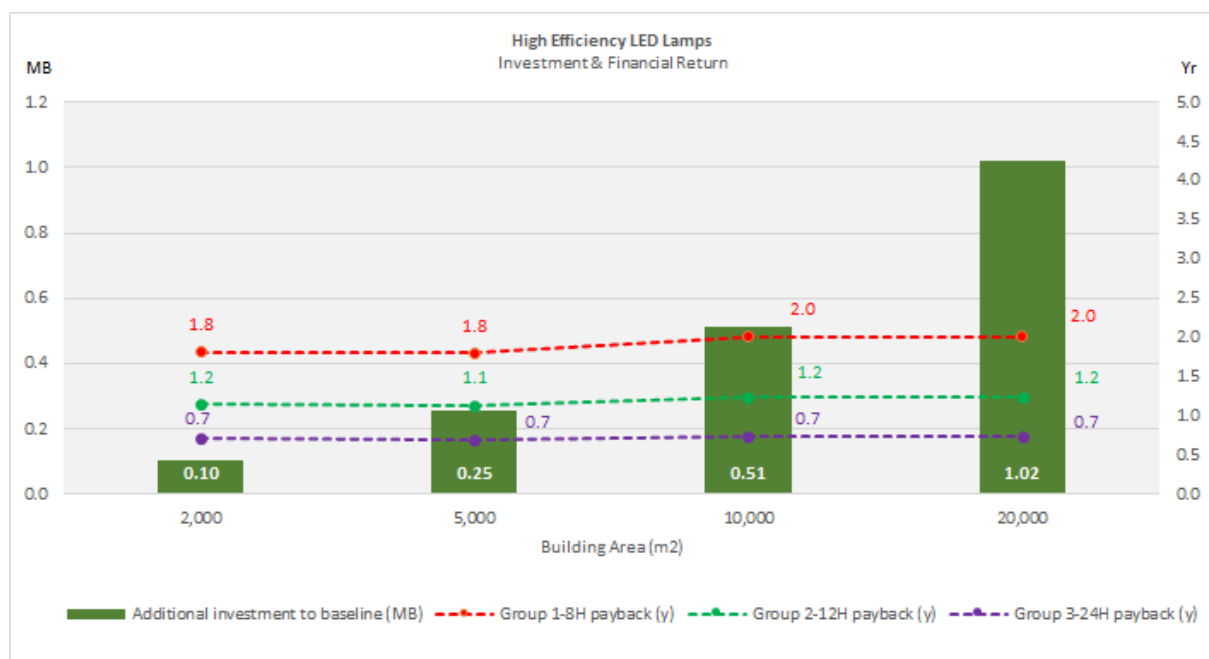


Figure 19: Investment and financial return of high efficiency LED lamps

The simulation confirms the excellent return on investment on very high efficiency LED lamps compared to normal LED lamps. Paybacks are within 2 years in all cases and even less than 1 year on building Group 3-24Hr.

4.3 COMPONENT 3: AIR CONDITIONING SYSTEM

4.3.1 Technology 3-1 High efficiency Inverter split-type air conditioners with label no.5 3-star

Inverter split-type air conditioners with label no.5 3-star rating provide premium efficiency over common label no.5 split type air conditioners. Energy consumption can be calculated and compared for air conditioners with different efficiencies indicated by SEER (Seasonal Energy Efficiency Ratio).

$$\text{Power consumption (kW)} = \frac{\text{Cooling capacity (Btu/h)}}{\text{SEER (Btu/Wh)}} \times \frac{1}{1,000}$$

Table 28: Power consumption comparison of split-type air conditioners

Air conditioner size (Btu/h)	12,000	18,000	24,000	30,000	36,000
Baseline Technology	Fixed speed split-type air conditioner with label no.5				
Air conditioner efficiency SEER (Btu/Wh)	12.85	12.85	12.85	12.40	12.40
Power consumption (kW)	0.93	1.40	1.87	2.42	2.90
BEC Technology	Inverter split-type air conditioner with label no.5 3-star				
Air conditioner efficiency SEER (Btu/Wh)	22.50	22.50	22.50	21.50	21.50
Power consumption (kW)	0.53	0.80	1.07	1.40	1.67
Energy saving percentage (%)	43%	43%	43%	42%	42%

Conservatively assuming 40% utilization factor, table 29 compares electricity consumption of the air conditioners at standard cooling capacities for each BEC building category.

$$\begin{aligned} \text{Energy consumption (kWh/y)} \\ &= \text{Power consumption (kW)} \times \text{Operating hours (hr/y)} \times \text{Utilization factor (\%)} \end{aligned}$$

$$\begin{aligned} \text{Demand saving (kW)} \\ &= \text{Power consumption of baseline technology (kW)} \\ &\quad - \text{Power consumption BEC technology (kW)} \end{aligned}$$

$$\begin{aligned} \text{Energy saving (kWh/y)} \\ &= \text{Energy consumption of baseline technology (kWh/y)} \\ &\quad - \text{Energy consumption of BEC technology (kWh/y)} \end{aligned}$$

Table 29: Energy consumption comparison of split-type air conditioners

Air conditioner size (Btu/h)	12,000	18,000	24,000	30,000	36,000
Group 1-8Hr					
Baseline consumption (kWh/y)	874	1,311	1,748	2,265	2,717
BEC technology consumption (kWh/y)	499	749	998	1,306	1,567
Demand saving (kW)	0.40	0.60	0.80	1.02	1.23
Total energy saving (kWh/y)	375	562	750	958	1,150
Group 2-12Hr					
Baseline consumption (kWh/y)	1,636	2,454	3,272	4,239	5,086
BEC technology consumption (kWh/y)	934	1,402	1,869	2,445	2,934
Demand saving (kW)	0.40	0.60	0.80	1.02	1.23
Total energy saving (kWh/y)	702	1,053	1,403	1,794	2,153
Group 3-24Hr					
Baseline consumption (kWh/y)	3,272	4,908	6,544	8,477	10,173
BEC technology consumption (kWh/y)	1,869	2,803	3,738	4,889	5,867
Demand saving (kW)	0.40	0.60	0.80	1.02	1.23
Total energy saving (kWh/y)	1,403	2,105	2,807	3,588	4,306
Energy saving percentage (%)	43%	43%	43%	42%	42%

From the simulation high efficiency Inverter split-type air conditioners with label no.5 3-star can potentially save over 40% of energy consumption compared with normal fixed speed label no.5 split-type air conditioners.

Table 30 compares energy consumption, investment, savings and payback from high efficiency split type air conditioners for each building group.

Table 30: Energy consumption, investment and savings from high efficiency inverter split-type air conditioners

Air conditioner size (Btu/h)	12,000	18,000	24,000	30,000	36,000
Price of fixed speed split-type air conditioner (THB)	22,857	29,357	32,786	39,000	44,286
Price of high efficiency inverter split-type air conditioners with label no.5 3-star (THB)	32,000	41,100	45,900	54,600	62,000
Group 1-8Hr energy consumption (kWh/y)	375	562	750	958	1,150
Group 2-12Hr energy consumption (kWh/y)	702	1,053	1,403	1,794	2,153
Group 3-24Hr energy consumption (kWh/y)	1,403	2,105	2,807	3,588	4,306
Additional investment to baseline (THB)	9,143	11,743	13,114	15,600	17,714
Group 1-8Hr saving (THB/y)	2,474	3,711	4,948	6,326	7,591
Group 1-8Hr payback (y)	3.7	3.2	2.7	2.5	2.3
Group 2-12Hr saving (THB/y)	3,553	5,329	7,105	9,083	10,900
Group 2-12Hr payback (y)	2.6	2.2	1.8	1.7	1.6
Group 3-24Hr saving (THB/y)	5,362	8,043	10,725	13,710	16,452
Group 3-24Hr payback (y)	1.7	1.5	1.2	1.1	1.1

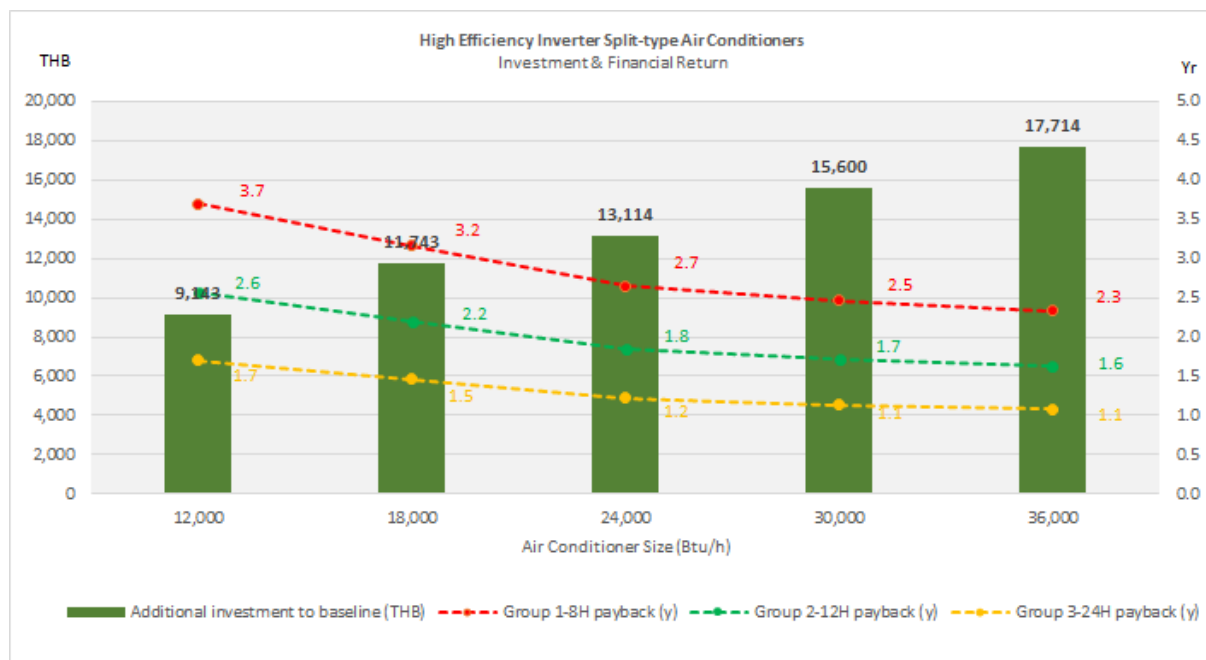


Figure 20: Investment and financial return of high efficiency inverter split-type air conditioners

With an average price premium of around 40% high efficiency inverter split-type air conditioners with label no.5 3-star provide very good payback less than 4 years over normal fixed speed label no.5 split-type in all cases and should be a common energy efficiency measure applicable to all BEC buildings.

4.3.2 Technology 3-2 VRF/VRV air conditioning system

VRF or VRV air conditioning system offers high efficiency air conditioning and usage flexibility for small to medium-sized buildings. In the simulation the 40 RT VRF system are compared with the similar sized air-cooled chilled water system. Typical cooling load patterns are used as representatives for BEC building groups. Details of the analysis are summarized as below.

Table 31 and 32 show typical specification and efficiencies of 40 RT VRF system and air-cooled chillers used in the simulation.

Table 31: Typical specification of air-cooled chilled water system and VRF air conditioning system

Baseline Technology	Air-cooled chiller-scroll
Chiller cooling capacity (RT)	40.0
COP	3.15
Chiller power consumption (kW)	44.7
Chiller full load efficiency (kW/RT)	1.12
Chilled water pump consumption (kW)	5.5
Fan coil cooling capacity (Btu/h/unit)	24,000
Fan coil power (kW/unit)	0.17
No. of fan coil unit	20
Total cooling capacity (RT)	40.0
Total fan coil power (kW)	3.4
Total full load power consumption (kW)	53.6
BEC Technology	VRF/VRV air conditioning system
VRV condensing unit cooling capacity (Btu/h)	480,000
VRF condensing unit power (kW)	35.40
VRF full load efficiency (kW/RT)	0.89
VRF fan coil cooling capacity (Btu/h/unit)	24,000
VRF fan coil power (kW/unit)	0.05
No. of VRF fan coil unit	20
Total cooling capacity (RT)	40.0
Total VRF fan coil power (kW)	1.01
Total full load power consumption (kW)	36.4

Table 32: Part load efficiencies of air-cooled chiller and VRF system

% Cooling Load	Air-cooled scroll chiller (kW/RT)	VRF system (kW/RT)
20%	2.50	
30%	2.30	0.45
40%	1.80	0.47
50%	1.55	0.48
60%	1.40	0.53
70%	1.30	0.61
80%	1.20	0.69
90%	1.10	0.78
100%	1.00	0.89

From typical cooling load patterns and part load efficiencies, energy consumption of the air-cooled chilled water system and VRF system can be estimated and compared for each BEC building group using the following formula.

Baseline Technology

$$\begin{aligned} & \text{Energy consumption of baseline technology (kWh/y)} \\ & = \text{Energy consumption of air cooled chilled water system (kWh/y)} \end{aligned}$$

$$\begin{aligned} & \text{Energy consumption of air cooled chilled water system (kWh/y)} \\ & = \text{Energy consumption of air cooled chiller (kWh/y)} \\ & + \text{Energy consumption of chilled water pumps (kWh/y)} \\ & + \text{Energy consumption of fan coil units (kWh/y)} \end{aligned}$$

$$\begin{aligned} & \text{Energy consumption of air cooled chiller (kWh/y)} \\ & = \sum_{i=1}^{8760} [\text{Cooling load hour}_i \text{ (RT)} \times \text{Efficiency at cooling load hour}_i \text{ (kW/RT)}] \end{aligned}$$



$$\begin{aligned} & \text{Energy consumption of chilled water pumps (kWh/y)} \\ &= \sum_i [\text{Power consumption of chilled water pump}_i \text{ (kW)} \\ & \times \text{Operating hour of pump}_i \text{ (hr/y)}] \end{aligned}$$

$$\begin{aligned} & \text{Energy consumption of fan coil units (kWh/y)} \\ &= \sum_i [\text{Power consumption of fan coil unit}_i \text{ (kW)} \\ & \times \text{Operating hour of fan coil unit}_i \text{ (hr/y)}] \end{aligned}$$

BEC Technology

$$\text{Energy consumption of BEC technology (kWh/y)} = \text{Energy consumption of VRF system (kWh/y)}$$

$$\begin{aligned} & \text{Energy consumption of VRF system (kWh/y)} \\ &= \text{Energy consumption of VRF condensing unit (kWh/y)} \\ &+ \text{Energy consumption of VRF fan coil units (kWh/y)} \end{aligned}$$

$$\begin{aligned} & \text{Energy consumption of VRF condensing unit (kWh/y)} \\ &= \sum_{i=1}^{8760} [\text{Cooling load hour}_i \text{ (RT)} \times \text{Efficiency at cooling load hour}_i \text{ (kW/RT)}] \end{aligned}$$

$$\begin{aligned} & \text{Energy consumption of VRF fan coil units (kWh/y)} \\ &= \sum_i [\text{Power consumption of VRF fan coil unit}_i \text{ (kW)} \\ & \times \text{Operating hour of VRF fan coil unit}_i \text{ (hr/y)}] \end{aligned}$$

Table 33: Energy consumption comparison of 40-RT air-cooled chilled water system and VRF system

Time Period	Group 1-8Hr	Air conditioning power (kW)		Group 2-12Hr	Air conditioning power (kW)		Group 3-24Hr	Air conditioning power (kW)	
	Cooling load (RT)	Air-cooled chiller	VRF	Cooling load (RT)	Air-cooled chiller	VRF	Cooling load (RT)	Air-cooled chiller	VRF
00:00							18	43	10
01:00							16	41	9
02:00							16	41	9
03:00							16	41	9
04:00							16	41	9
05:00							16	41	9
06:00							16	41	9
07:00							38	53	33
08:00	40	54	36				38	53	33
09:00	36	53	29				40	54	36
10:00	34	53	26	36	53	29	40	54	36
11:00	32	52	23	40	54	36	38	53	33
12:00	32	52	23	34	53	26	38	53	33
13:00	32	52	23	32	52	23	38	53	33
14:00	34	53	26	32	52	23	40	54	36
15:00	36	53	29	34	53	26	40	54	36
16:00	34	53	26	34	53	26	40	54	36
17:00				34	53	26	38	53	33
18:00				32	52	23	30	51	21
19:00				30	51	21	28	50	18
20:00				30	51	21	28	50	18
21:00				26	48	16	24	46	14
22:00							24	46	14



Time Period	Group 1-8Hr	Air conditioning power (kW)		Group 2-12Hr	Air conditioning power (kW)		Group 3-24Hr	Air conditioning power (kW)	
	Cooling load (RT)	Air-cooled chiller	VRF	Cooling load (RT)	Air-cooled chiller	VRF	Cooling load (RT)	Air-cooled chiller	VRF
23:00							18	43	10
Energy consumption (kWh/day)		473	242		622	296		1,163	532
Energy consumption (kWh/y)		122,917	62,852		226,965	107,883		424,346	194,230

Energy savings of 40-RT VRF air conditioning system compared with 40-RT air-cooled chilled water system in the simulation is summarized below.

Demand saving (kW)

$$= \text{Power consumption of baseline technology (kW)} \\ - \text{Power consumption of BEC technology (kW)}$$

Energy saving (kWh/y)

$$= \text{Energy consumption of baseline technology (kWh/y)} \\ - \text{Energy consumption of BEC technology (kWh/y)}$$

Table 34: Energy saving of VRF air conditioning system over air-cooled chilled water system

	Group 1-8Hr	Group 2-12Hr	Group 3-24Hr
Demand saving (kW)	24	17	17
On-peak energy saving (kWh/y)	52,612	80,258	72,528
Off-peak energy saving (kWh/y)	7,453	38,824	157,587
Total energy saving (kWh/y)	60,065	119,082	230,116
Energy saving percentage (%)	49%	52%	54%

From the simulation of 40 RT cooling capacity, VRF air conditioning system can significantly save around 50% of energy consumption compared with air-cooled chilled water system.

Table 35 compares the investment costs between VRF/VRV air conditioning system and air-cooled chilled water system and figure 21 shows the return on investment on all building groups.

Table 35: Comparison of investment between VRF/VRV and air-cooled chilled water system

	Baseline Technology	BEC Technology
Air conditioning type	Air-cooled chiller-scroll	VRF/VRV air conditioning system
Air-cooled chiller price (THB/RT)	18,400	60,000
Accessory equipment cost (% of chiller)	15%	15%
Installation cost (% of chiller)	15%	15%
Total price (THB)	956,800	3,120,000

From the simulation model of a typical sized 40 RT VRF system compared with air-cooled chiller, payback on additional investment are ranged from 3 to 7 years depending on operating hours of the building and cooling load profile of the building. Despite high investment cost VRF system has very attractive investment on high operating hours building Group 3-24Hr.



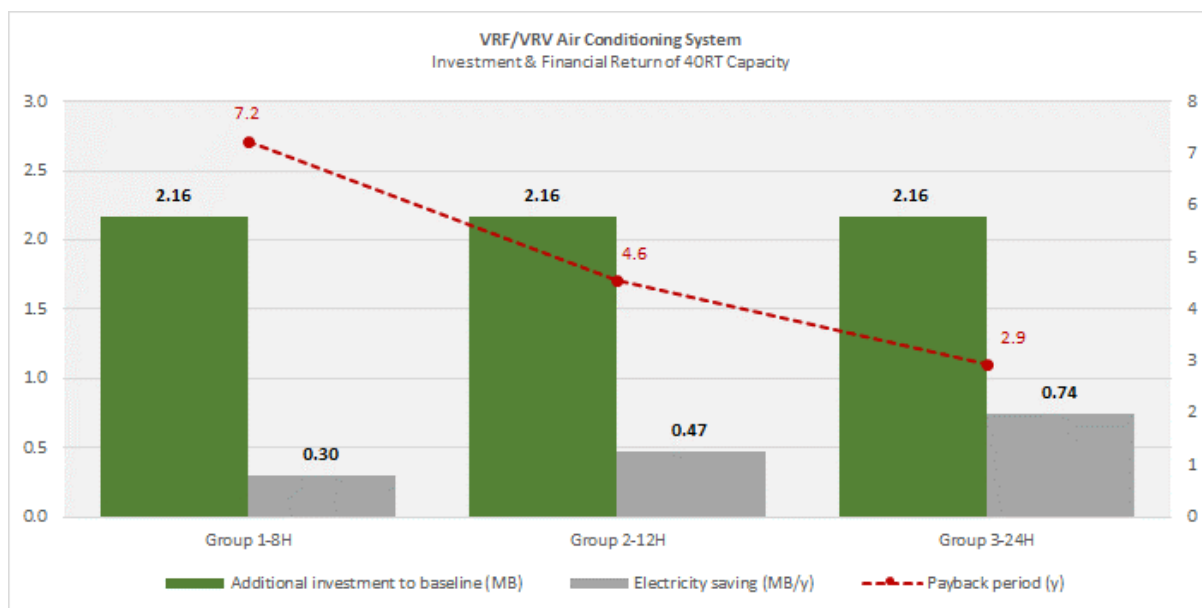


Figure 21: Investment and financial return of VRF/VRV air conditioning system

4.3.3 Technology 3-3 High efficiency chillers/Oil-free magnetic bearing chillers

High efficiency chillers with improved technologies including variable speed centrifugal compressors and magnetic bearing can greatly improve chiller efficiency (COP) and reduce energy consumption. Applying representative cooling load patterns energy consumption and energy performance of high efficiency chillers over conventional chillers can be simulated. Typical specification of chillers for different sizes of buildings are assumed for comparison analysis.

Table 36: Typical specification of chiller models on different building sizes in the simulation

Building area (m ²)	Cooling load (RT) @15 m ² /RT	Baseline Technology		BEC Technology	
		Chiller type	Full load eff (kW/RT)	Chiller type	Full load eff (kW/RT)
2,000	133	Air-cooled screw chiller	1.11	Air-cooled centrifugal magnetic bearing chiller	0.70
5,000	333	Air-cooled screw chiller	1.12	Air-cooled centrifugal magnetic bearing chiller	0.70
10,000	667	Water-cooled centrifugal chiller	0.63	Water-cooled centrifugal magnetic bearing chiller	0.55
20,000	1,333	Water-cooled centrifugal chiller	0.60	Water-cooled centrifugal magnetic bearing chiller	0.55

Table 37: Part-load efficiency factors of different chiller types in the simulation

% Full load	Air-cooled screw	Water-cooled screw	Water-cooled centrifugal	Air-cooled magnetic	Water-cooled magnetic
20%	2.50	1.46	1.16	0.33	0.43
30%	2.30	1.25	1.05	0.37	0.42

% Full load	Air-cooled screw	Water-cooled screw	Water-cooled centrifugal	Air-cooled magnetic	Water-cooled magnetic
40%	1.80	1.12	0.93	0.43	0.42
50%	1.55	1.04	0.83	0.51	0.45
60%	1.40	1.01	0.83	0.58	0.52
70%	1.30	1.00	0.84	0.67	0.63
80%	1.20	1.00	0.90	0.77	0.74
90%	1.10	1.00	0.95	0.88	0.88
100%	1.00	1.00	1.00	1.00	1.00

Incorporating part load efficiency factors the energy consumption of high efficiency chillers and baseline chillers can be calculated and compared.

Energy consumption of chiller (kWh/y)

$$= \sum_{i=1}^{8760} [\text{Cooling load hour}_i (\text{RT}) \times \text{Chiller efficiency at cooling load hour}_i (\text{kW/RT})]$$

where

Chiller efficiency at cooling load hour_i (kW/RT)

$$= \text{Chiller full load efficiency (kW/RT)} \\ \times \text{Part load efficiency factor at cooling load hour}_i$$

Table 38 summarizes the result of simulation to compare the energy consumption of baseline chillers and high efficiency magnetic bearing chillers for BEC buildings of different sizes and types.

Table 38: Energy consumption comparison of chillers

Building area (m ²)	2,000	5,000	10,000	20,000
Group 1-8Hr				
Energy consumption of baseline technology (kWh/y)	338,335	853,459	846,300	1,612,000
Energy consumption of BEC technology (kWh/y)	158,601	396,502	612,564	1,225,129
Energy saving (kWh/y)	179,735	456,957	233,736	386,871
Energy saving percentage (%)	53%	54%	28%	24%
Group 2-12Hr				
Energy consumption of baseline technology (kWh/y)	622,986	1,571,495	1,510,503	2,877,149
Energy consumption of BEC technology (kWh/y)	269,757	674,392	1,033,628	2,067,257
Energy saving (kWh/y)	353,229	897,103	476,875	809,892
Energy saving percentage (%)	57%	57%	32%	28%
Group 3-24Hr				
Energy consumption of baseline technology (kWh/y)	1,147,925	2,895,667	2,717,469	5,176,131
Energy consumption of BEC technology (kWh/y)	476,490	1,191,226	1,843,855	3,687,711
Energy saving (kWh/y)	671,435	1,704,441	873,614	1,488,421
Energy saving percentage (%)	58%	59%	32%	29%

The simulation results show significant energy saving of over 50% for small-sized buildings and around 25-30% for larger buildings. The saving percentage for larger buildings are smaller because of smaller differences in chiller efficiencies on large-sized chillers. Large-sized chillers are normally more efficient with water-cooled and high efficient compressors.

Table 39 shows typical investment cost of chilled water air conditioning system used in the simulation model. For smaller buildings of 2,000 and 5,000 m² comparison are made between air-cooled oil-free magnetic bearing chillers and normal air-cooled chillers. For larger buildings of 10,000 and 20,000 m² magnetic bearings and normal water-cooled chillers are compared.

Table 39: Investment costs for chilled water air conditioning system

Chiller	Size (RT)	Chiller Price (THB/RT)
Air-cooled chiller		



Chiller	Size (RT)	Chiller Price (THB/RT)
High efficiency chiller	>=50	18,400
Inverter chiller	>=150	16,100
Magnetic bearing chiller	>=100	45,700
Water-cooled chiller		
High efficiency chiller	>=100	14,000
Inverter chiller	>=150	15,000
Magnetic bearing chiller	>=80	23,600
Accessory equipment	15%	of chiller
Installation	15%	of chiller
Old chiller removal	12%	of chiller
Cooling tower		
	THB/RT	
Cooling tower	1,200	
Accessory equipment	15%	of cooling tower
Installation	15%	of cooling tower

Investment, savings and payback periods of magnetic bearing to baseline chillers are presented in table 40 and figure 22.

Table 40: Investment and saving from high efficiency chillers/Oil-free magnetic bearing chillers

Building Area(m ²)	Investment (THB)		Additional Investment (THB)	Tariff	Saving (THB/y)	Payback on additional investment (y)
	Baseline	Magnetic Bearing				
Building Group 1-8Hr						
2,000	3,667,733	7,853,733	4,186,000	TOU 3.2.3/4.2.3	894,466	4.68
5,000	9,169,333	19,634,333	10,465,000	TOU 3.2.3/4.2.3	2,274,223	4.60
10,000	13,953,333	21,313,333	7,360,000	TOU 3.2.2/4.2.2	1,041,234	7.07
20,000	27,906,667	42,626,667	14,720,000	TOU 3.2.2/4.2.2	1,722,575	8.55
Building Group 2-12Hr						
2,000	3,667,733	7,853,733	4,186,000	TOU 3.2.3/4.2.3	1,418,073	2.95
5,000	9,169,333	19,634,333	10,465,000	TOU 3.2.3/4.2.3	3,604,441	2.90
10,000	13,953,333	21,313,333	7,360,000	TOU 3.2.2/4.2.2	1,761,535	4.18
20,000	27,906,667	42,626,667	14,720,000	TOU 3.2.2/4.2.2	2,953,530	4.98
Building Group 3-24Hr						
2,000	3,667,733	7,853,733	4,186,000	TOU 3.2.3/4.2.3	2,177,052	1.92
5,000	9,169,333	19,634,333	10,465,000	TOU 3.2.3/4.2.3	5,532,717	1.89
10,000	13,953,333	21,313,333	7,360,000	TOU 3.2.2/4.2.2	2,647,839	2.78
20,000	27,906,667	42,626,667	14,720,000	TOU 3.2.2/4.2.2	4,417,934	3.33



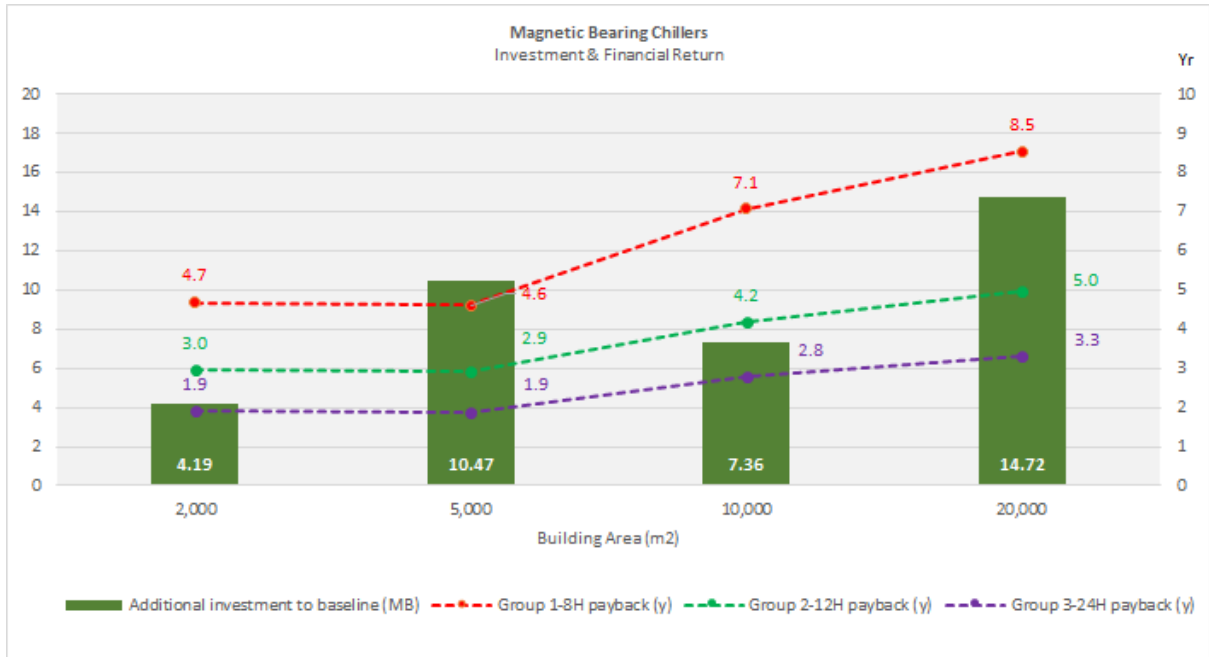


Figure 22: Investment and financial return of high efficiency chillers/Oil-free magnetic bearing chillers

High efficiency/magnetic bearing chillers provides high return on investment with short payback period less than 5 years in most cases except for large sized buildings of 10,000 and 20,000 m² and low operating hours of building Group 1-8Hr. This is due to the lower efficiency differences between magnetic bearing and baseline water-cooled chillers, which are normally high efficient.



4.4 COMPONENT 4: HOT WATER GENERATION SYSTEM

4.4.1 Technology 4-1 Heat pump hot water generation

Heat pump hot water generators can be used in place of fuel hot water boilers in total or partial production of hot water for the buildings. The following calculation illustrates comparison between heat pump system using electricity and fuel oil boiler for hot water production.

Referring average hot water consumption per guest room from DEDE¹ at 160 liters per day and 5% heat loss in storage and piping system, the energy required for hot water production can be calculated using the formula:

$$\begin{aligned} \text{Hot water energy per room (kJ/day)} &= [\text{Hot water temperature (C)} - \text{Water temperature (C)}] \\ &\times \text{Water specific heat (kJ/kgC)} \times \text{Hot water consumption (liter/day)} \\ &\times \frac{1}{(1 - \text{Heat loss (\%)})} \end{aligned}$$

$$\begin{aligned} \text{Hot water energy per room (kJ/day)} &= (60 \text{ C} - 30 \text{ C}) \times 4.186 \text{ kJ/kgC} \times 160 \text{ liter/day} \times \frac{1}{(1 - 5\%)} \\ &= 21,150 \text{ kJ/day} \end{aligned}$$

$$\text{Energy supply for hot water generation per room (kJ/day)} = \frac{\text{Hot water energy per room (kJ/day)}}{\text{Efficiency of hot water boiler (\%)}}$$

$$\text{Energy source per room (unit/day)} = \frac{\text{Energy supply per room (kJ/day)}}{\text{Energy per fuel unit (kJ/unit)}}$$

Table 41: Comparison of daily energy supply for hot water generation

	Baseline Technology	BEC Technology
Hot Water Generator Type	Fuel Oil Boiler (Grade C)	Air-source heat pump boiler
Efficiency	85%	350% (COP = 3.5)
Energy supply per room (kJ/day)	24,883	6,043
Energy per fuel unit	39,770 kJ/liter	3,600 kJ/kWh
Energy source per room (unit/day)	Fuel oil 0.63 liter/day	Electricity 1.68 kWh/day

Since hot water generation systems are implemented in hotels and hospitals, which are the building Group 3-24Hr, the energy consumption and savings based on 365 day-per-year can be calculated.

$$\text{Energy consumption (MJ/y)} = \text{Energy supply per room (kJ/day)} \times 365 \text{ day/y} \times \frac{1}{1,000}$$

$$\begin{aligned} \text{Energy saving (MJ/y)} &= \text{Energy consumption of baseline technology (MJ/y)} \\ &- \text{Energy consumption of BEC technology (MJ/y)} \end{aligned}$$

Table 42: Energy consumption comparison of hot water generation system

Number of guest rooms	Baseline Technology		BEC Technology				
	Fuel oil consumption (l/y)	Energy consumption (MJ/y)	Electricity Demand (kW)	Electricity consumption (kWh/y)	Energy consumption (MJ/y)	Energy saving (MJ/y)	Energy saving (%)
100	22,837	908,219	47	61,269	220,568	687,652	76%

¹ Source: Pilot Implementation of Advanced Technologies for Energy Conservation, DEDE, 2009



200	45,674	1,816,439	94	122,538	441,135	1,375,304	76%
500	114,184	4,541,097	236	306,344	1,102,838	3,438,259	76%
1,000	228,368	9,082,194	472	612,688	2,205,676	6,876,519	76%

From the simulation result heat pump hot water system could save 76% of energy consumption compared with fuel oil hot water boiler.

With the average investment cost of 210,000 THB/Ton per hour production of fuel oil boiler and 28,000 THB/kW for heat pump hot water generator system, amount of investment, savings and payback on investment can be calculated and compared.

Table 43: Comparison of investment and saving from heat pump hot water generator to fuel oil boiler

Number of rooms	Investment (THB)		Additional investment to baseline (MB)	Tariff	Saving (MB/y)	Payback on additional investment (y)
	Fuel oil boiler	Heat pump				
100	945,000	1,321,895	0.38	TOU 3.2.3/4.2.3	0.10	3.87
200	1,890,000	2,643,789	0.75	TOU 3.2.3/4.2.3	0.19	3.87
500	4,725,000	6,609,474	1.88	TOU 3.2.2/4.2.2	0.73	2.59
1,000	9,450,000	13,218,947	3.77	TOU 3.2.2/4.2.2	1.46	2.59

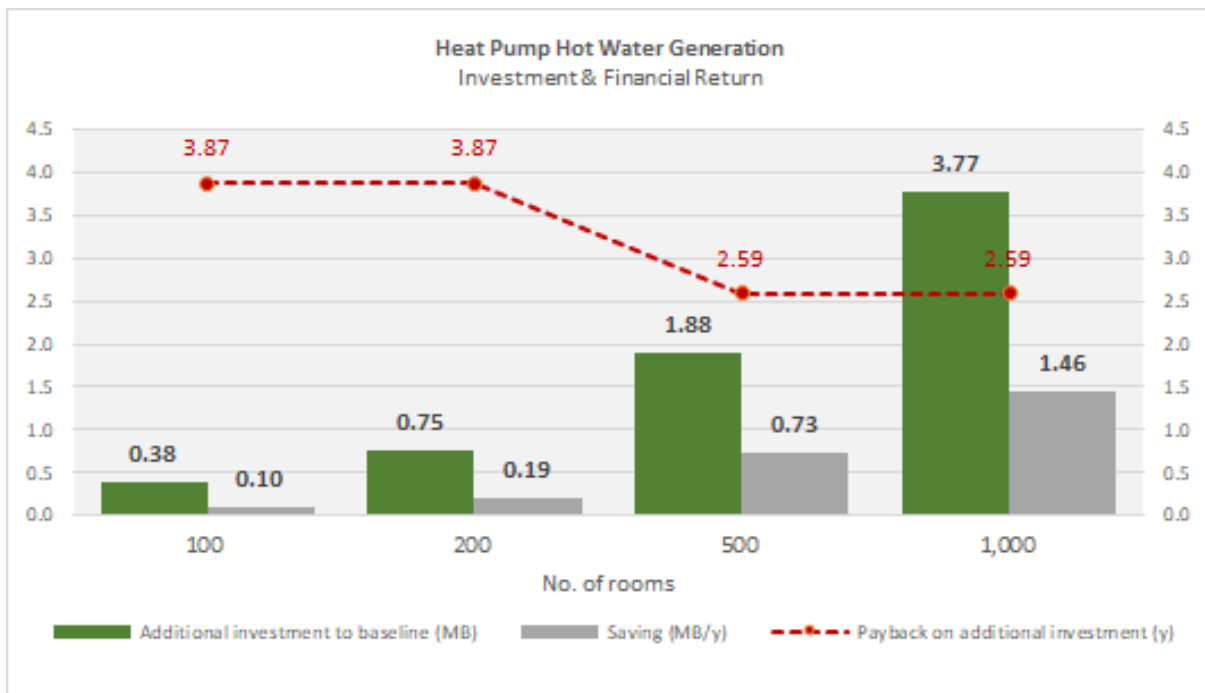


Figure 23: Investment and financial return of heat pump hot water generation

From the simulation heat pump hot water generation system can offer good savings and return on investment over fuel oil boiler with short payback less than four years in all cases of hotels or hospitals with 100, 200, 500 and 1,000 guest rooms.

4.5 COMPONENT 5: RENEWABLE ENERGY GENERATION

4.5.1 Technology 5-1 Rooftop solar PV without grid selling and battery system

BEC buildings have great potentials to generate electricity from the free solar energy source. Potential power generation from different capacity of solar rooftop is analyzed and presented in this section. The calculation of power production are based on the solar production profile, normalized from the average of actual energy production of solar PV installed on building roof in Bangkok area. The profile in figure 24 indicates the net production level in percentage of the installed capacity of the solar system.

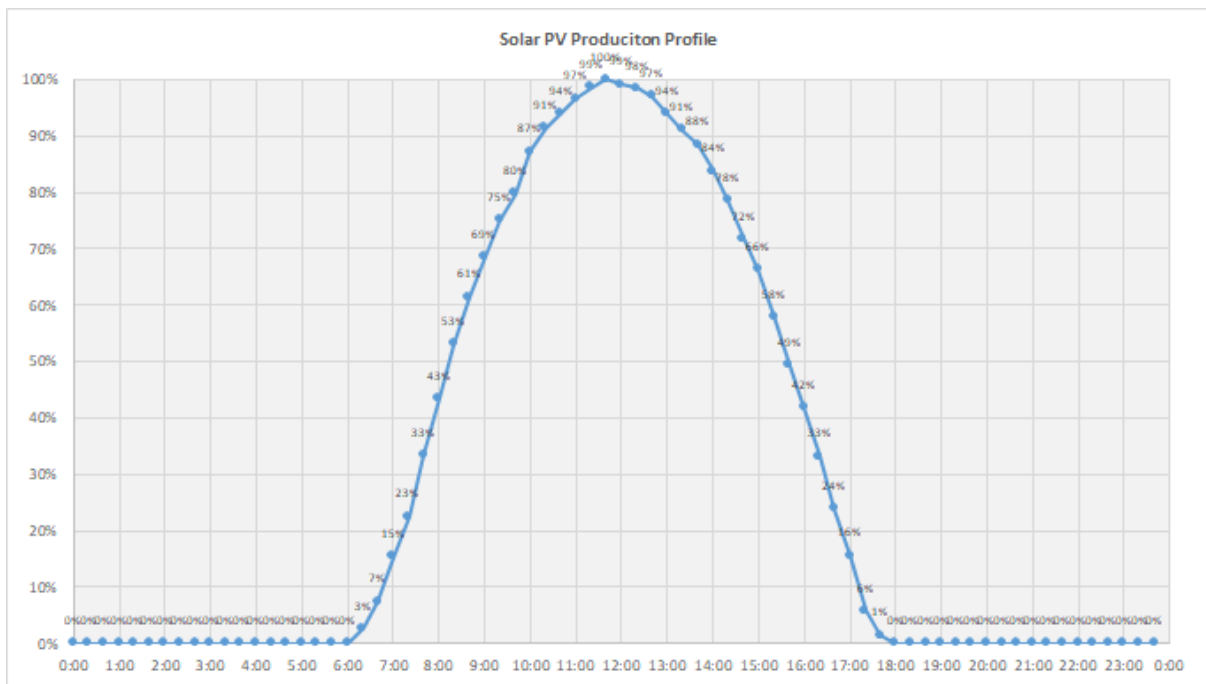


Figure 24: Rooftop solar PV production profile used for simulation

With the installed power per PV panel of 450 Watt and required space per panel of 2.2 m² the required roof area for solar system and average daily energy production can be estimated for each solar PV installed capacity.

$$\text{Number of solar panels} = \frac{\text{Solar installed capacity (kW)}}{\text{Solar panel rated power (kW/panel)}}$$

$$\text{Required roof space (m}^2\text{)} = \text{Number of solar panels} \times \text{Required space per panel (m}^2\text{/panel)}$$

$$\begin{aligned} \text{Energy production hour}_i \text{ (kWh)} \\ = \text{Installed capacity (kW)} \times \text{Solar production factor hour}_i \text{ (%) } \times 1 \text{ hour} \end{aligned}$$

$$\text{Energy production (kWh/day)} = \sum_{i=1}^{24} \text{Energy production hour}_i \text{ (kWh)}$$

Table 44: Required roof space and daily energy production of solar PV rooftop

Solar PV installed capacity (kW)	5	10	20	40	100	200	400	1,000
Solar panel rated power (W)	450	450	450	450	450	450	450	450
Number of solar panels	12	23	45	89	223	445	889	2,223
Required space per panel (m ²)	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2

Solar PV installed capacity (kW)	5	10	20	40	100	200	400	1,000
Total required space (m ²)	26	51	99	196	491	979	1,956	4,891
Inverter size (kW)	5	10	20	20	20	20	20	20
Number of inverters	1	1	1	2	5	10	20	50
Number of string	1	2	4	8	20	40	80	200
Total energy production (kWh/day)	30.7	58.8	114.9	227.3	569.6	1,136.7	2,270.9	5,678.4

By matching of hourly energy production from the solar PV system to the building operating hours, annual energy production to avoided electricity import from the grid can be calculated for BEC building group 1 (8 hours/day: 2,340 hours/year), group 2 (12 hours/day: 4,380 hours) and group 3 (24 hours/day: 8,760 hours/year). Noting that all electricity produced is internally consumed without selling to the grid.

$$\text{Energy production per year (kWh/y)} = \sum_i \text{Energy production hour}_i$$

Where i = Operating hours of the BEC building in a year

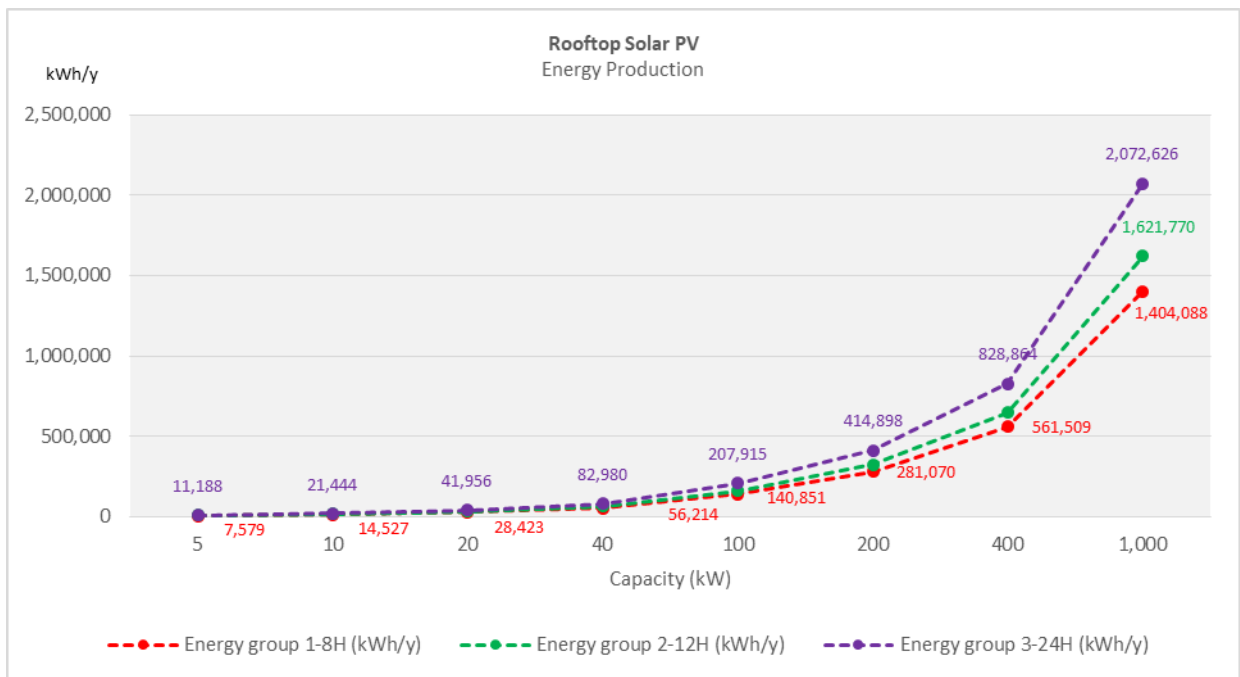


Figure 45: Energy production from rooftop solar PV