

Handbook-3:

Guidelines for BEC Building Development

For Investors



Preface

In Thailand, Energy consumption in the building sector has been increasing rapidly over the years. In 2019, the Department of Energy Alternative Development and Efficiency (DEDE) reported that around 25% of total energy consumption was in the building sector. The consumption has increased at an average of 5.9% per year during 2010 – 2019. Therefore, the promotion on energy conservation in the building sector is an important factor in meeting the goals of the Energy Conservation Plan in Thailand. In addition, increasing the implementation of energy efficiency measures in commercial buildings and government buildings can reduce greenhouse gas (GHG) emissions by about 1 million tonnes CO₂. BEC is considered to be one of these strategic measures according to Thailand’s Nationally Determined Contribution (NDC) Roadmap on Mitigation 2021-2030.

Building Energy Code (BEC) is the standards setting minimum energy efficiency requirements for buildings that request permission for construction or modification with DEDE, according to the Ministerial Regulation B.E. 2552. BEC is the key tool assuring buildings will be designed to conserve maximum energy, increase energy efficiency in new or renovated buildings, and reduce energy consumption and greenhouse gas emissions. In addition, it will contribute to the reduction of overall operation costs of the building in the long run. The Cabinet approved the revised BEC 2020 on July 8, 2020, and the revised BEC has been promulgated in the Government Gazette since November 12, 2020.

This document is a part of the project on “Enabling Readiness for Up Scaling Investments in Building Energy Efficiency for Achieving NDC Goals in Thailand” jointly commissioned by the Climate Technology Centre and Network (CTCN), the Office of National Higher Education Science Research and Innovation Policy Council (NXPO), and DEDE and funded by Global Climate Fund (GCF). The document aims to (i) be one of the tools to assist Thailand in achieving NDC Goals, (ii) build capacity for the project owner, investor, or project developer– to implement Thailand BEC according to the new Ministerial Regulation, which will be enforced in 2022., and (iii) encourage inspiration and provide guidelines on designing and implementing BEC buildings according to the regulations for energy conservation and achieving higher-energy performance buildings.

Bangkok

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Contents

Introduction of BEC Regulation Requirements	7
The Regulation of the Ministerial Regulation	7
Procedure of construction permit under BEC Compliance	8
Evaluation criteria of BEC buildings	8
Option for designing building under the BEC standards	9
BEC Minimum Performance Standard Value	10
Component 1: Overall Thermal Transfer Value of Building's Envelope System	10
Component 2: Lighting System (LPD)	11
Component 3: Air Conditioning System	11
Component 4: Hot water generating system	12
Reference of applicable documents on BEC	13
Statistic of BEC Implementation	15
Overview of BEC implementation in Thailand	15
Benchmarking of the EUI Trend	15
Importance of passing on the BEC standard	16
Critical of BEC building envelope design	17
Statistic of OTTV and RTTV of BEC buildings	18
Factors related to heat transfer value	20
Correlation between OTTV and WWR	21
Potential of High Energy Efficiency Technology Design	23
Assessment of High Energy Efficiency Technology Potential	24
Example of High Energy Efficiency Technology Analysis	26
Component 1: Building Envelope OTTV & RTTV	26
Building Envelope models	27
Describes symbolic of building envelop materials used in each model	28
Description of the example of energy-saving potential analysis in each model	29
Group -1Models	30
Group 1 – Energy Saving Potential	31
Group 2-Models	32
Group 2 – Energy Saving Potential	33
Group 3-Models	34
Group 3 – Energy Saving Potential	35

Component 2: Lighting System	36
Component 3: Air Conditioning System	37
Component 4: Hot Water Generation System	43
Component 5: Renewable Energy Generation	44
Conclusion	46
Glossary	47

Introduction

In Thailand, BEC is the minimum performance requirement on energy conservation for large commercial buildings and it is a mandatory prescriptive code to improve the energy performance for large new buildings in commercial sector. The Ministerial Regulation B.E. 2552 (2009) has been issued by the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy. Recently, the BEC was revised in order to strengthen the code requirements and it was designed to cover both new and retrofitted buildings with floor areas equivalent to or exceeding 2,000 square meters. The revised BEC 2020 was promulgated in the Government Gazette on November 12, 2020, and it is scheduled to be enforced starting in 2022.

In accordance with the Ministerial Regulation B.E. 2563, new or retrofitted buildings being constructed which have the total area of all stories equal to 2000 square-meters or more must be designed under the energy conservation requirements. There are nine types of targeted buildings for BEC: 1) Exhibition building, 2) Hotel, 3) Entertainment service, 4) Hospital, 5) School, 6) Office, 7) Department Store, 8) Condominium and 9) Theatre.

For Investors, consider constructing a building that meets the minimum energy performance requirements and complies with the law. In addition, a good building design with high energy efficiency performance benefits the building in reducing energy consumption and operation costs in the long run over the lifetime; and would be worth the investment.

This handbook aims to provide guidelines and principles on designing the buildings according to the regulation's BEC minimum requirements, by considering selecting high-performance technology and materials available commercially. In addition, it will provide an initial estimation of energy-saving potential and return on investment to encourage and inspire investing in high-efficiency performance buildings in the future.

Highlights:

- Why should investors/developers aim to design and build high-energy efficiency building performance? What would be your benefits?
- Designing buildings according to minimum energy efficiency requirements (BEC) is not difficult, and good building design with high energy efficiency performance from the beginning will potentially save energy costs of the building in the long run.
- Examples of high-performance technology potential assessments, energy-saving potential, and preliminary estimated return on investment.

This handbook is divided into three main sections as follows:



Introduction of BEC regulation requirements

This section will provide a key summary of the BEC regulation requirements in accordance with the Ministerial Regulations of Building Energy Code (B.E. 2563) in Thailand, including assessment BEC certification procedures to be officially enforced in 2022. This section aims to provide information to support investors and BEC developers, including providing a reference document guide on regulations and publishable legal requirements so that interested persons can study further.



Statistics of BEC implementation

This section aims to provide an overview of 10-years historical BEC implementation in Thailand from 2009-to 2019, categorized into three groups of buildings according to BEC standard criteria. Importance of passing BEC standards by the system, historical statistics on passing OTTV and RTTV criteria, and the importance of building envelope design to achieve the minimum energy performance for buildings.



Potential of high energy efficiency technology designed according to BEC criteria

This section aims to provide an example on designing the building to achieve the BEC minimum requirements and up to the higher energy performance standards, by considering the selection of high-performance technology and materials available commercially. In addition, it will provide an initial estimation of energy-saving potential and return on investment to encourage and inspire investing in high-efficiency performance buildings in the future.

Part 1: Introduction of BEC

Regulation Requirements

The Regulation of the Ministerial Regulation

In accordance with the Ministerial Regulation B.E. 2563, new or retrofitted buildings being constructed which have the total area of all stories equal to 2000 square-meters or more must be designed under the energy conservation requirement. There are nine types of targeted buildings for BEC: 1) Exhibition building, 2) Hotel, 3) Entertainment service, 4) Hospital, 5) School, 6) Office, 7) Department Store, 8) Condominium and 9) Theatre.

The BEC regulation distinguishes three different patterns based on the operating hour usages, which it is identified as follows:

- **Group 1:** Op.hr usage 8 hr/day, will be complied with Office building, and School.
- **Group 2:** Op.hr usage 12 hr/day, will be complied with Department Store, Exhibition building/Conventional Hall, Entertainment service, and Theater.
- **Group 3:** Op.hr usage 24 hr/day, will be complied with Hotel, Hospital, and Condominium.



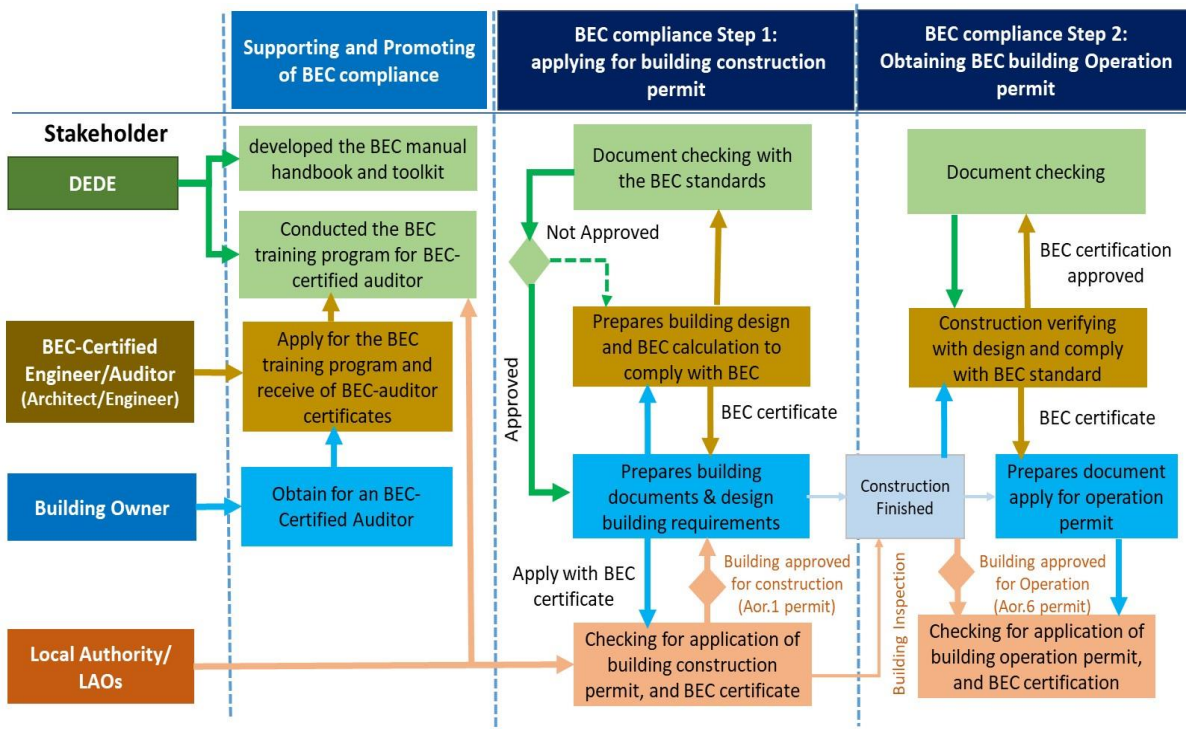
In 2022, the new code is scheduled to apply in full to a massive building of floor area over 10,000 square meters-however, a phase-step compliance strategy over three years.

In this regard, the essence of revised regulation in the new BEC ministerial code are: (1) Condition of the Minimum standard, criteria, and procedure for energy conservation design buildings. (2) Determination of a BEC auditor/inspector to evaluate the BEC-designed building; needs to be trained and certified by the accredited training agency registered with DEDE. (3) Determination of certification methods, procedures and document formatting, and the conditions for enforcement.

Procedure for construction permit under BEC Compliance

Following the BEC compliance regulation, it is a requirement for the building owner to prepare an application document and design the building complying to the BEC standard. Before applying to the local administration organization for building construction/modification permit, the building design must be approved by an authorized person holding BEC-certified professional license (for professional engineer/architect).

The role of stakeholder and procedure of applying for the construction permit under BEC compliance is illustrated in diagram below.



Procedures for Applying for a Construction Permit under BEC and Role of Stakeholder

Evaluation criteria of BEC buildings

The evaluation certificate of energy conservation building design as required in accordance with the Ministry of Energy's Notification B.E. 2564 (BEC standard) must be complied with six components under BEC standard as follows:

- 1) Building Envelope (Wall and Roof)
- 2) Lighting system
- 3) Air conditioning system
- 4) Hot water generating system
- 5) Renewable energy performance
- 6) Whole building energy performance

OTTV
Overall Thermal Transfer Value

RTTV
Roof Thermal Transfer Value

A/C
Air Conditioner

LPD
Lighting Power Density

RENEW
Renewable Energy

WHOLE
Building Energy

Group 1

- Office building
- School

Operating hour usage
8 hr/day

OTTV ≤ 50 W/m²
RTTV ≤ 10 W/m²
LPD ≤ 10 W/m²

Group 2

- Department Store
- Exhibition building/ Conventional Hall
- Entertainment service
- Theater

Operating hour usage
12 hr/day

OTTV ≤ 40 W/m²
RTTV ≤ 8 W/m²
LPD ≤ 11 W/m²

Group 3

- Hospital
- Condominium
- Hotel

Operating hour usage
24 hr/day

OTTV ≤ 30 W/m²
RTTV ≤ 6 W/m²
LPD ≤ 12 W/m²



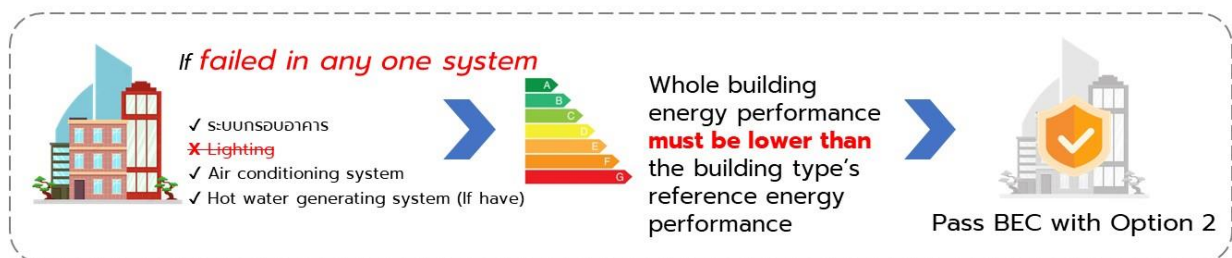
Option for designing building under the BEC standards

Following the BEC ministerial regulation, there are two options for building design to be qualified under BEC standard, as shown in figure below:

Option 1: Passing for all energy performance standard for all four systems



Option 2 Passing in whole building energy performance and hot water generating system



Option 1: Qualified by passing energy performance standard for all four systems (building envelope, lighting system, air conditioning system and hot water generation system)

Option 2: Qualified by passing whole building energy performance and hot water generating system. If the design for new building/retrofitted building does not meet the energy performance standard with option 1 for all four systems, option 2 calculating the whole building energy performance must be lower than that building type's reference energy performance.

BEC Minimum Performance Standard Value

This sub-section will indicate the revised BEC's energy efficiency performance standard minimum value of components 1-4. For more information, references of the applicable documents on BEC building design are listed in this chapter.

Component 1: Overall Thermal Transfer Value of Building's Envelope System

The Overall Thermal Transfer Value (OTTV) and Roof Thermal Transfer Value (RTTV) are used to measure annual average heat gained pass through building envelope as a cooling load of the air conditioning system. To comply with the BEC standard requirement, the OTTV and RTTV of the building envelope shall comply with the following maximum standard value.



Group of BEC building type	Overall Thermal Transfer Value	
	OTTV (W/m ²)	RTTV (W/m ²)
Group 1: Office building, and School	≤ 50	≤ 10
Group 2: Exhibition building, Theater, Entertainment service, and Department store	≤ 40	≤ 8
Group 3: Hotel, Hospital, Condominium	≤ 30	≤ 6

Component 2: Lighting System (LPD)



Minimum value of the lighting power density (LPD) for each type of building shall calculate from its average value per total usage area of the building. For each building, LPD value shall comply with the following standard value given in table:

Group of BEC building type	Lighting Power Density (LPD), W/m ²
Group 1: Office building, and School	≤ 10
Group 2: Exhibition building, Theater, Entertainment service, and Department store	≤ 11
Group 3: Hotel, Hospital, Condominium	≤ 12

Component 3: Air Conditioning System



The Coefficient of Performance (COP) of energy and the Seasonal Cooling Energy Efficiency Ratio (SEER) is the energy efficiency of the air conditioning system used in the building. For each type of air conditioning system installed in the building, COP and SEER shall comply with the BEC standards requirements as follows:

(1) COP and SEER standards for small air-conditioning system (split type)

For small air conditioning system– a split type in which the cooling capacity is not more than 12,000 Watt shall have a minimum seasonal energy efficiency ratio to comply with the current minimum energy efficiency criteria of the No.5 label standard for the air conditioner as follows:

Type of split type AC	Size of Cooling capacity (CC)	Minimum of Energy Efficiency Ratio	
		COP (W/W)	SEER (Btu/h/W)
Fixed speed	CC ≤ 8,000 Watt (27,296 Btu/hr)	≥ 3.76	≥ 12.85
	8,000 > CC ≤ 12,000 Watt (CC > 27,296 - 40,994 Btu/hr)	≥ 3.63	≥ 12.40
Inverter	CC ≤ 8,000 Watt (27,296 Btu/hr)	≥ 4.39	≥ 15.0
	8,000 > CC ≤ 12,000 Watt (CC > 27,296 - 40,994 Btu/hr)	≥ 4.10	≥ 14.0

(2) COP standards for large air-conditioning system (Vapor-Compression Chiller System)

For large air conditioning system (Chiller), the minimum requirement values for coefficient of performance are based on type of chiller installed as shown in table below. For the integrated system of a large air-conditioning system, maximum allowable value of rated power of the air-handling system, condenser water cooling system, and chilled water transport system taken together is 0.5 kW/TR.

Type of Condenser	Type of Compressor	Cooling capacity at full cooling load (Ton refrigeration)	Coefficient of Performance
			(kW/TR)
Air-cooled chiller	All Type	≤ 300	≤ 1.12
Water-cooled chiller	Reciprocating	All Type	≤ 0.88
	Rotary, Screw	All Type	≤ 0.70
	Scroll	All Type	≤ 0.89
	Centrifugal	≤ 300	≤ 0.67
≥ 300		≤ 0.61	

(3) Absorption Chiller

For absorption chiller, the energy performance is specified with the condition of inlet and outlet chilled water temperature, and the inlet temperature of the condensing cooling water and the flowrate. The minimum energy performance requirement of absorption chiller is shown in table below:

Condition		Type of Absorption chiller	
		Single stage	Double stage
Chilled water	Inlet-chilled water temperature (°C)	12.0	12.0
	Outlet-chilled water temperature (°C)	7.0	7.0
Condenser cooling water	Inlet-condenser cooling water temperature (°C)	32.0	32.0
	Outlet-condenser cooling water temperature (°C)	37.5	37.5
	Flow rate of water flow into condenser (l/s/kW)	0.105	0.079
Minimum Coefficient of Performance (COP)		≥ 0.65	≥ 1.10

Component 4: Hot water generating system

Hot water generating system is divided into two systems: (1) boiler and (2) air-source heat pump water heater. Standard for these two systems is shown in table below:

(1) Steam Boiler/Hot Water Boiler

Type of Steam Boiler/Hot Water Boiler	Efficiency (%)
Oil Fired Steam Boiler	≥ 85
Oil Fired Hot Water Boiler	≥ 80
Gas Fired Steam Boiler	≥ 80
Gas Fired Hot Water Boiler	≥ 80



(2) Air -Source Heat Pump Water Heater

Standard condition of performance	Type 1	Type 2
Temperature of water inflow (°C)	30.0	30.0
Temperature of water outflow (°C)	50.0	60.0
Temperature of ambient (°C)	30.0	30.0
Minimum Coefficient of Performance (COP)	≥ 3.5	≥ 3.0



Reference of applicable documents on BEC

The reference of applicable documents on BEC building design criteria following BEC legislation and handbook for energy conservation building design are listed as follows:

- 1) The Ministerial Regulation on Prescribing Types or Size of Building and Standard, Criteria and Procedure in Designing Building for Energy Conservation B.E. 2563
- 2) Ministry of Energy's Notification on prescribing standard values for designing building for energy conservation B.E. 2564
- 3) Ministry of Energy's Notification on Criteria, Calculation Methods and Assessment for designing building for energy conservation of various systems, overall energy consumption of buildings and use of renewable energy system B.E. 2564
- 4) Handbook of procedure guideline for BEC compliance
- 5) Guidelines for building design and construction auditing for energy conservation buildings according to the Building Control Act- for local officer authorities
- 6) Handbook of building design guidelines for energy efficiency conservation, DEDE
- 7) Handbook of Architectural High-Performance Building Design



For more information, please find out in the publishable of the Ministerial regulation announcement documents, and available publishable papers of the Department of Alternative Energy Development and Efficiency, and other published documents of the Building Design Coordination Center for Energy Conservation.

<http://new.2e-building.com>

Handbook of building design guidelines for energy efficiency conservation buildings, DEDE



Handbook of Architectural High-Performance Building Design

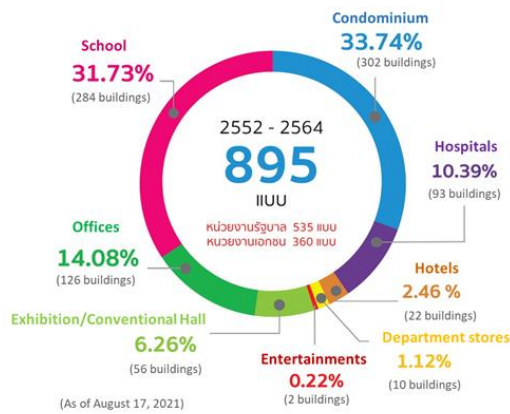


Part 2 Statistics of BEC Implementation

Designing buildings to meet good energy efficiency standards, excellent functionality, and outstanding architectural design is the ultimate goal for building owners/developers. Planning to construct a building with a good energy efficiency performance at the design stage would save energy costs over the lifetime of the building operations. In addition, it also can create a good image and reputation in terms of the building being energy and environmentally friendly.

This section aims to provide an idea to the investors/developers - why should we aim to design and build high-energy efficiency performance buildings? What would be your benefits? By looking at the 10-years historical BEC performance statistics in Thailand from 2009-to 2019, designing buildings according to minimum energy efficiency requirements (BEC) is not difficult to achieve; and the importance of passing BEC standards by the system.

Overview of BEC implementation in Thailand



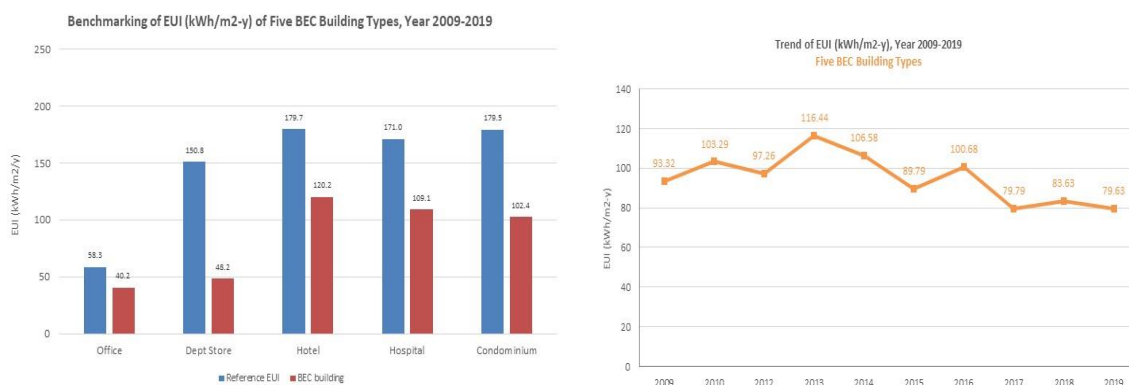
From 2009 to 2021, a total of 895 buildings in 9 Building types has been designed and certified according to the BEC Ministerial Regulations. The Energy Conservation Building Design Coordination Center (2e-Building Center) has provided BEC building designed assessment services for 535 government and 360 private buildings.

Benchmarking of the EUI Trend

From the BEC Assessment database over the BEC implementation period, from 2009 to 2019, under this guidebook analysis, a breakdown of the five-building types under the Thai BEC compliance program, namely, offices, hotels, department stores, hospital or medical center, and condominiums were conducted. The total number of the five building types was 506, with the sum of building area 7,447,527 m². Using the energy use index (EUI) in kWh/m²/year as an indicator for benchmarking of energy efficiency, the breakdown of the EUI profile based on the percentile of the number of five building types, benchmarking against the reference EUI is shown in the table below.

BEC Buildings Type	No. of Buildings	EUI ranges (kWh/m ² -y) based on percentiles					Reference EUI
		1%-25%	26%-50%	51%-75%	76%-100%	Average EUI	
Group 1 - Office	114	4.48-31.31	31.66-39.15	39.25-52.56	52.81-102.65	40.19	58.26
Group 2 – Department store	10	34.35-39.76	40.54-54.42	67.82-90.63	94.58-112.64	48.17	150.81
Group 3 - Hotel	21	53.28-79.48	79.96-117.40	117.43-134.66	137.15-188.36	121.93	179.67
Hospital	87	11.67-80.86	82.12-116.84	117.43-132.31	134.89-256.98	111.18	171.03
Condominium	273	17.48-90.54	90.62-108.75	108.77-126.16	126.46-390.42	102.40	179.48

Statistics show that the minimum energy consumption benchmark BEC can play an essential role in improving energy efficiency in the building sector if adopted at the design stage.



The above graph shows the average energy use intensity (EUIs) of all five building types over 10 years from 2009 to 2019 in Thailand. Based on the historical data, the results indicate the decreasing trend of the average EUI with a 15% reduction over ten years from 93.3 kWh/m²-y to 79.6 kWh/m²-y.

Importance of passing on the BEC standard

Following the BEC ministerial regulation, there are two options for building design to be qualified under BEC standards. Most of the buildings fails to comply with the individual system performance requirements of option 1. With option 2 of the BEC standard, most buildings can pass BEC criteria with the whole building energy performance criteria by using high-efficiency equipment to reduce overall energy consumption, e.g., high-efficiency air conditioning, lighting system.

Bbreakdowns 2009 ,compliance of Five Building Types-of BEC compliance and Non-2019

BEC Compliance of Five Building Types (BEC 2009)	Office	Dept Store	Hotel	Hospital	Condo	Total
BEC Compliance Option 1						
Pass all criteria	27.0%	50.0%	36.4%	30.6%	13.4%	21.1%
Pass OTTV-RTTV but fail to AC or LPD	3.6%	0.0%	0.0%	1.2%	3.0%	2.6%
Pass OTTV but fail to RTTV	5.4%	0.0%	13.6%	5.9%	2.6%	4.2%
Fail OTTV but pass RTTV	37.8%	50.0%	22.7%	47.1%	66.2%	54.3%
Fail both OTTV-RTTV	26.1%	0.0%	27.3%	15.3%	14.9%	17.7%
BEC Compliance Option 2						
Fail option 1 but pass overall EUI criteria	69.4%	50.0%	59.1%	69.4%	86.2%	77.7%
Fail option 1 and fail overall EUI criteria	3.6%	0.0%	4.5%	0.0%	0.4%	1.2%
Total BEC compliance buildings	96.4%	100.0%	95.5%	100.0%	99.6%	98.8%

Most BEC buildings can easily comply with the BEC-option 2 of the whole building energy performance standard, accounting for 97.2% of the buildings. However, 21.1% of the BEC buildings could meet all energy performance system criteria, and only 3% of the buildings fail the air conditioning system or lighting power density criteria.

Based on the statistics, designing a building to meet each system's minimum energy efficiency (BEC) criteria is not an impossibility. But it can be achieved through the use of efficient technology and building materials that are commercially available.

Critical requirements for BEC building envelope design

The building envelope consists of opaque walls, transparent walls, and windows, opaque and translucent roofs. The thermal transfer properties of the building envelope directly impact the cooling loads and energy consumption of the air conditioning system. BEC specifies the maximum overall thermal transfer value (OTTV) for walls and windows and the roof thermal transfer value (RTTV) for the roof to limit external heat transfer through the building envelope. This BEC criterion aims to reduce the external cooling load of the building, which is indirect will help reduce the energy consumption of the air conditioning system in the long run.

Most building developers/owners often focus on investing in high-efficiency types of equipment to reduce power consumption, e.g., use of high-efficiency air conditioner or lighting system. But may not pay much attention to designing the building envelope for efficient performance to reduce the amount of heat transferred into the building, which determines the cooling load of the building. As a result, the cooling load in the facilities remain high.

A building designed with a high Window to Wall Ratio (WWR) results in a large amount of heat being transmitted through the translucent building wall into the building. This in turn leads to an increase in the cooling load of the air conditioning system.



When the building has been designed with a high WWR ratio. Improving the building envelope will require additional investment, such as installing heat-reflective film on the glass inside the building or opting for more efficient glass. Choosing to design a building envelope with high-efficiency performance from the beginning will produce better results, and it may be cheaper than solving the problem when the building is finished

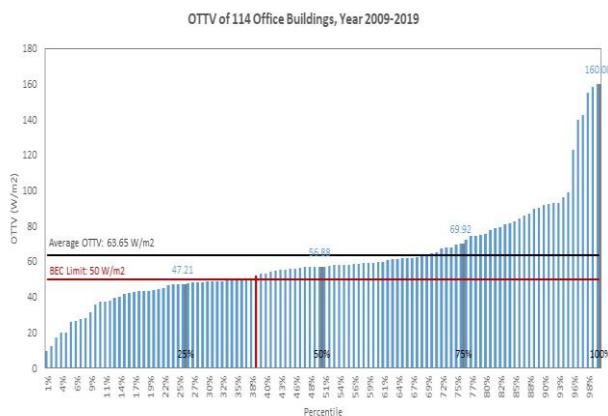
It is not impossible to design a building to meet the OTTV and RTTV criteria according to the minimum energy efficiency BEC standards. The design should consider the internal and external factors that affect the external heat transfer through the building envelope, and use highly efficient technology and building materials that have been developed and commercially available. .

Statistics of OTTV and RTTV of BEC buildings

Based on Thailand's 10-year BEC database (2009-2019) in 5 types of buildings with high energy consumption, it was found that 21.1% of buildings were able to pass BEC minimum energy efficiency standards in all systems, especially on conditional of OTTV and RTTV criteria. Statistics of OTTV and RTTV of each BEC building group are as follows:

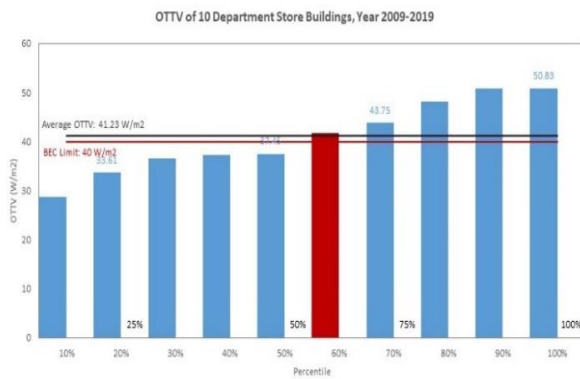
Overall Thermal Transfer Value (OTTV) of external wall of the building

- Group 1: Office buildings



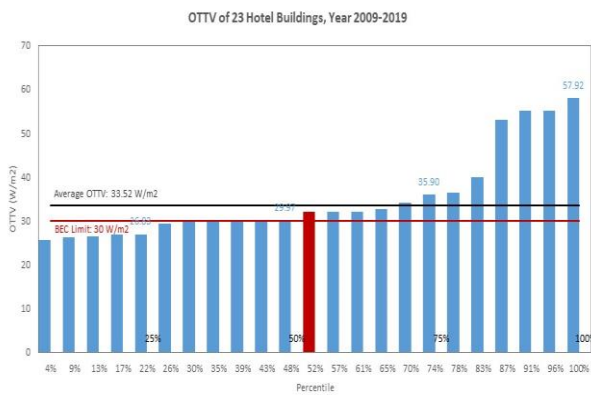
Based on historical BEC assessment data, office buildings have an average OTTV from the BEC building assessment of 63.65 W/m2. Still, 38 out of 114 BEC office buildings can pass the OTTV minimum criteria of ≤ 50 W/m2, representing 38% of office buildings that can achieve these BEC standards.

- Group 2: Department stores



Department stores buildings have an average OTTV from the BEC building assessment of 41.23 W/m². More than 50% of BEC buildings can pass the criteria of the OTTV minimum standard of ≤ 40 W/m².

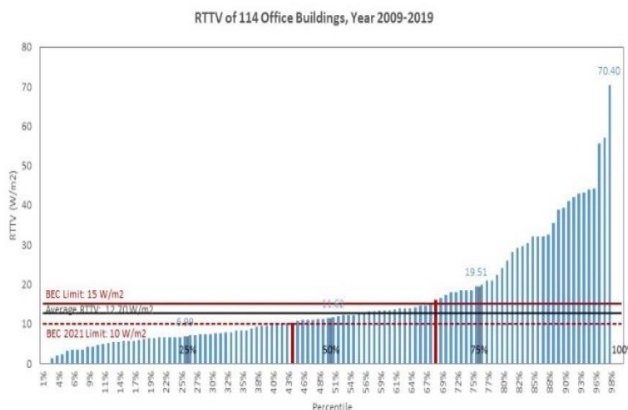
- Group 3: Hotels



Hotel buildings have an average OTTV from the BEC building assessment of 33.52 W/m². More than 52% of BEC buildings can pass the criteria of the OTTV minimum standard of ≤ 30 W/m².

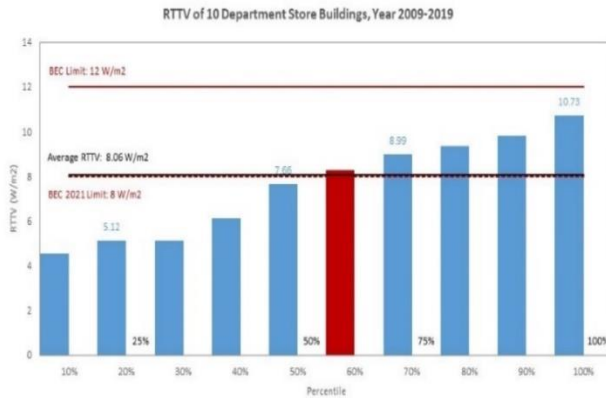
Roof Thermal Transfer Value (RTTV)

- Group 1: Offices



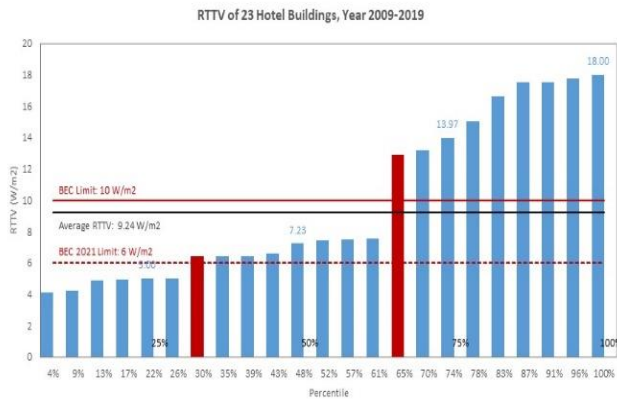
Based on historical BEC assessment data, the office buildings have an average RTTV from the BEC building assessment of 12.70 W/m². Still, 48 out of 114 BEC office buildings can pass the RTTV minimum criteria of ≤ 10 W/m², representing 43% of office buildings that can achieve these BEC standards.

- Group 2: Department stores



Department stores buildings have an average RTTV from the BEC building assessment of 8.06 W/m². More than 60% of BEC buildings can pass the criteria of the RTTV minimum standard of ≤ 8 W/m² (new BEC 2022 criteria).

- Group 3: Hotels



Hotel buildings have an average RTTV from the BEC building assessment of 9.24 W/m². More than 30% of BEC buildings can pass the criteria of the RTTV minimum standard of ≤ 6 W/m² (new BEC 2022 criteria).

Based on the historical statistics, there is good evidence to prove that designing a building to meet the minimum energy efficiency performance OTTV and RTTV criteria of BEC standards can be achieved with commercial availability of technologies and building materials.

Factors related to heat transfer value

Factors related to building design that affect the amount of heat transmitted through the building (OTTV and RTTV) consist of both internal factors and external factors are as follows:

1. Internal factors:

- Thermal properties of solid and translucent wall materials, e.g., thermal conductivity (U), material’s density (p), specific heat capacity (Cp), Solar heat gain coefficient (SHGC), Visible transmittance (VT) of light through a transparent wall, etc.
- Material thickness, and color of wall and roof related to coefficient for thermal absorption.

- Window to wall ratio (WWR)
- Direction of the building, inclination angles of the wall and roof surface, shading instrument installation, etc.

2. **External factors:** such as direction of sunlight, building landscape, natural plants cultivation, and ground plants cultivation.

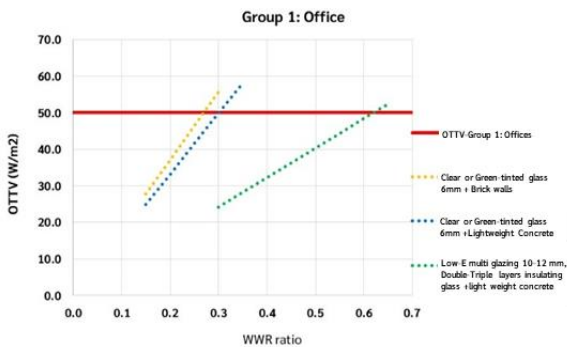
Correlation between OTTV and WWR

One of the most viable approaches is to design a building with a proper WWR ratio, including investing in appropriate high-performance materials and equipment. This approach may help avoid or reduce additional costs after construction.

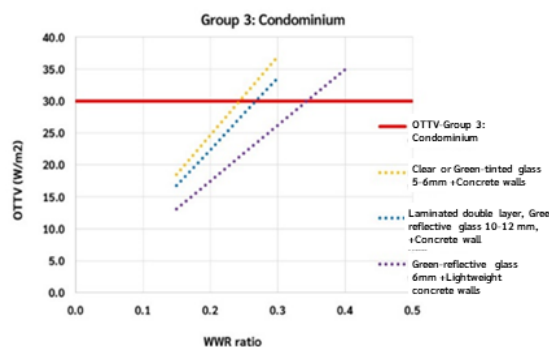
Using the 10-year BEC historical data, this section shows the standard practice model of a building designed with WWR ratio and various common construction materials used by BEC buildings in Thailand. It shows the effectiveness of a correlation of building designed WWR ratio and the calculated OTTV value of the certified BEC building. The analysis data will be a guide to select and design the structure with a proper WWR ratio per the preferred materials used. It also shows what type of material should be used and how it fits with the WWR ratio, if it is necessary to design a building with a large proportion of glass space in the building envelope.

Correlation between OTTV and WWR

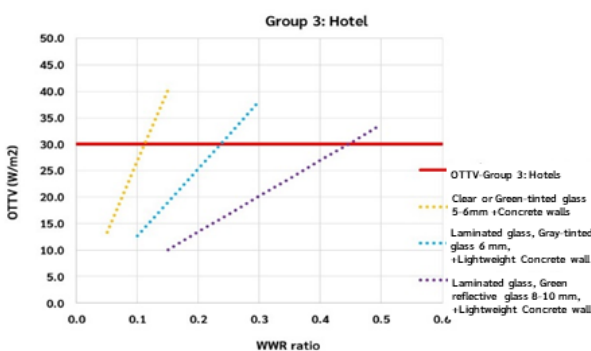
• Offices



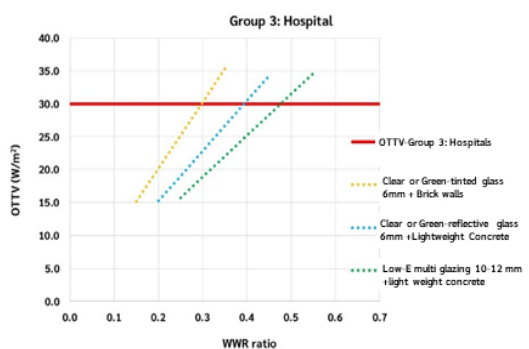
• Condominiums



• Hotels



• Hospitals



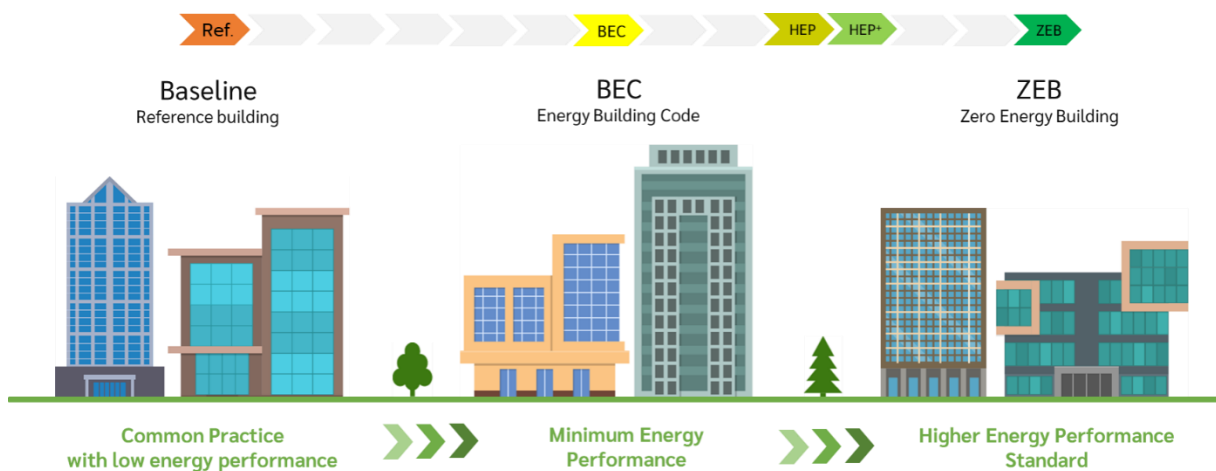
The correlation graph shows the requirements to pass the OTTV criteria:

- If using a clear glass or green-tinted glass 5-6 mm thickness with common concrete walls or brick walls, the building should be designed to have a WWR of less than 15% for all types of buildings.
- Using a green laminated or green-tinted glass of 6 mm up to 8 mm thickness with light weight concrete blocks, the building should be designed to have a WWR of less than 15-25%.
- Using a green laminated or reflective glass of 8 mm to 10 mm thick with light weight concrete blocks, the WWR ratio should be between 15 and 40%.
- Using a highly efficient insulating glass, Low-E multi glazing 10-12 mm thickness or double-triple insulating glass 2-3 layers with light weight concrete blocks, WWR ratio should be between 30-50%.

Note: Despite choosing the appropriate WWR ratio, the building design must consider other relevant external factors as well, e.g., building's orientation and shading instrument design and installation.

Part 3 Potential of High Energy Efficiency Technology Design

This section presents an example of designing the building to achieve the BEC minimum requirements and up to the higher performance standards of energy conservation buildings (HEP, HEP+, ZEB) according to the Thai government policy programs. This section highlights the potential energy savings of a highly energy efficient building design. It also provides an initial estimation of energy-saving potential and return on investment to encourage and inspire investing in high-efficiency performance buildings and creating motivation for further consideration of project developers.



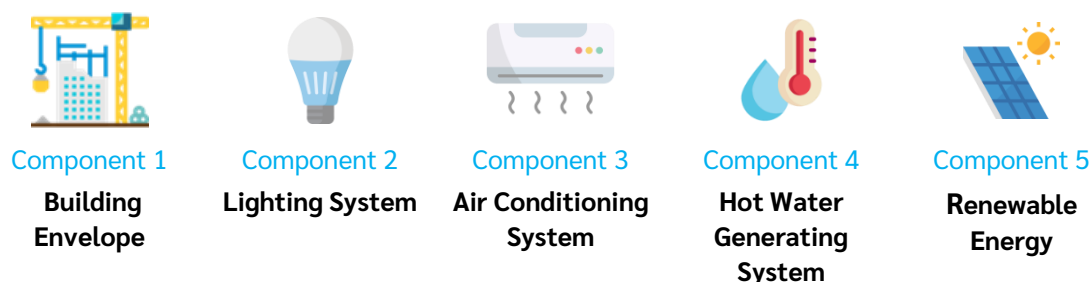
According to the Thai government policy program on the energy efficiency implementation plan for buildings 2020-2036 by the Department of Alternative Energy Development and Efficiency, the aim is to promote the improvement of building efficiency in 4 levels as follows:

Energy Efficiency Level for Energy Conservation Building	Target year under the policy			
	B.E. 2563	B.E. 2568	พ.ศ. 2574	พ.ศ. 2579
	BEC	HEP	HEP+	ZEB
Building Envelope: OTTV (W/m ²)	50	40	35	20
Lighting system: LPD (W/m ²)	14	10	8	2
Air Conditioning System: AC (kW/TR)	1.12	0.8	0.7	0.4

Note: Reference to the energy efficiency implementation plan for energy conservation building 2020-2036, DEDE.

Assessment of High Energy Efficiency Technology Potential

This section will show an example of the potential technology assessment in each system, using a building with a total area of 10,000 square meters as an example. The analysis is based on commercially available high-performance technology that meet the minimum BEC performance criteria.



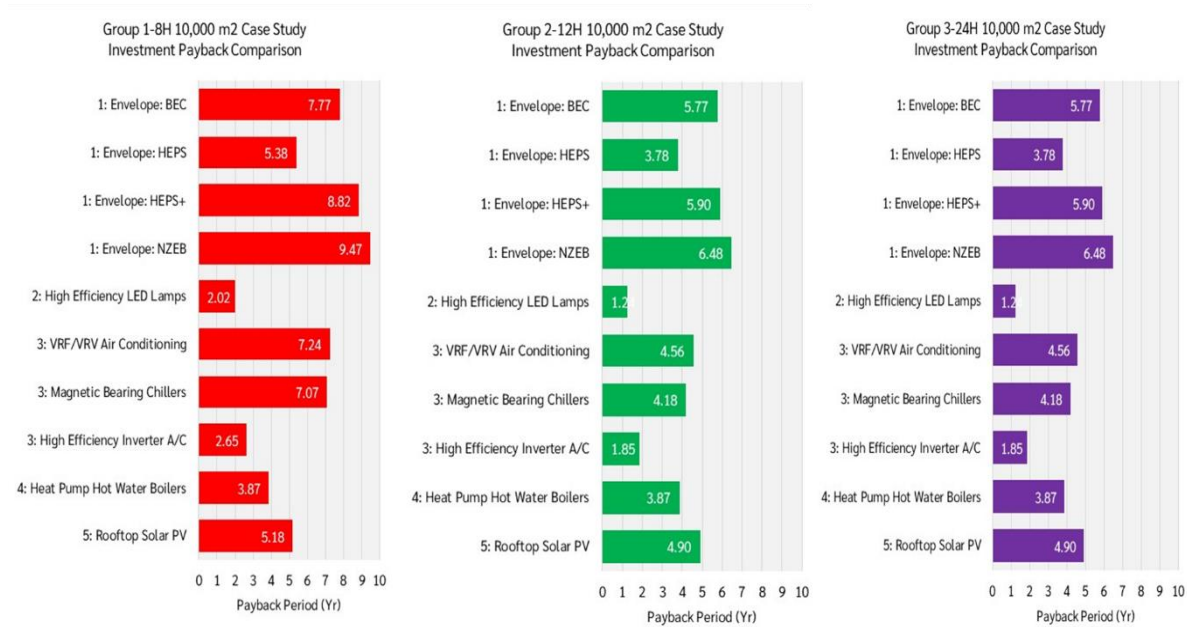
The assessment will analyze the potential of energy saving results according to the group of BEC buildings, which is classified by operating hours as follows:

- Group 1** – Operating hours 8 hr/day
- Group 2** – Operating hours 12 hr/day
- Group 3** – Operating hours 24 hr/day

Component 1 building envelope technology is integrated to the BEC analytic model for simulation of 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 individual basis to estimate energy savings from lighting, air conditioning, hot water generation and renewable energy systems. The analysis of financial return is based on the net additional investment and the net operating cost savings of the technology over the baseline scenario.

Comparison of return on investment for potential technologies in different BEC component is shown in the figure below:

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



The financial assessment results show attractive 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 of 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 but would generate savings in a long term throughout the building lifetime.

A good building design is a highly desirable option right from the start. It is not desirable just to pass BEC standard with only Option 2 whole building energy performance criteria. Designing buildings to meet good energy efficiency standards, excellent functionality, and outstanding architectural design from the beginning will produce better results. This is achieved by selecting the appropriate building envelope materials to reduce the heat transferred into the building. Choosing high-efficiency equipment such as air conditioning, lighting, other electrical systems, etc., will help save on annual energy costs over the life of the building.

Although, some high-performance technologies may require a higher initial investment it is attractive when considering lifetime-costs. The price of new technologies may also tend to decrease when more products are commercially available.

Example of High Energy Efficiency Technology Analysis

Component 1: Building Envelope OTTV & RTTV

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 largest energy end-use of the building. For simulation, the conceptual building models are developed as the representative for each BEC building type. Baseline model represents building with conventional materials with poor insulation and model BEC, HEPS (High Energy Performance Standard), HEPS+ (Higher Energy Performance Standard) and ZEB (Zero Energy Building) indicate the progressive increase of heat insulation materials of the building envelope.



The combination of opaque walls, window glass, roof materials, and window-to-wall ratio (WWR) are set for each building model. Improvement of various building envelope will determine to achieve each OTTV and RTTV level of the building, such as the properties of solid wall materials. The simulation include translucent walls or windows roof features wall and roof color and the ratio of the glass area to the concrete wall area, etc.

The simulation deploys web based BEC program for setting material properties and calculate thermal transfer value (OTTV/RTTV) per unit area (W/m^2) of each type of envelope and building group. However, only 10,000 m^2 building are selected as the example illustration. The examples presented in this section are based on model simulations according to the OTTV and RTTV level into four models as follows:

Efficiency Level	Model 1	Model 2	Model 3	Model 4
	BEC	HEP	HEP+	ZEB
Building Envelope: OTTV (W/m^2)	$\leq 50 W/m^2$	$\leq 40 W/m^2$	$\leq 35 W/m^2$	$\leq 20 W/m^2$
RTTV (W/m^2)	$\leq 10 W/m$	$\leq 8 W/m$	$\leq 6 W/m$	$\leq 4 W/m$

The simulation results shown in the following pages 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.

Building Envelope models

Description of model analysis

The example of the building energy efficiency analysis is based on the performance criteria of each model's high-efficiency building design. There is four comparisons of model analysis based on performance criteria of building design: BEC, HEP, HEP+, and ZEB.

OTTV&RTTV analysis is classified by a group of operating hours

Group 1 –8 hr/day

Group 2 –12 hr/day

Group 3 –24 hr/day

Model 1 – BEC level

- Efficiency level pass BEC with Option 2, or
- OTTV $\leq 50 \text{ W/m}^2$



Model 3 – HEP level

- Efficiency level pass HEP level, or
- OTTV $\leq 40 \text{ W/m}^2$



Model 3 - HEP+ level

- Efficiency level pass HEP+ level, or
- OTTV $\leq 35 \text{ W/m}^2$

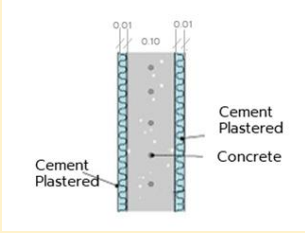
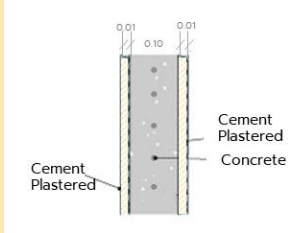
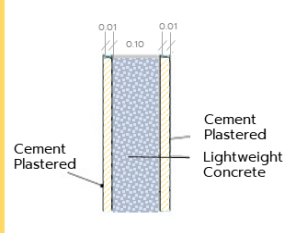
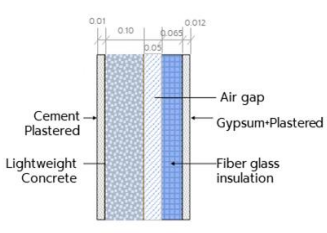
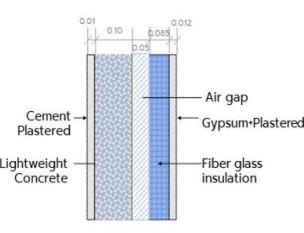

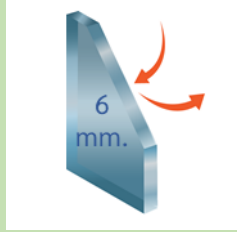
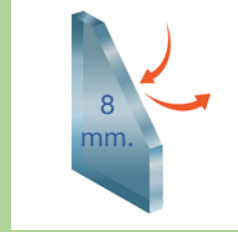


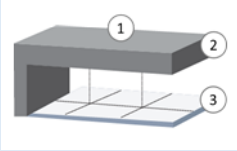
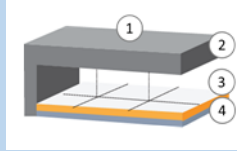
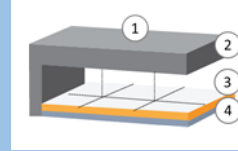
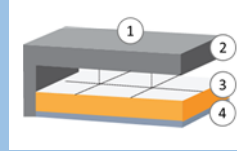
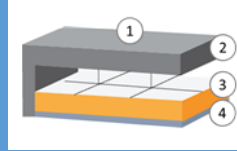


Model 4 – ZEB level

- Efficiency level pass ZEB level, or
- OTTV $\leq 20 \text{ W/m}^2$

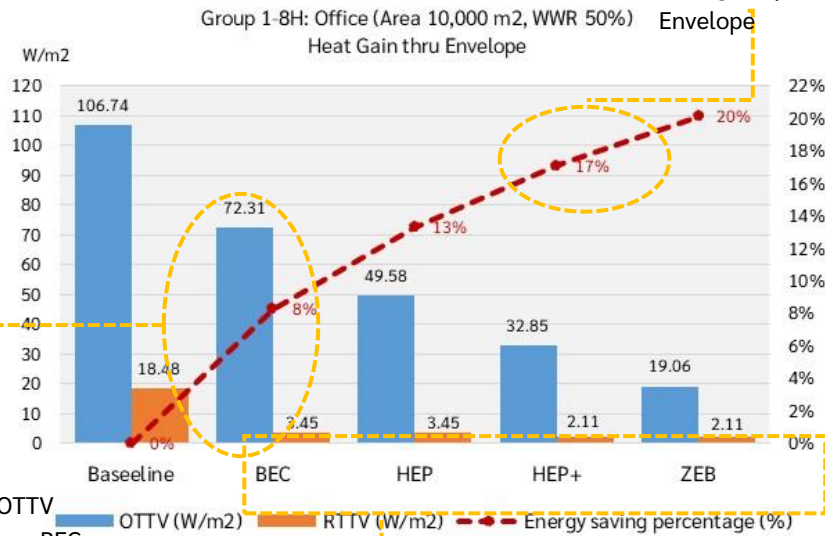


Describes symbolic of building envelop materials used in each model

	Baseline	BEC	HEP	HEP+	ZEB
Opaque Wall	<p>Opaque Wall-01</p>  <p>Cement Plastered Concrete</p> <p>Plastered Concrete Pale color paint</p>	<p>Opaque Wall-02</p>  <p>Cement Plastered Concrete</p> <p>Plastered Concrete Light color or Reflective color</p>	<p>Opaque Wall-03</p>  <p>Cement Plastered Lightweight Concrete</p> <p>Plastered Lightweight Concrete Light color or Reflective color</p>	<p>Opaque Wall-04</p>  <p>Cement Plastered Lightweight Concrete Air gap Gypsum+Plastered Fiber glass insulation</p> <p>Lightweight Concrete & Insulation Light color or Reflective color</p>	<p>Opaque Wall-04</p>  <p>Cement Plastered Lightweight Concrete Air gap Gypsum+Plastered Fiber glass insulation</p> <p>Lightweight Concrete & Insulation Light color or Reflective color</p>
Transparent Wall	<p>Glass Win-01</p>  <p>WWR 50%, VT= 0.76, SHGC = 0.60</p>	<p>Glass Win-02</p>  <p>6 mm.</p> <p>WWR 50%, VT= 0.326, SHGC = 0.37</p>	<p>Glass Win-03</p>  <p>8 mm.</p> <p>WWR 50%, VT= 0.325, SHGC = 0.35</p>	<p>Glass Win-04</p>  <p>Low-E</p> <p>WWR 50%, VT= 0.6, SHGC = 0.39</p>	<p>Glass Win-05</p>  <p>Heat stop Low-E</p> <p>WWR 50%, VT= 0.38, SHGC = 0.20</p>
Roof	<p>Concrete Roof-01</p>  <p>1 - Concrete 20 cm Pale color 2 - Air gap 100 cm 3 - Gypsum 1.2 cm</p>	<p>Concrete Roof-02</p>  <p>1 - Concrete 20 cm Light color 2 - Air gap 100 cm 3 - Fiberglass Insulator 7.5 cm 4 - Gypsum 1.2 cm</p>	<p>Concrete Roof-02</p>  <p>1 - Concrete 20 cm Light color 2 - Air gap 100 cm 3 - Fiberglass Insulator 7.5 cm 4 - Gypsum 1.2 cm</p>	<p>Concrete Roof-03</p>  <p>1 - Concrete 20 cm Light color 2 - Air gap 100 cm 3 - Fiberglass Insulator 15 cm 4 - Gypsum 1.2 cm</p>	<p>Concrete Roof-03</p>  <p>1 - Concrete 20 cm Light color 2 - Air gap 100 cm 3 - Fiberglass Insulator 15 cm 4 - Gypsum 1.2 cm</p>

Description of the example of energy-saving potential analysis in each model

Energy saving potential

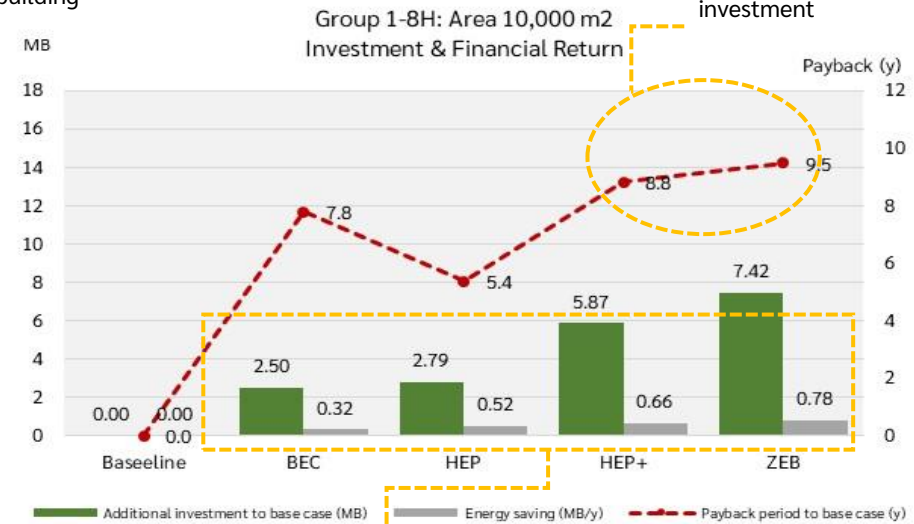


Calculated OTTV and RTTV from BEC simulation model Baseline

Representative building models for building envelope simulation

Energy saving potential from reduced heat gain through improved building Envelope

Financial return on investment



Estimated return on investment

Estimated scale of additional investment, net saving and payback of model BEC, HEP, HEP+, and ZEB) compared to baseline scenario.

The highlights of potential energy savings of a highly efficient energy conservation building design is summarized here. The simulation results indicate the energy-saving potential of air conditioning from reduced heat gain through the improved building envelope. The estimated scale of additional investment, net saving, and payback from enhanced building envelope efficiency (model BEC, HEP, HEP+, and ZEB) are noted; compared to the baseline scenario.

Group 1-Models

Baseline

Opaque

Wall-01

Window glass

Win-01,

WWR 50%

Roof

Roof-01



Group 1 OTTV 106.74 W/m²
RTTV 18.48 W/m²

Baseline is assumed to be a common practice characteristic of a typical building with a rectangular shape; with a 10-floor tower, dimension of 25 x 40 m. The materials used are a common practice of constructed buildings in Thailand in office buildings, hotels, hospitals, and condominiums.

The combination of opaque wall, window glass, roof materials, and WWR ratio is set for each building model, as indicated in the symbolic description table.

Group 1 - Model 1 (BEC)

Opaque

Wall-02

Glass

Win-02,

WWR 50%

Roof

Roof-02



Group 1 OTTV 72.31 W/m²
RTTV 3.45 W/m²

If the wall is concrete and the glass is 6 mm reflective glass at 50% WWR and the building wall color will be light color or heat-reflective color. Although it cannot pass the OTTV threshold of ≤ 50 W/m², it could reduce the heat load into the building by 8%.

Group 1 – Model 3 (HEP+)

Opaque

Wall-04

Glass

Win-04,

WWR 50%

Roof

Roof-03



Group 1 OTTV 32.85 W/m²
RTTV 2.11 W/m²

Changing the window to be a double glassing Low-E 6-12-6 mm, building with a lightweight concrete wall with an insulation layer and light color painting, and adding insulation on ceiling roof. It will result in OTTV passing the HEP+ threshold of ≤ 35 W/m², thereby reducing the heat load entering the building by 17%.

Group 1 – Model 2 (HEP)

Opaque

Wall-03

Glass

Win-03,

WWR 50%

Roof

Roof-02



Group 1 OTTV 49.57 W/m²
RTTV 3.45 W/m²

Changing to a reflective glass 8 mm with 50% WWR, building with a lightweight concrete wall with light color painting, and adding insulation on top ceiling roof. It will result in OTTV passing the threshold of ≤ 50 W/m², thereby reducing the heat load entering the building by 13%.

Group 1 – Model 4 (ZEB)

Opaque

Wall-04

Glass

Win-05,

WWR 50%

Roof

Roof-03

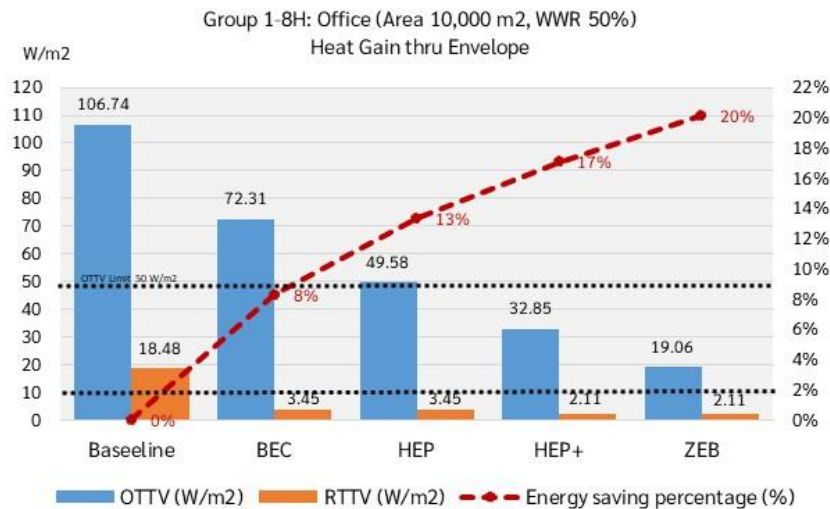


Group 1 OTTV 19.06 W/m²
RTTV 2.11 W/m²

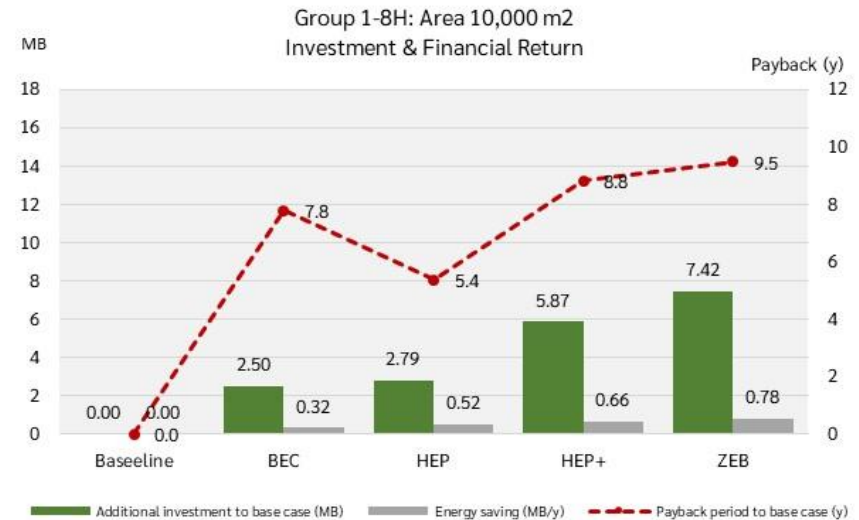
If changing to a more high-efficiency glass of Double Glass Heat Stop Low-E 24 mm, even with 50% WWR, it will pass the ZEB standard at OTTV ≤ 20 W/m². Thereby, it will reduce the heat load entering the building by 20% compared to the baseline scenario.

Group 1 – Energy Saving Potential

Energy saving potential



Financial return on investment



For buildings designed where a large glass area is required (WWR50%), it should consider using an insulated concrete or lightweight concrete wall with a reflective glass of at least 8 mm thickness; to meet the BEC minimum requirements of Group 1 of OTTV ≤ 50 W/m². Higher efficiency glass with low SHGC that allows less heat to pass through should also be selected or consider switching to Low-E double-glazed windows. By an estimate, improving the efficiency of OTTV and RTTV to reduce the amount of heat transfer through the building envelope and passing the BEC minimum standards will result in air conditioners cooling load reduction by 8-13%, equal to approximately potential energy saving of 0.32-0.52 million baht/year. The difference of additional incremental cost is approximately 250-279 baht/sqm. The payback period does not exceed eight years. But high investment may be required if designed to meet a higher HEP level at OTTV ≤ 40 W/m²; additional cost will be up to 587 baht/sqm.

For buildings that do not require high investment costs and intend to design with a standard concrete opaque wall with 6 mm clear window glass, the WWR ratio used should be less than 15%.

Group 2-Models

Baseline

Opaque

Wall-01

Window glass

Win-01,

WWR 50%

Roof

Roof-01



Group 2 OTTV 86.09 W/m²
RTTV 18.28 W/m²

Baseline assumed a common practice characteristic of a typical building with a rectangular shape; with a 10-floor tower, dimension of 25 x 40 m. The materials used are combination of opaque wall, window glass, roof materials, and WWR ratio is set at 50%.

Note that the saving percentage for Group 2-12Hr is lower than Group1 because the building operates both day and partially at nighttime. The annual energy savings for Group 2-12Hr is the lower due to building operating hours.

Group 2 – Model 1 (BEC)

Opaque

Wall-02

Glass

Win-02,

WWR 50%

Roof

Roof-02



Group 2 OTTV 60.14 W/m²
RTTV 3.72 W/m²

If the wall is concrete and the glass is 6 mm reflective glass at 50% WWR and the building wall color will be light color or heat-reflective color. Although it cannot pass the OTTV threshold of ≤ 40 W/m², it could reduce the heat load into the building by 6%

Group 2 - Model 3 (HEP+)

Opaque

Wall-04

Glass

Win-04,

WWR 50%

Roof

Roof-03



Group 2 OTTV 24.62 W/m²
RTTV 2.28 W/m²

Changing the window to be a double glassing Low-E 6-12-6 mm, building with a lightweight concrete wall with an insulation layer, and adding insulation on ceiling roof. It will result in OTTV passing the HEP+ threshold of ≤ 35 W/m², thereby reducing the heat load entering the building by 14%

Group 2 – Model 2 (HEP)

Opaque

Wall-03

Glass

Win-03,

WWR 50%

Roof

Roof-02



Group 2 OTTV 39.54 W/m²
RTTV 3.72 W/m²

Changing to a reflective glass 8 mm with 50% WWR, building with a lightweight concrete wall with light color painting, and adding insulation on top ceiling roof. It will result in OTTV passing the threshold of ≤ 40 W/m², thereby reducing the heat load entering the building by 11%.

Group 2 – Model 4 (ZEB)

Opaque

Wall-04

Glass

Win-05,

WWR 50%

Roof

Roof-03

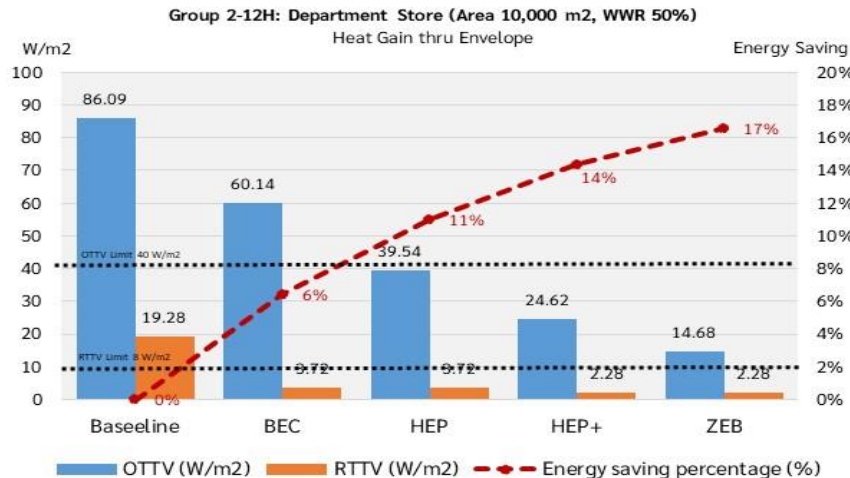


Group 2 OTTV 14.68 W/m²
RTTV 2.28 W/m²

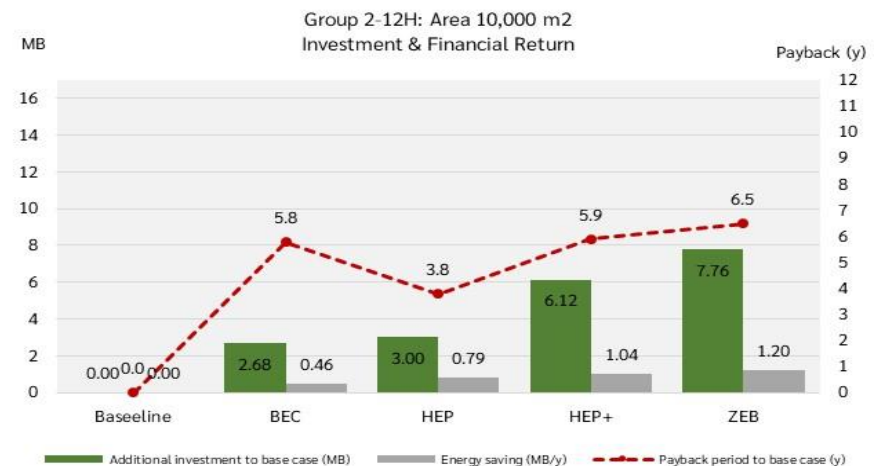
If changing to a more high-efficiency glass of Double Glass Heat Stop Low-E 24 mm, even with 50% WWR, it will pass the ZEB standard at OTTV ≤ 20 W/m². Thereby, it will reduce the heat load entering the building by 17% compared to the baseline scenario.

Group 2 – Energy Saving Potential

Energy saving potential



Financial return on investment



For buildings Group 2, if designed where a large glass area is required (WWR50%), it should consider using an insulated concrete or lightweight concrete wall with a reflective glass of at least 8 mm thickness; to meet the BEC minimum requirements of OTTV ≤ 40 W/m². Higher efficiency glass with low SHGC that allows less heat to pass through should also be selected or consider switching to Low-E double-glazed windows. By an estimate, improving the efficiency of OTTV and RTTV to reduce the amount of heat transfer through the building envelop and passing the BEC minimum standards will result in air conditioners cooling load reduction by 6-11%, equal to approximately potential energy saving of 0.46-0.79 million baht/year. The difference of additional incremental cost is approximately 268-300 baht/sqm. The payback period does not exceed six years. But the high investment may be required if designed to meet a higher HEP level at OTTV ≤ 30 W/m²; additional cost will be up to 612-776 baht/sqm.

For buildings that do not require high investment costs and intend to design with a standard concrete opaque wall with 6 mm clear window glass, the WWR ratio used should be less than 15-20%

Group 3-Models

Baseline

Opaque

Wall-01

Window glass

Win-01,

WWR 50%

Roof

Roof-01



Group 3 OTTV 52.99 W/m²
RTTV 13.12 W/m²

Baseline is assumed to be a common practice characteristic of a typical building with a rectangular shape like Group 1 and Group 2.

Despite working 24 hours a day, the air conditioning system's workload from the heat transferred through the building envelope will be more effective during the day than at night.

However, using high-efficiency building materials would reduce the heat load transferred into the building; as a result, it reduces the air system's energy consumption by 4-10%.

Group 3 - Model 1 (BEC)

Opaque

Wall-02

Glass

Win-02,

WWR 50%

Roof

Roof-02



Group 3 OTTV 36.92 W/m²
RTTV 2.60 W/m²

If the wall is concrete and the glass is 6 mm reflective glass at 50% WWR and the building wall color will be light color or heat-reflective color. Although it cannot pass the OTTV threshold of ≤ 30 W/m², it could reduce the heat load into the building by 4%

Group 3 - Model 3 (HEP+)

Opaque

Wall-04

Glass

Win-04,

WWR 50%

หลังคา

Roof-03



Group 3 OTTV 14.99 W/m²
RTTV 1.59 W/m²

Changing the window to be a double glassing Low-E 6-12-6 mm, building with a lightweight concrete wall with an insulation layer, and adding insulation on ceiling roof. It will result in OTTV passing the HEP+ threshold of ≤ 25 W/m², thereby reducing the heat load entering the building by 9%

Group 3 - Model 2 (HEP)

Opaque

Wall-03

Glass

Win-03,

WWR 50%

Roof

Roof-02



Group 3 OTTV 23.78 W/m²
RTTV 2.60 W/m²

Changing to a reflective glass 8 mm with 50% WWR, building with a lightweight concrete wall with light color painting, and adding insulation on top ceiling roof. It will result in OTTV passing the threshold of ≤ 30 W/m², thereby reducing the heat load entering the building by 7%.

Group 3 - Model 4 (ZEB)

Opaque

Wall-04

Glass

Win-05,

WWR 50%

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Roof-03

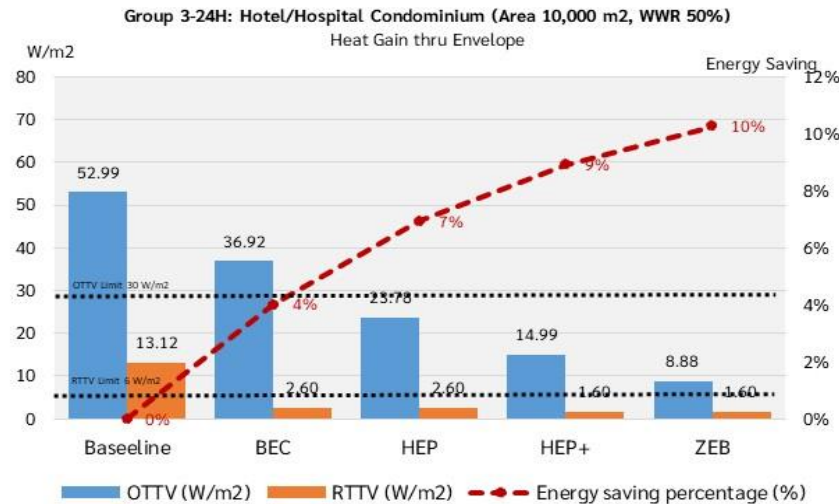


Group 3 OTTV 8.88 W/m²
RTTV 1.59 W/m²

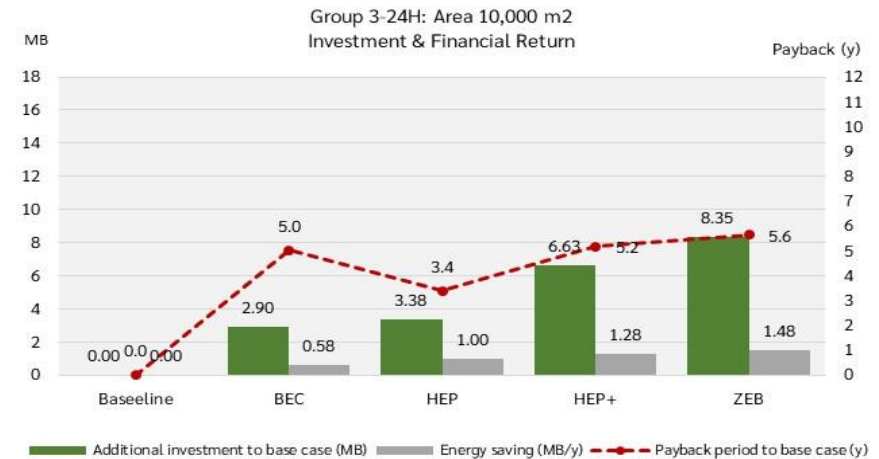
If changing to a more high-efficiency glass of Double Glass Heat Stop Low-E 24 mm, even with 50% WWR, it will pass the ZEB standard at OTTV ≤ 20 W/m². Thereby, it will reduce the heat load entering the building by 10% compared to the baseline scenario.

Group 3 – Energy Saving Potential

Energy saving potential



Financial return on investment



For buildings Group 3, if designed where a large glass area is required (WWR50%), it should consider using an insulated concrete or lightweight concrete wall with a reflective glass of at least 8 mm thickness; to meet the BEC minimum requirements of OTTV ≤ 30 W/m². Higher efficiency glass with low SHGC that allows less heat to pass through should also be selected or consider switching to Low-E double-glazed windows. , By an estimate, improving the efficiency of OTTV and RTTV to reduce the amount of heat transfer through the building envelop and passing the BEC minimum standards will result in air conditioners cooling load reduction by 4-7%, equal to approximately potential energy saving of 0.58-1.0 million baht/year. The difference of additional incremental cost is approximately 290-338 baht/sqm. The payback period does not exceed seven years. But the high investment may be required if designed to meet a higher efficiency ZEB level at OTTV ≤ 20 W/m²; additional cost will be up to 835 baht/sqm.

For buildings that do not require high investment costs and intend to design with a standard concrete opaque wall with 6 mm clear window glass, the WWR ratio used should be less than 10-15%

Component 2: Lighting System

The design of high-efficiency lighting systems determines an appropriate maximum LPD power per unit area (W/m^2) to reduce the lighting system's energy consumption as much as possible but still have enough luminous flux. The design approach based on the BEC criteria is using high-efficiency lamps or LED lamps, in combination with the utilization of natural light and control of on-off electrical switches in areas not needed.

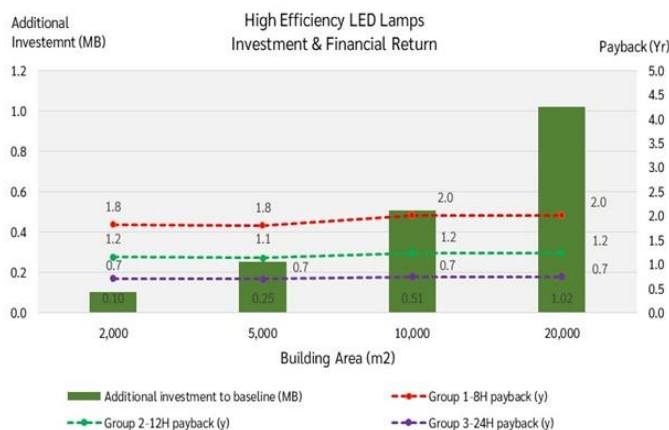


High efficiency LED lamps are the new LED technology with higher lumen per Watt than normal LED lamp commonly used in the buildings. Examples will be a comparison of a high-efficiency LED light bulb of 200 lm/W with current LED lamps with a light output of 105 lm/W. The table below shows the light output and efficiency comparison between the high-efficiency tubular LED lamp and standard tubular LED lamp.

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

Estimated potential energy saving	BEC building groups		
	Group 1: 8 Op.hr/day	Group 2: 12 Op.hr/day	Group 3: 24 Op.hr/day
Energy consumption of baseline technology (kWh/y)	119,387	223,468	446,935
Energy consumption of BEC technology (kWh/y)	62,675	117,314	234,628
Energy saving potential (kWh/y)	56,712	106,154	212,307
Energy saving percentage (%)	48%		

Additional investment and payback period compared to baseline scenario:



The simulation confirms the excellent return on investment on high efficiency LED lamps compared to normal LED lamps. The use of high efficiency LED light bulbs will be able to provide 48% more energy saving, with an additional investment of 0.10-1.02 million baht. Paybacks are under 2 years in all cases and even less than 1 year in building Group 3-24 hr.

Component 3: Air Conditioning System

Designing a high-efficiency air conditioning system should not only consider choosing an appropriate air conditioner size to suit the cooling load of the building. However, in selecting an air conditioner consideration should be given to high COP performance coefficient or a low power per ton (kW/TR) or using a split type with a high SEER value. Good air conditioning system design with high-efficiency performance equipment will help reduce the long-term electricity consumption of the air-conditioning system



Three examples of high-efficiency air conditioning systems are selected to present as follows:

- 1) High efficiency inverter split type air conditioners with label no.5 three stars
- 2) VRF/VRV air conditioning system
- 3) เครื่องทำน้ำเย็นประสิทธิภาพสูง ชนิด Oil-free magnetic bearing chiller

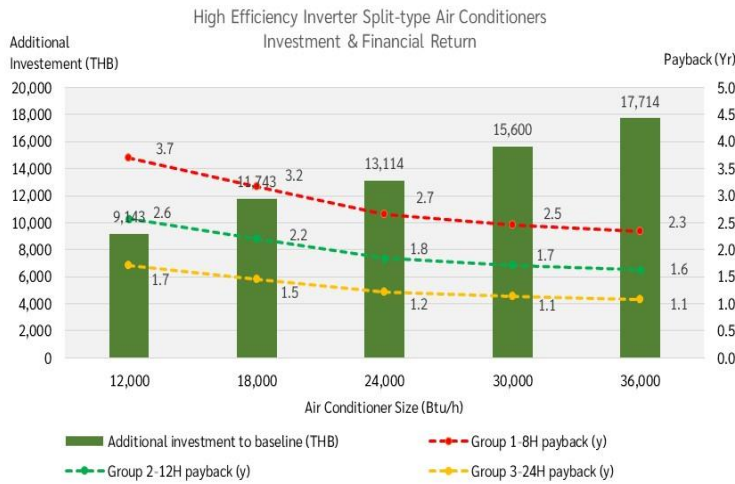
Example 3-1: High Efficiency Inverter Split Type

Split air conditioners are often used in medium and small office buildings, government office buildings, hospitals, educational institutions, and residential condominiums.

The example will compare the different efficiencies of split-type units indicated by the seasonal energy efficiency ratio (SEER). Inverter split-type air conditioners with label no.5 three-star rating provide premium efficiency over standard label no.5 fixed speed-split type air conditioners. Energy consumption can be calculated and compared for air conditioners with different efficiencies SEER. The analysis shows results vary with the cooling capacity from 12,000 – 36,000 Btu/hr, and conservatively assuming 40% utilization factor is used for calculating the energy-saving potential.

Air conditioner cooling capacity (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 three star					
Air conditioner efficiency (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 potential (kWh/year)					
Building group 1 – 8 Hr	375	562	750	958	1,150
Building group 2 – 12 Hr	702	1,053	1,403	1,794	2,153
Building group 3 – 24 Hr	1,403	2,105	2,807	3,588	4,306
Energy saving percentage (%)	43%	43%	43%	42%	42%

Additional investment, saving and payback period from high efficiency split type air conditioners for each building group:



With an average price premium of around 40% high efficiency inverter split-type air conditioners with label no.5 three-star provide good payback of 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.

Example 3-2: VRF/VRV Air Conditioning System

Variable refrigerant flow (VRF), also known as variable refrigerant volume (VRV), is an air conditioning system that can change the amount of refrigerant according to a cooling load and the number of units inside the installation place. VRF systems, unlike conventional chiller-based systems, allow for varying degrees of cooling in more specific areas. VRF or VRV air conditioning system offers high-efficiency air conditioning and usage flexibility for small to medium-sized buildings.

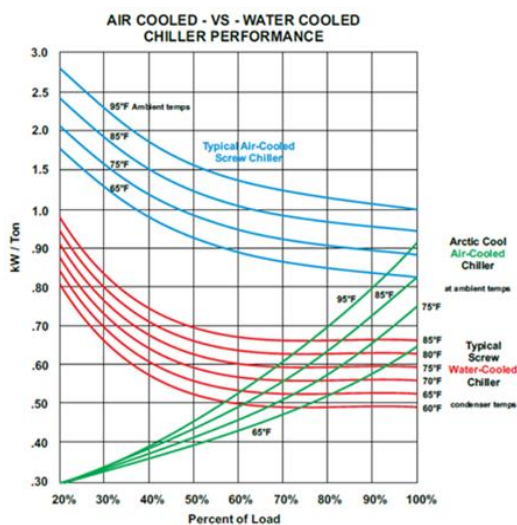


The example in the simulation used the 40 RT VRF system compared with the similar-sized air-cooled chilled water system. The energy-saving will be obtained from a high-efficiency VRF/VRV air conditioner of 0.89 kW/TR at full load efficiency compared to an air-cool chiller water system- scroll type 1.12 kW/TR at full load efficiency. Typical cooling load patterns are used as representative for BEC building groups. Details of chosen technology and analysis are summarized as below.

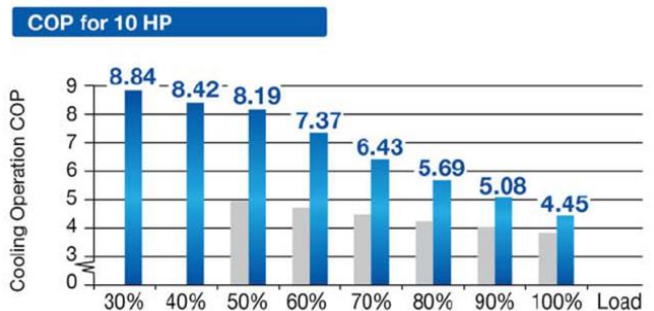
	Baseline Technology	BEC Technology
Technology type	Air-cooled chiller Scroll type	ระบบ VRF/VRV system
Chiller Cooling Capacity, TR	40	40
Full load efficiency – kW/TR	1.12	0.89
Coefficient of Performance (COP)	(COP 3.5)	(COP 3.97)

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

Part Load efficiency		
% 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

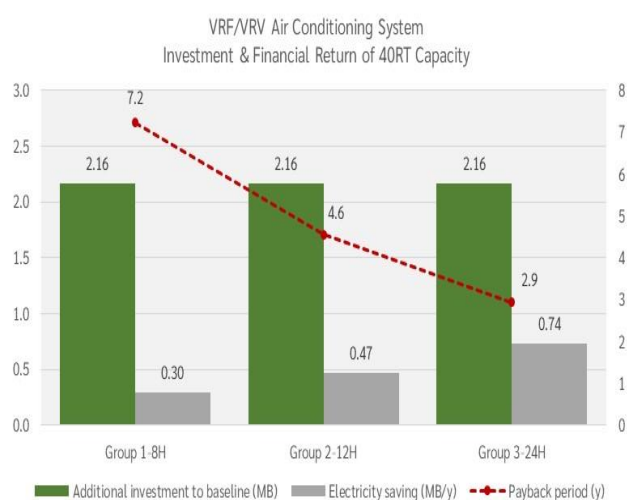


Higher Coefficient of Performance (COP)



Energy saving of VRF air conditioning system over air-cooled chilled water system are as follows:

Energy Saving Potential	BEC building		
	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 show significant savings of around 49-54% in energy consumption compared with air-cooled chilled water system, with additional investment costs of 2.16 MB, payback on additional investment ranged from 3 to 7 years depending on operating hours of the building and cooling load profile of the building.

Example 3-3: High Efficiency Chillers/ Oil-free Magnetic Bearing Chillers

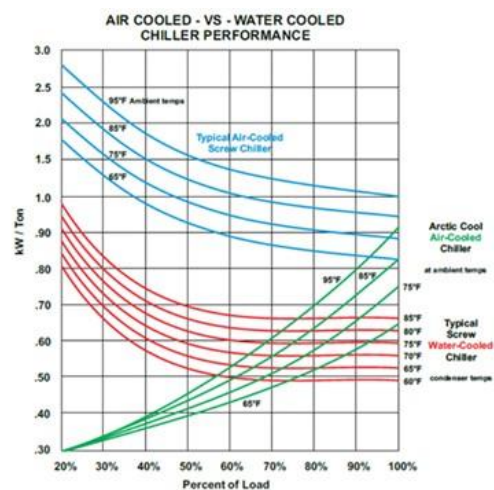
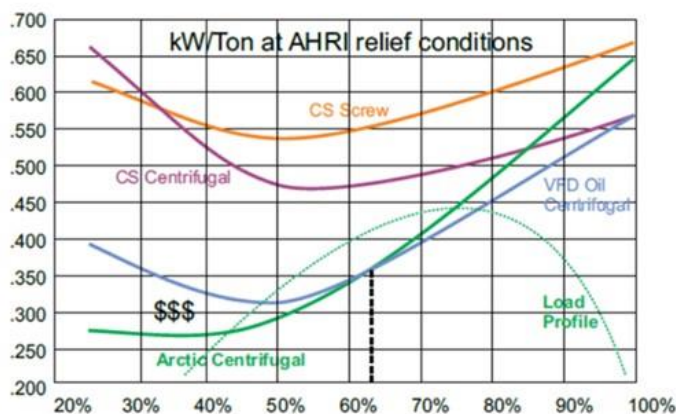
High efficiency chillers with improved technologies including variable speed centrifugal compressors and magnetic bearing can greatly improve chiller efficiency (COP) and reduce energy consumption. Currently, water chiller technology has been developed to be more efficient, reducing electricity consumption and maintenance costs, such as an Oil-free magnetic bearing chiller. The Oil-free magnetic bearing chiller has a lower power consumption of 0.55-0.70 kW/TR, and it can operate at part loads down to 20-40%. It considers a high-efficiency chiller compared to a large centrifugal water-cooled chiller or Screw type, which are not capable of operating under 40% full load.

The example applied a representative cooling load pattern of 15 m²/TR for simulating energy consumption and energy performance of high-efficiency chillers over conventional chillers. For smaller buildings of 2,000 and 5,000 m², comparisons are made between air-cooled oil-free magnetic bearing chillers 0.70 kW/TR and standard air-cooled chillers 1.11-1.12 kW/TR. For

larger buildings of 10,000 m², magnetic bearings 0.55 kW/TR and normal water-cooled chillers 0.63 kW/TR are compared. Typical specifications of chillers for different buildings are assumed for the comparative analysis as follows:

Building area (m ²)	Cooling load @15 m ² /TR	Baseline Technology		BEC Technology	
		Chiller type	Full load efficiency (kW/TR)	Chiller type	Full load efficiency (kW/TR)
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

Part-load efficiency factors of chiller					
% 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



The table below summarizes the results of simulation to compare the energy consumption of baseline chillers and high-efficiency magnetic bearing chillers for BEC buildings of different sizes and types:

Energy Saving Potential	BEC building		
	Group 1–8Hr	Group 2–12Hr	Group 3–24Hr
Building area 2,000 m²			
Energy consumption of baseline technology (kWh/y)	338,335	622,986	1,147,925
Energy consumption of BEC technology (kWh/y)	158,601	269,757	476,490
Energy saving potential (kWh/y):	179,735	353,229	671,435
Energy saving percentage (%)	53%	57%	58%
Building area 5,000 m²			
Energy consumption of baseline technology (kWh/y)	853,459	1,571,495	2,895,667
Energy consumption of BEC technology (kWh/y)	396,502	674,392	1,191,226
Energy saving potential (kWh/y):	456,957	897,103	1,704,441
Energy saving percentage (%)	54%	57%	59%
Building area 10,000 m²			
Energy consumption of baseline technology (kWh/y)	846,300	1,510,503	2,717,469
Energy consumption of BEC technology (kWh/y)	612,564	1,033,628	1,843,855
Energy saving potential (kWh/y):	233,736	476,875	873,614
Energy saving percentage (%)	28%	32%	32%



The simulation results show significant energy savings 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 2-8.5 years depending on the size of the building and operating hours, with an additional investment required of approximately 4-15 MB.

Component 4: Hot Water Generation System

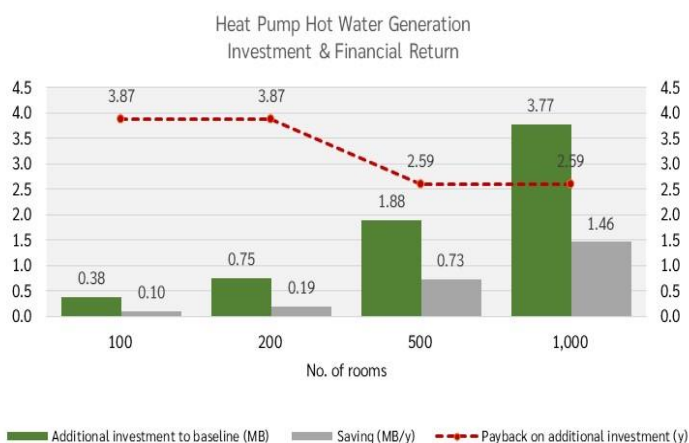
Water heaters are used in many buildings such as hospitals, hotels, resorts, etc. The original hot water generation system is primarily a steam boiler or an electric heater, which is highly energy-consuming and costly. Choosing a more efficient air-source heat pump water heater will help to reduce the operation costs of producing a hot water supply.



The example applied to a building representative Group 3-24Hr since hot water generation systems are normally installed in hotels and hospitals. The simulation compares the potential saving of two types of hot water generation technology; an air-source heat pump water heater to replace a steam boiler that uses fuel oil. The analysis scenario is applied to the hotel guest room to compare the savings obtained, and the energy consumption and savings calculation is based on 365 day-per-year.

Energy saving potential and return on investment are as follows:

	Baseline Technology	BEC Technology		
Hot water generation 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		
Energy Saving Potential	Number of guest room			
	100	200	500	1000
Electricity Demand (kW)	47	94	236	472
Electricity consumption (kWh/y)	61,269	122,538	306,344	612,688
Energy saving (MJ/y)	687,652	1,375,304	3,438,259	6,876,519
Energy saving (%)	76%			



The simulation result show that the heat pump hot water system could save 76% of energy consumption compared with fuel oil hot water boiler, with the average additional investment to baseline 0.38-3.77 MB. Return on investment over fuel oil boiler with short payback less than four years in all cases.

Component 5: Renewable Energy Generation

BEC buildings have great potential to generate electricity from solar energy. If the building is equipped with a solar power generation system, it will help reduce energy costs.

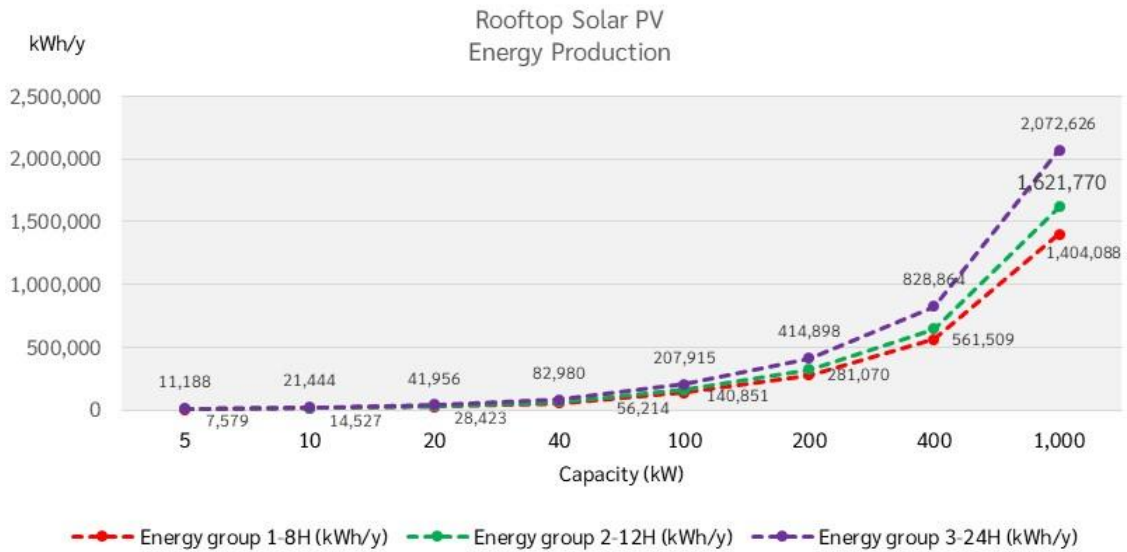


According to the BEC regulations, if there is a renewable generation in the building and consumes energy from its renewable power generation source (solar PV system), it is allowed to consider the power generation from the RE system to deduct from the whole building energy performance value.

The example aims to present a guideline for considering solar power generation systems investment. Potential power generation from different capacities of solar rooftops is analyzed and presented in this section. The calculation of power production is based on the solar production profile, normalized from the average of actual energy production of solar PV installed on building roof in Bangkok area. Noting that all electricity produced is internally consumed without selling to the grid.

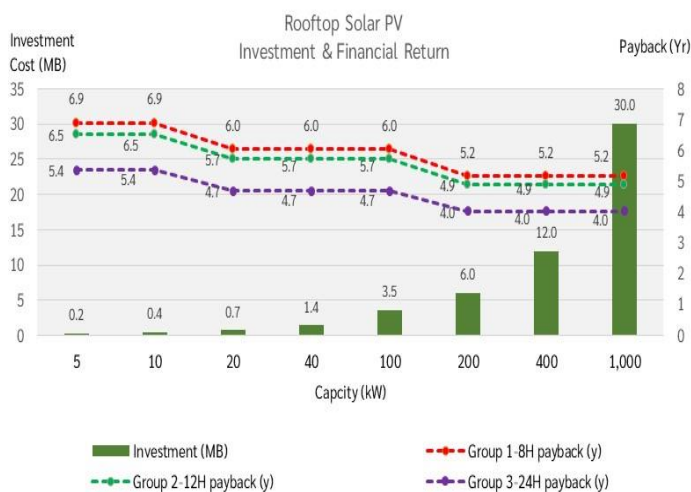
Total electricity production potential and return on investment are as follows:

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 strings	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



Energy saving potential and return on investment are as follows:

Energy saving potential and return on investment are as follows:



Rooftop solar PV system provides savings for BEC buildings with a 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 internally consumed without selling to the grid.

However, in case the building has limited investment budget, and if all electricity produced is internally consumed without selling to the grid. Therefore, it is therefore important to design a suitable capacity that matches the building electricity profile to maximize return on investment.

Conclusions

Although the BEC regulation allows, to pass BEC standard with only Option 2 whole building energy performance criteria is not the best option. Based on the statistics, designing a building to meet each system's minimum energy efficiency (BEC) criteria is not an impossibility. It can be achieved by using the technology and building materials continuously developed and are commercially available.

Most building developers/owners often focus on investing in high-efficiency types of equipment to reduce power consumption, e.g., use of high-efficiency air conditioner or lighting system. But does not pay much attention to designing with efficient performance building envelope to reduce the amount of heat transferred into the building, which is the main contributor to the cooling load of the building. As a result, facilities still need a lot of energy for air conditioning.

A good building design is critical for the overall building energy performance. Designing buildings to meet good energy efficiency standards, excellent functionality, and outstanding architectural design from the beginning will produce better results; by selecting the appropriate building envelope materials to reduce the heat transferred into the building e. Choosing to use high-efficiency equipment such as air conditioning, lighting, other electrical systems, etc., will help save on annual building's energy costs over the life of the building.

Although some high-performance technologies may require a higher investment cost today, when technology becomes more commercially available and e adopted, the price trend will be inevitably decrease. It will make investing in those technologies more attractive and worthwhile.

Furthermore, BEC buildings have great potential to generate electricity from the solar energy. To invest in a solar power generation system will help reduce energy costs. In addition, BEC allows the power generation from the RE system to be deducted from the whole building energy performance value. However, it is essential to design a suitable capacity that matches the building electricity profile to maximize return on investment.

Glossary

BEC	Building Energy Code
COP	Coefficient of Performance
EUI	Energy Use Intensity
HEP	High Energy Performance
LED	Lighting Emitting Diode
LPD	Lighting Power Density
OTTV	Overall Thermal Transfer Value
RTTV	Roof Thermal Transfer Value
SC	Shading Coefficient
SEER	Seasonal Cooling Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
U	Thermal conductivity of material (W/m ² K)
VRF	Variable Refrigerant Flow or VRV (Variable Refrigerant Volume)
VT	Visible Transmittance
WWR	Window-to-Wall Ratio
ZEB	Zero Energy Building