International Institute for Energy Conservation

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 2

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CLIMATE TECHNOLOGY CENTRE & NETWORK

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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 summarizes the completed project activities in the second reporting period of the project (January to March 2021).

This progress report provides the completed deliverable result of Task 1 (sub-activity 1.2 to 1.4) and portion of Task 2 (sub-activities 2.1). Analysis of BEC energy benchmarking, energy consumption and GHG emission are revised to the update database received from DEDE and related BEC stakeholders. In addition, detailed benchmarking and gap analysis on the BEC compliance of each type of buildings are performed. Distribution profiles of the OTTV and RTTV (pre-BEC assessment) of five building types over ten years of BEC implementation are developed. The analysis results provide the common ground for the assessment and prioritizing of technologies in project task 2.

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

- Over ten years (from 2009 to 2019), the average energy use intensity (EUIs) data of all five building types indicate the decreasing trend of the average EUI by 15%, from 93.3 kWh/m^2-y to 79.6 kWh/m^2-y. The EUIs of all building types, both pre and post-BEC assessment are much lower than the reference EUI. The detailed EUI profile of five building types benchmarking against Reference EUI is shown in Table 1 of Chapter 2.
- The Thai BEC offers two options for compliance. Under option 1, the must pass the energy performance requirements of each individual systems; building envelope, lighting, air conditioning, and hot water generation system. Failing to meet any of these system requirements will result in option 1 noncompliance, and option 2 will be used for re-evaluation. Option 2 evaluates building energy consumption as a whole and allows trade-off among components as long as the overall building energy consumption is lower than the consumption of the reference building.
- It is found that the BEC compliance percentage of five building types using BEC 2009 criteria, the majority of the buildings fail to comply with the individual performance requirements of option 1 (21%). However, most of the failed buildings from option 1 are able to pass the overall EUI criteria of option 2, making the total passing of BEC 2009 almost 99%. With this result it, seems that the current criteria set on option 1 are ineffective compared with option 2.
- Most option 1 non-compliances are due to the building envelope's OTTV and RTTV criteria. The average OTTV of most building types and sizes fail to comply with OTTV criteria. For RTTV, only the hospital type can meet BEC 2009 criteria on all building sizes. It is clearly seen that the BEC envelope criteria of OTTV and RTTV are the most difficult to comply.
- Building systems including air conditioning, lighting, hot water generation and renewable energy have no impact on BEC compliance. Only 3% of the buildings fail the air conditioning (AC) or lighting power density (LPD) criteria. Energy-efficient air conditioning and lighting are well aware and included in building design.

Under sub-activities 1.4, the first stakeholder consultation workshop for the 'Enabling Readiness for Up-Scaling Investments in Building Energy Efficiency for Achieving NDC Goals in Thailand'' project was successfully organized in Bangkok, on Monday, March 8th, 2021. The results of the BEC data analysis and benchmarking of activity 1.1 to 1.3 were consulted with DEDE's BEC working group and the stakeholder consultation workshop, to share the results and validate the data. The summary of stakeholder consultation workshop is reported in Chapter 4. The policy-related and technical-related issues were discussed and noted from the stakeholder consultation workshop as follows.

Policy-related issues

- Based on DEDE's update of the BEC status, the effective date of the BEC 2020 in March 2021 was delayed. The BEC 2020 enforcement process is still under consideration by the Building Control Board-Department of Public Works and Town and Country Planning (DPT). It is expected that the draft of new Ministerial regulation of the building control is approved and announced by Ministry of Interior in September 2021, and scheduled for the new BEC to be implemented by the local administrative organization (LAO) by December 2021.
- As BEC is targeted for inclusion to the building construction permission, both option 1 and option 2 should be remained but use in different perspectives. However, it is recommended that the detailed setting of the criteria should be investigated for a better balance of both option effectiveness; otherwise further enforcement would be weak.
- With its main objective, BEC should never be treated as the design target but rather as the minimum requirements that every building design should pass.
- Option 2 could be used as the pushing mechanism to force all buildings, including buildings with low energy efficiency awareness, to comply with the BEC. Option 1 could be used as a pulling mechanism for encouraging the building designer and owner to better their building energy efficiency design.
- BEC might consider putting more incentive of using renewable energy or mandate certain extent of renewable or alternative energy in some buildings i.e. PV system in buildings with large roof area and high operating hours, which have been proven to be cost effective and applicable in many countries. With option 2 the building designer can have their choices to compensate for the deficit with the use of advanced technology or renewable energy.
- It is suggested to add some kind of verification mechanism after construction completion and when the buildings are in operation to track actual energy performance in comparison with the calculation estimated during BEC assessment.
- It is suggested that GHG emission from the building energy consumption be included in the BEC assessment. This would raise more awareness on the environmental impact of the building design and help the country to meet the GHG emission reduction goal.

Technical-related issues

- The average EUI of the 10-year database seems to be very low compared to the country with tropical climate and high efficiency standard like Singapore. The energy calculation in the BEC assessment calculation need investigation and verification.
- It is agreed that all settings of BEC criteria have been well accepted as they are based on proper technical and market study. The criteria settings are comparable to international standard and applicable to Thailand. So far there is no objection from the stakeholders.
- While the calculation formula of the energy consumption of the reference building in BEC calculation program is correct, some applied parameters might be outdated and need adjustments to reflect changes in building materials, technology and operation of the present buildings.
- Benchmark analysis of the building database provides good understanding of the building energy efficiency performance situation, which are valuable for further adjustment and design of the policy. The expansion of the database and the analytic capability would also be very useful for public benchmarking and creating the awareness of the energy efficiency design to the energy consumption and life-long energy costs of the buildings.

Chapter 3 reports the work in progress of Task 2, to provide the overview of the BEC compliance requirements and parameters that are relevant to technology in building design. Subsequently technologies for building design and their relevance to building energy performance in each BEC components are listed, including the analysis of the BEC assessment database to identify materials commonly used in building design and how they affect to the BEC compliance. The listing of applicable technologies for six BEC components is summarized in Table 15. The simulation of technology impacts to building energy performance will be carried out in Task 2 and 3 for the next step deliverables.

of the challenges faced during the implementation during this progress report are: 1) Non-standardized of BEC recorded data, and 2) Incomplete and non-systematic details of BEC components. Much efforts were taken to clean, interpret and standardize the names in order to classify the data before the detailed gap analysis and benchmarking. It is recommended that the BEC assessment database is verified and cleaned to standardize its record data. More details of other BEC components such as sizes, types and energy consumption of lighting and air conditioning can be added for comprehensive analysis of other systems. Adding automatic data export and analysis tools are worth considering to prepare this database for the full enhancement and enforcement of BEC in the coming years.

1 Summary of Activities

This report summarizes the project's progress from January to March 2021 and deliverables under Task 1 (sub-activity 1.2 to 1.4) and portion of Task 2 (sub-activities 2.1). The activities undertaken by the IIEC project team during this reporting period are summarized as follows.

- Following the data gathering and preliminary analysis result of in activity 1.1, the IIEC project team used the available existing energy consumption data from the ten-year BEC database, from 2009 to 2019, to conduct a detailed assessment and to streamline of energy consumption baseline and benchmark, including GHG emissions of the five selected building types.
- The information extracted from the BEC assessment database is consolidated into a single database for subsequent analysis and simulation using the Microsoft Excel spreadsheet.
- The IIEC project team coordinated and conducted the consultation meeting with the BEC working team comprising DEDE and the Coordinating Center for Energy Conservation Building Design (2e-Building Center) consultants, to share the fact-finding of BEC's ten-year data assessment for internal validation and comments. The two internal stakeholder consultation meetings with DEDE and the consultants were held on Wednesday, February 18th 2021 and Tuesday 23th February 2021.
- Following the internal consultation meeting, the project team organized a stakeholder consultation workshop to share the results and validate the established energy and GHG baselines and energy benchmarks. The first stakeholder consultation workshop for the 'Enabling Readiness for Up-Scaling Investments in Building Energy Efficiency for Achieving NDC Goals in Thailand" project was successfully organized in Bangkok, on Monday, March 8th, 2021. The representing the local building energy efficiency experts from 12 key national organizations joined this event.
- Following the completion of the workshops, the evaluation was conducted through the workshop satisfaction assessment form.
- The simulation of Energy and GHG Benchmarks will be carried out in conjunction with findings from activities under Task 2 and 3 in the subsequent deliverables.

The progress and results of Activity 1.2 to 1.4 are presented in Chapter 2 to Chapter 4.

2 PROGRESS BY TASK 1

This chapter provides the complete result of project task 1. Some contents of this chapter overlap with progress report 1 but being revised to the additional information received from DEDE and related BEC stakeholders. Adding to the benchmarking of energy, GHG baselines and consumptions already reported in progress report 1, detailed benchmarking and gap analysis on the BEC compliance of each type of buildings are performed. The analysis results provide the common ground for the assessment and prioritizing of technologies in project task 2.

2.1 ACTIVITY 1.1: EVALUATION OF EXISTING ENERGY CONSUMPTION DATA

2.1.1 Collection of missing BEC energy consumption data of BEC assessment database

Continued from the progress report 1, the project has obtained update data on the BEC assessment database including the missing data found previously.

(1) BEC energy consumption data of the year 2009.

(2) Confirmation of no building data for the year 2011 due to the non-operation of BEC causing by major flooding in Thailand.

(3) Classification of building types on the building data for the year 2016.

The collection of the BEC assessment database is deemed complete for five BEC building types under the project scope, covering 10-year of BEC implementation from 2009 to 2019.

2.1.2 Confirmation of using BEC assessment database as the main source for analysis

Initially the project team planned to use the Database of Building Construction Permits, managed by Kasetsart University (http://bec.dede.go.th) to represent BEC building population. However after detailed verification it was found that the data were inconsistent with the BEC assessment database. According to DEDE's BEC working team participation of the local administrative organizations to the BEC is still low as the BEC program is not being enforced as mandatory requirement in granting of Building Construction Permit. The building data submission is not verified and processed as part of the permit approval, resulting in the incompletion and inaccuracy of the building data.

Therefore, this project will utilize the BEC Assessment database as the main source for the analysis, although the size of the BEC assessment database is still low compared to the actual number of buildings newly designed and constructed each year. Once BEC mandatory enforcement is in place, it might be worth improving the coverage and accuracy of this building construction permit database for better monitoring of building population and tracking result of the BEC program.

2.1.3 Methodology for analysis of BEC energy consumption and benchmarking

The methodology for analysis of BEC energy consumption and benchmarking is revised with additional detailed benchmarking and gap analysis to the complete data of year 2009 to 2019. The revised methodology is illustrated as the diagram in Figure 1 with the step explained subsequently.

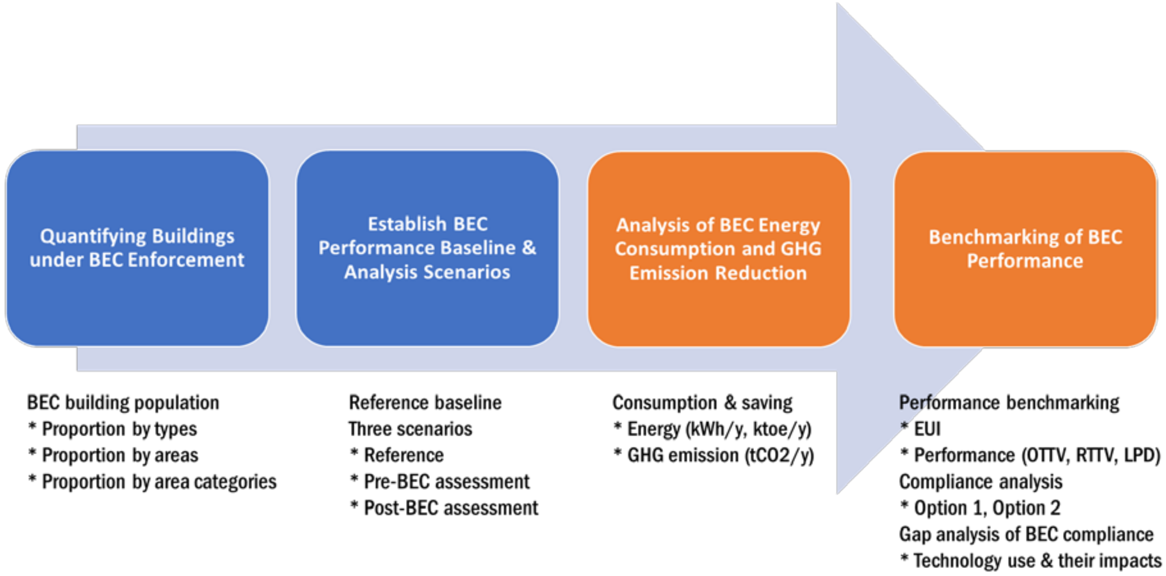


Figure 1: Analysis Methodology for BEC Benchmarking

Step 1: Quantifying buildings under BEC enforcement

Due to its availability and accuracy the building data stored, the BEC assessment database are treated as the representative of the BEC building population. To the project scope data of five building types: office, department store, hotel, hospital and condominium, are quantified and categorized by total building areas as per the new BEC 2020: 2000 m^2, 2000-5000 m^2, 5000-10000 m^2 and >10000 m^2.

Step 2: Establish BEC performance baseline and analysis scenarios

BEC reference baseline

The project uses current BEC reference baselines, which were established and have been used by DEDE since the launch of the BEC program in 2009, as the basis for BEC energy and performance benchmarking.

Reference baselines are representative energy consumptions for each building types and sizes, established from the reference building model with similar design (shape, floor area, envelope, orientation, air-conditioned zones and unconditioned spaces, equipment power density (EQD), design of occupancy (OCCU) and ventilation rate (VENT). Common building envelope materials, just comply with the OTTV, RTTV criteria, are used for baseline energy consumption calculation. The formula and calculation parameters are built based on DEDE energy audit reports of 1,800 designated buildings during 1996-2003. And have been applied to the current web-based BEC evaluation program for verifying of building energy performance (EUI), and calculation of energy consumption and savings.

Analysis scenarios

For the BEC analysis, three scenarios are established.

1. **Reference baseline** as the scenario should the BEC do not exist. Currently DEDE uses the reference baseline for reporting energy savings and GHG emission reduction achieved from the BEC implementation. It is assumed that the reference baseline is the consumption of each representative building types before the start of the BEC program more than 10 years ago.
2. **Pre-BEC assessment** takes the original building design at the first submission of BEC evaluation to represent building design and materials currently used in the market.

3. **Post-BEC assessment** is the scenario in which building designers improve their building designs to fully comply with the BEC criteria as a result of the BEC evaluation. Energy savings from this post-BEC assessment compared to the reference baseline represents the achievement of the BEC implementation.

Step 3: Analysis of BEC energy consumption and GHG emission reduction

The information extracted from the BEC assessment database are consolidated into the analysis model using the Microsoft Excel spreadsheet for benchmarking of the energy consumption and GHG emission reduction of the BEC. The model includes all available data of 10-year BEC implementation from 2009 to 2019.

In the analysis annual specific energy consumption (SEC) or energy use index (EUI) in kWh/m^2/year are used as indicators for energy efficiency. The energy unit of kWh/year is used for quantifying the energy consumption and energy savings from the BEC. The unit of ktoe/year directly converted from kWh/year is used for benchmarking of BEC achievement with the set target of the BEC program in National Energy Efficiency Plan (previously EEP2015 and now EEP2018).

GHG emission reduction is calculated in kg or ton CO_2 equivalent (kg CO_2e or t CO_2e). The GHG emission factor of kg CO_2 per kWh published by the Thailand Greenhouse Gas Management Organization (TGO) is used for conversion from energy consumption to GHG emission. The GHG emission reduction is determined by the avoided grid emission from the power generation incorporating 3% transmission and distribution losses. With latest emission factor update (year 2017), the GHG reduction factor for the BEC saving is 0.5834 kg CO_2/kWh. For the renewable energy system, emission factors of the fuels being replaced by renewable energy published by DEDE is used to calculate kg CO_2/TJ of renewable energy produced.

Step 4: Benchmarking of BEC performance

The step conducts the benchmarking and gap analysis of BEC performance with the following objectives.

- To compare the BEC performance of each building types and sizes.
- To identify how five building types comply with the BEC criteria, both individual system (BEC compliant option 1) and overall EUI (BEC compliant option 2).
- To identify the performance gap of each building types to meet the BEC criteria.

The benchmarking results provide the focus areas for technology assessment and direction for policy recommendation for BEC program enhancement in later project activities.

2.2 Activity 1.2: Streamlining of Energy and GHG Emission Baselines and Benchmarks for the Five Building Types

This section summarizes the analysis of the streamlined data from the BEC assessment database to establish energy consumption baselines and benchmarking of energy consumption and GHG emission reduction of the five building types covered in the project scope. The analysis is updated with the complete database from year 2009 to 2019.

2.2.1 Analysis of building population

From the BEC Assessment database over the BEC implementation period, from 2009 to 2019, the total number of the five BEC buildings is 506 buildings, with the total building area is 7,447,527 m^2. Breakdown of building number and area by building type can be seen in Figure 2.

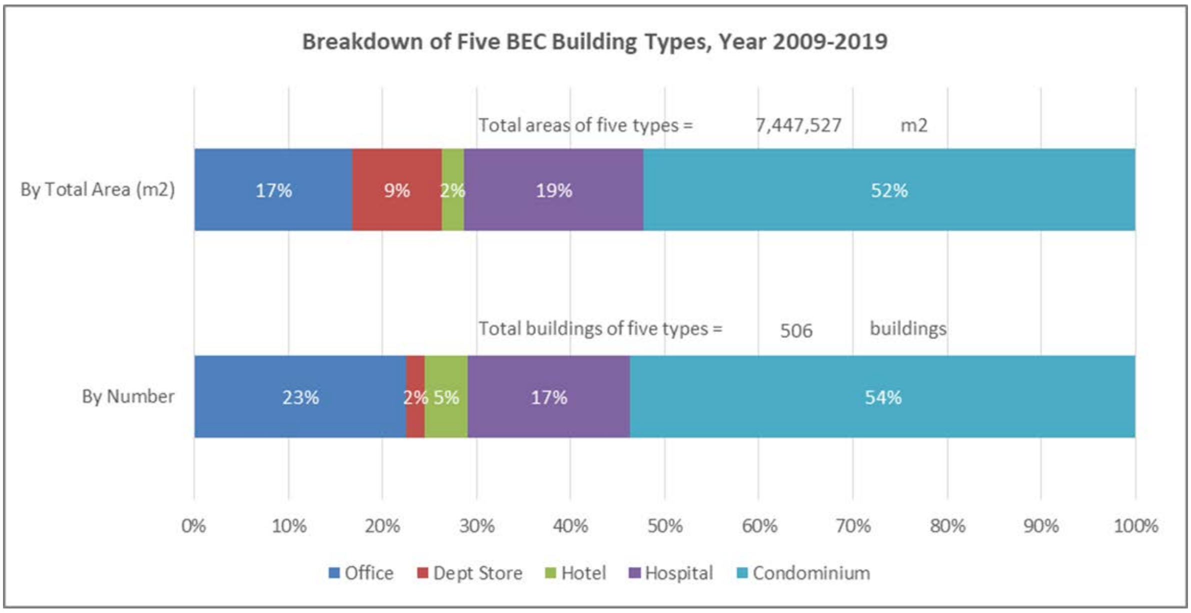


Figure 2: Breakdown of Number and Total Area by Building Type, 2009 to 2019

Of the five building types, condominium accounts for the largest share with 54% of the total number and 52% of the total building area. The office and hospital buildings follow with around 23% and 17% by numbers and 17% and 19% by total areas respectively. Despite small numbers of buildings, department store has the highest building areas per building, significantly higher than other building types, as shown in Figure 3.

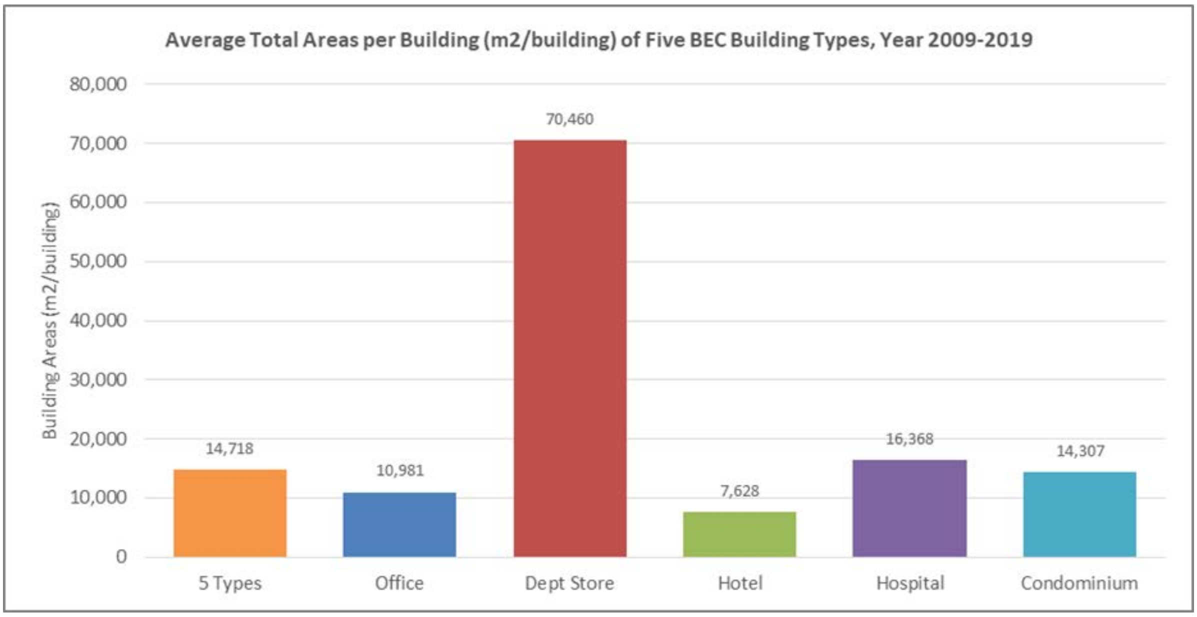


Figure 3: Average Total Area per Building of Five BEC Building Types, 2009 to 2019

Further analysis shows the histograms of total building areas of five BEC building types and area groups according to BEC 2020 (see Figure 4).

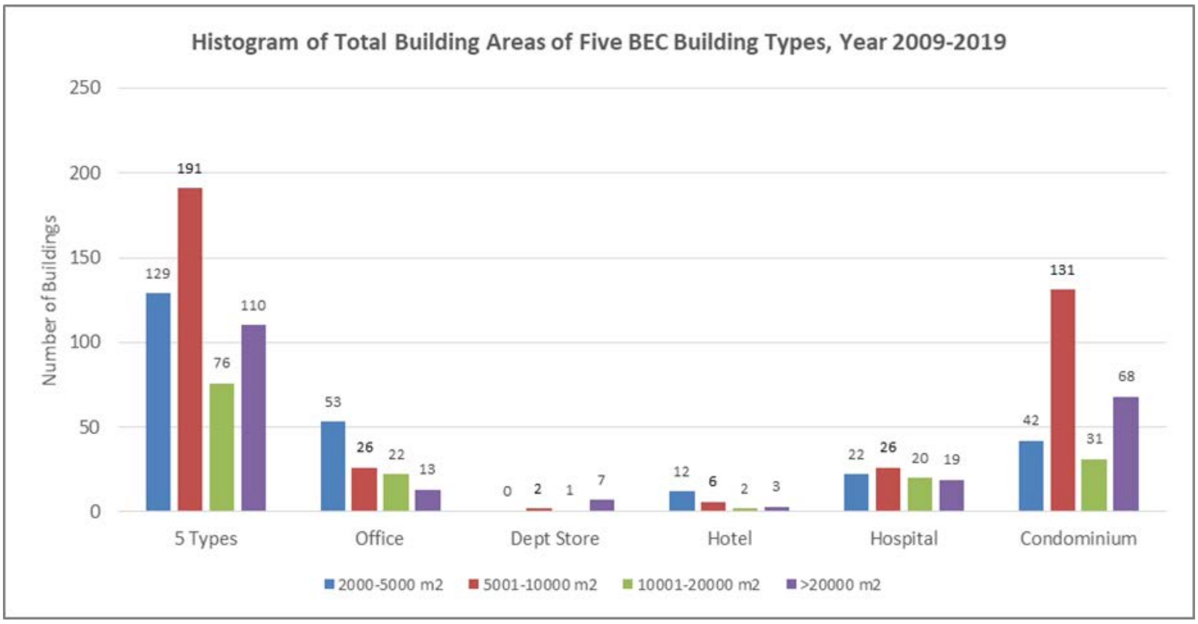


Figure 4: Histogram of Total Building Areas of Five BEC Building Types, 2009 to 2019

2.2.2 Reference baseline and benchmarking of energy consumption

Using EUIs of three scenarios from the BEC assessment database, energy consumption of reference baseline, pre-BEC assessment and post-BEC assessment of five building types from 2009 to 2019 can be calculated and shown in Figure 5.

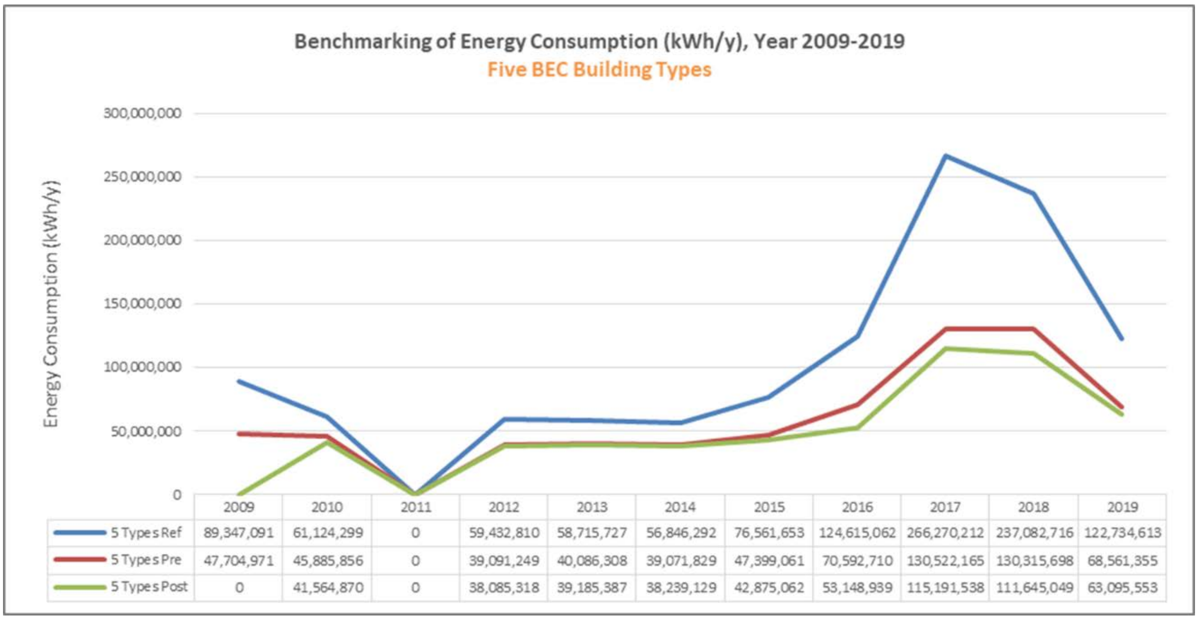
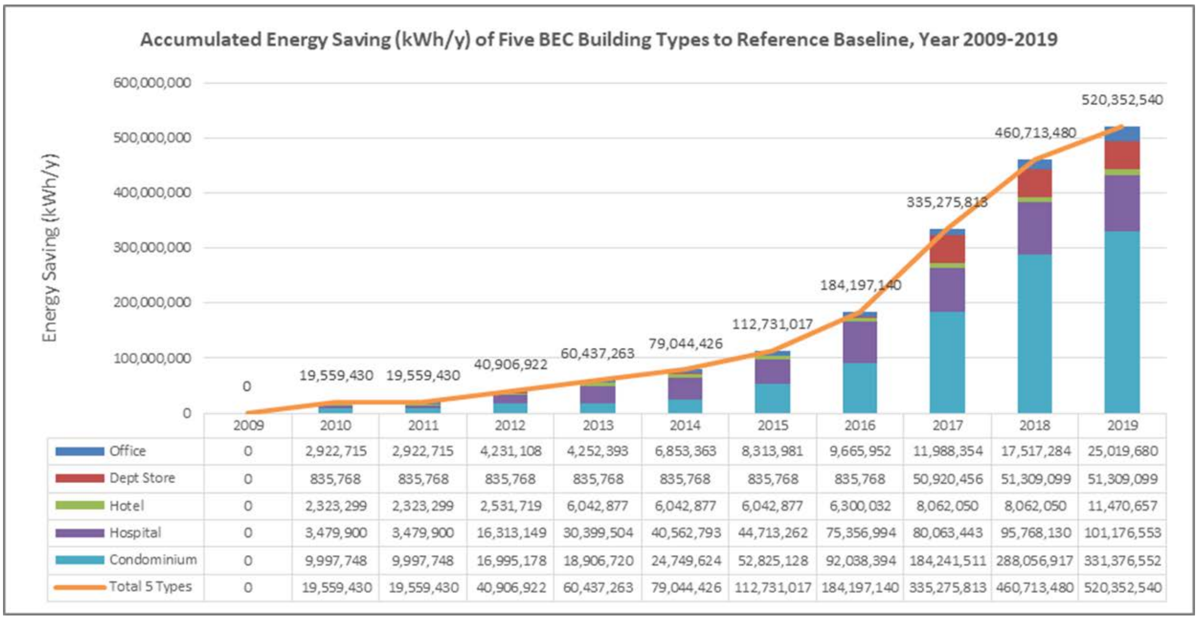


Figure 5: Benchmarking of Energy Consumption of Five BEC Building Types, 2009 to 2019

Comparing the energy consumption of the post-BEC assessment with the reference baseline, the energy savings from the BEC program can be illustrated in Figure 6.



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Office	0	2,922,715	2,922,715	4,231,108	4,252,393	6,853,363	8,313,981	9,665,952	11,988,354	17,517,284	25,019,680
Dept Store	0	835,768	835,768	835,768	835,768	835,768	835,768	835,768	50,920,456	51,309,099	51,309,099
Hotel	0	2,323,299	2,323,299	2,531,719	6,042,877	6,042,877	6,042,877	6,300,032	8,062,050	8,062,050	11,470,657
Hospital	0	3,479,900	3,479,900	16,313,149	30,399,504	40,562,793	44,713,262	75,356,994	80,063,443	95,768,130	101,176,553
Condominium	0	9,997,748	9,997,748	16,995,178	18,906,720	24,749,624	52,825,128	92,038,394	184,241,511	288,056,917	331,376,552
Total 5 Types	0	19,559,430	19,559,430	40,906,922	60,437,263	79,044,426	112,731,017	184,197,140	335,275,813	460,713,480	520,352,540

Figure 6: Accumulated Energy Savings of Five BEC Building Types, 2009-2019

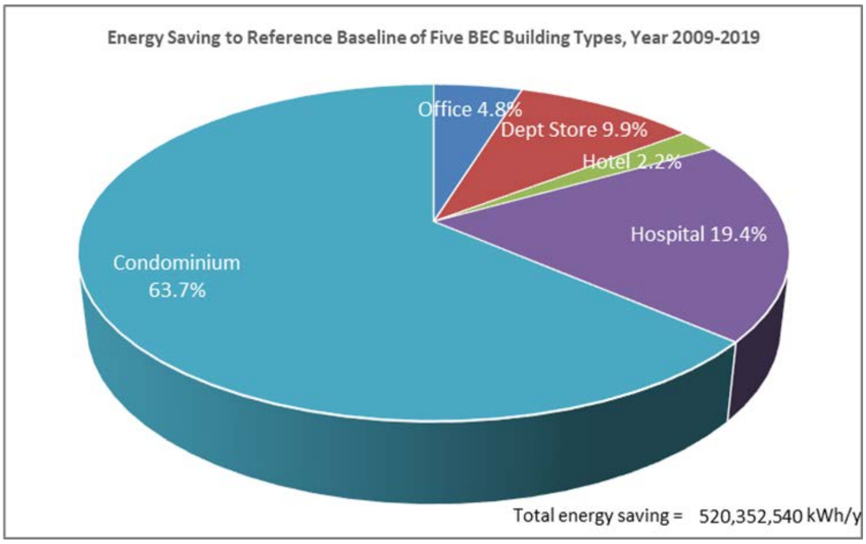


Figure 7: Breakdown of Energy Savings from Five BEC Building Types, 2009-2019

From the above charts, BEC implementation results in total energy savings in the year 2019 of 520.4 MWh/year compared with the reference baseline. Condominium by far contributes to the most energy saving portion among the five building types, accounting for 64% of the total energy savings.

2.2.3 Benchmarking of energy saving from BEC against the EEP2015 target

The accumulated energy saving of BEC implementation to five building types can result to the energy saving of 44.8 ktoe/year in 2019, well above the target of 21 ktoe/year prescribed in the Energy Efficiency Plan (EEP 2015).

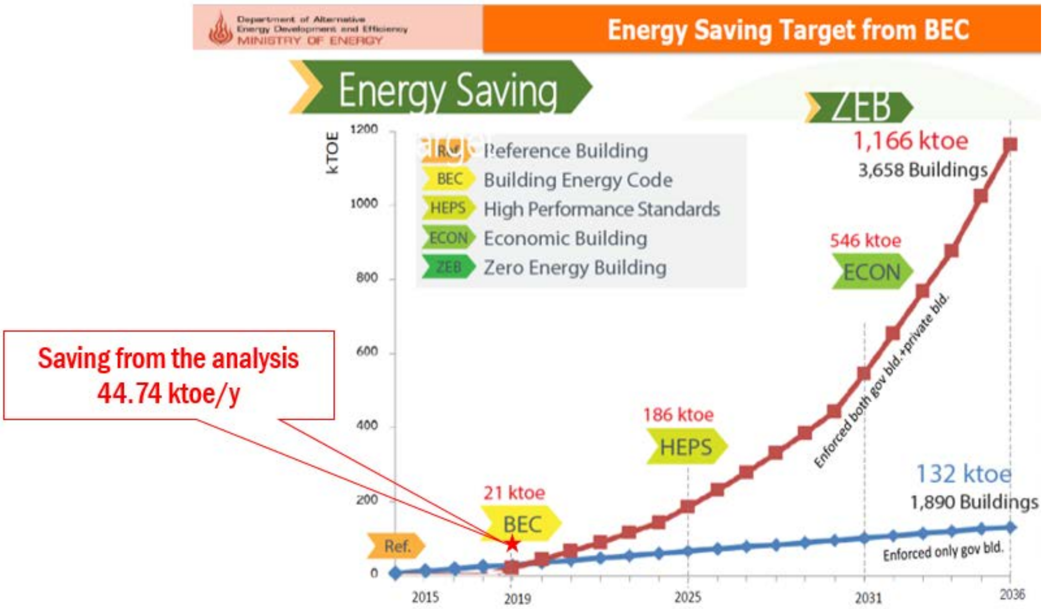
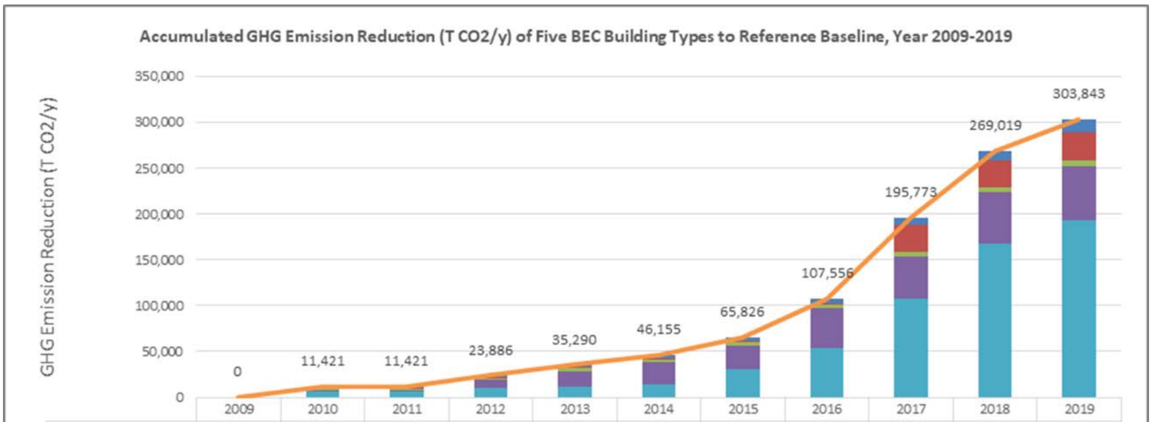


Figure 8: Benchmarking of Energy Saving from BEC against the EEP2015 Target

2.2.4 GHG emission reduction[n from BEC implementation

Applying the grid emission factor to the energy saving, BEC implementation of five building types can avoid GHG emission by the grid in the year 2019 at 303,843 tCO_2/year compared with the reference baseline scenario.



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Office	0	1,707	1,707	2,471	2,483	4,002	4,855	5,644	7,000	10,229	14,609
Dept Store	0	488	488	488	488	488	488	488	29,733	29,960	29,960
Hotel	0	1,357	1,357	1,478	3,529	3,529	3,529	3,679	4,708	4,708	6,698
Hospital	0	2,032	2,032	9,526	17,751	23,685	26,109	44,002	46,750	55,921	59,079
Condominium	0	5,838	5,838	9,924	11,040	14,452	30,846	53,743	107,582	168,201	193,497
Total 5 Types	0	11,421	11,421	23,886	35,290	46,155	65,826	107,556	195,773	269,019	303,843

Figure 9: Accumulated GHG Emission Reduction of Five BEC Building Types, 2009-2019

2.3 Activity 1.3: Simulation of Energy and GHG Benchmarks

The activity further utilizes the streamlined data from the BEC assessment database for benchmarking and gap analysis of BEC performance over 10-year of BEC implementation from 2009-2019.

2.3.1 Benchmarking of the EUI Trend

The following line graph (Figure 10) shows the average energy use intensity (EUIs) of all five building types (Pre-BEC assessment) over 10 years from 2009 to 2019. The graph indicate the decreasing trend of the average EUI with 15% reduction over ten years from 93.3 kWh/m^2-y to 79.6 kWh/m^2-y.

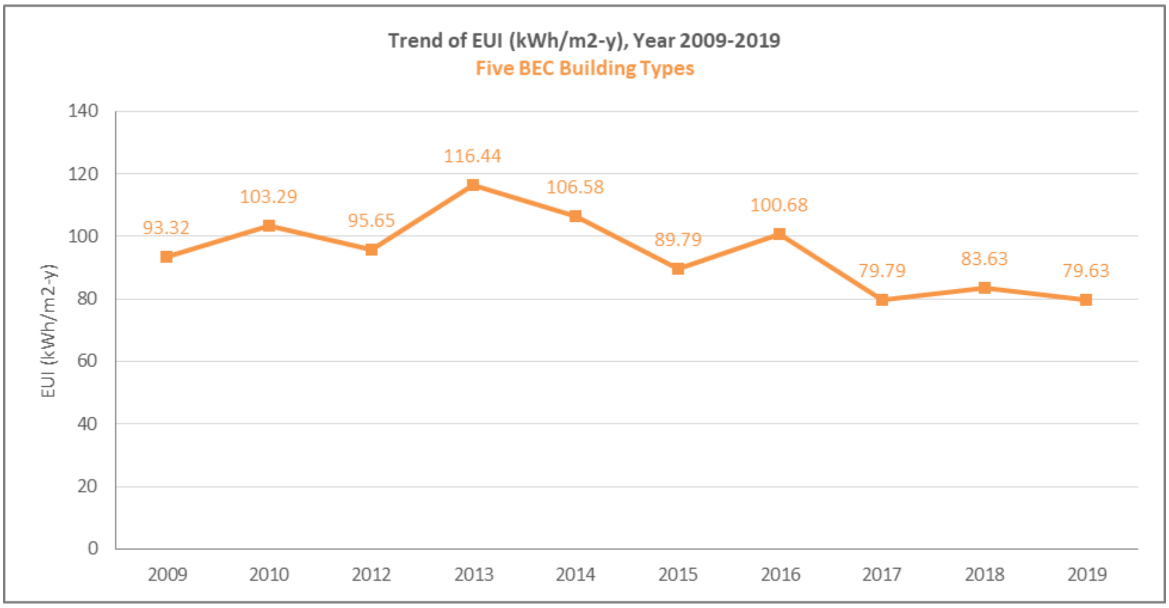


Figure 10: EUI Trend of Five BEC Building Types, 2009-2019

The trends and profiles of EUI of each building types are illustrated as Figure 11 to Figure 15 as the following.

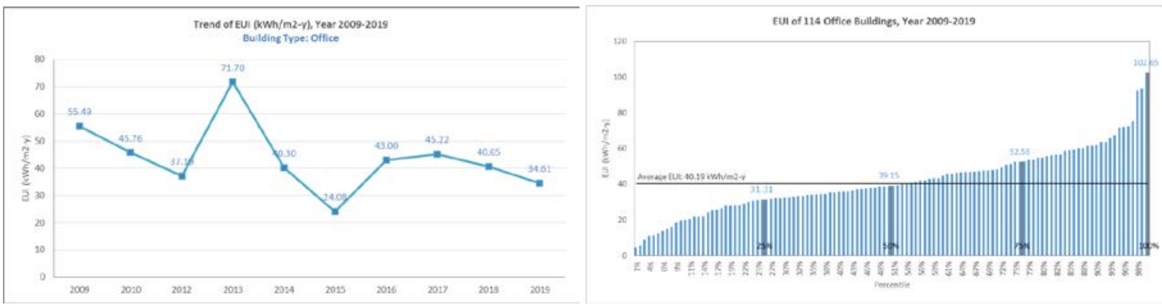


Figure 11: EUI Trend and Profile of Office, 2009-2019

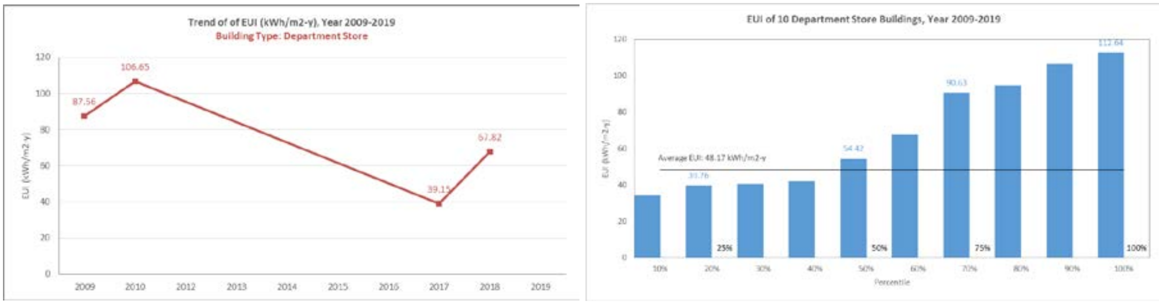


Figure 12: EUI Trend and Profile of Department Store, 2009-2019

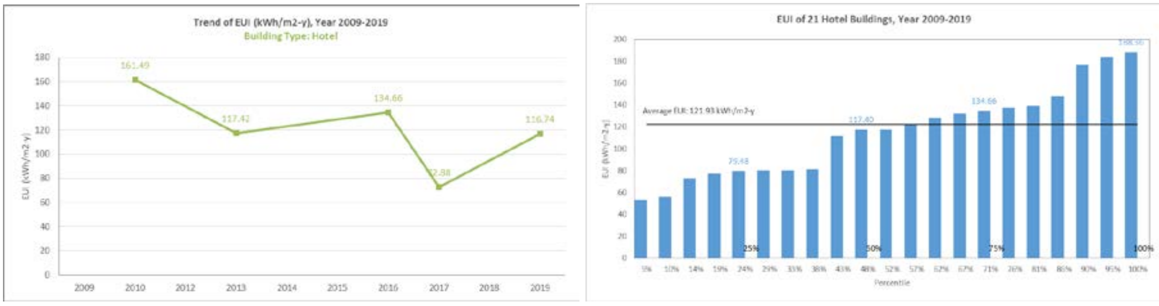


Figure 13: EUI Trend and Profile of Hotel, 2009-2019

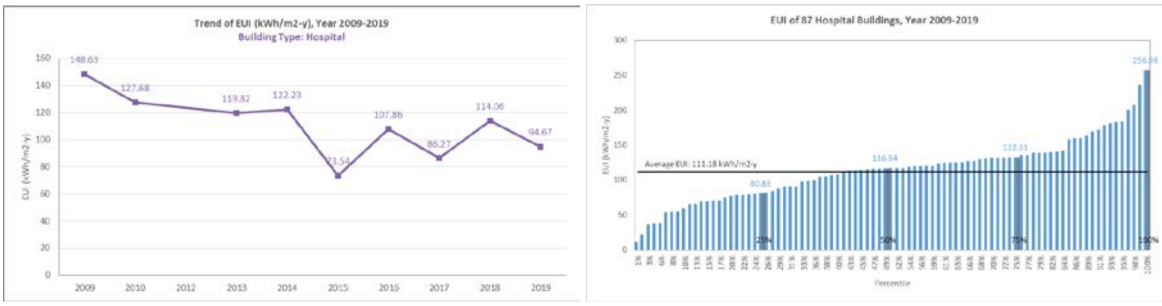


Figure 14: EUI Trend and Profile of Hospital, 2009-2019

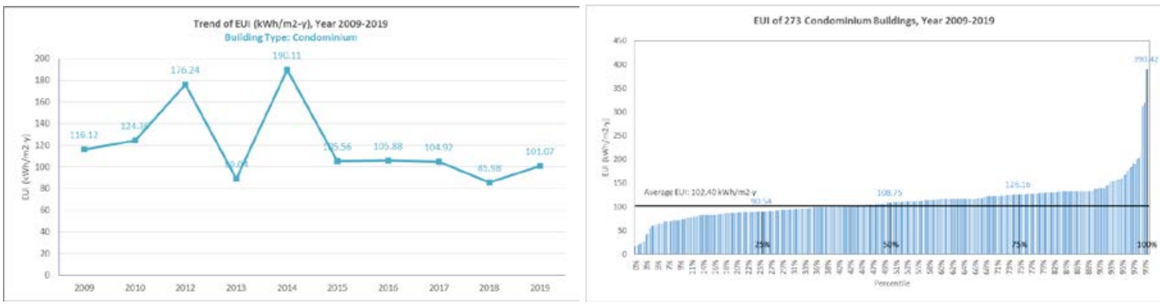


Figure 15: EUI Trend and Profile of Condominium, 2009-2019

2.3.2 Benchmarking of EUI to the reference baseline

Shown in Figure 16 are the EUIs of five building types with three scenarios of reference baseline, pre-BEC assessment and post-BEC assessment. It is obvious that the building operating hours have direct impact on the EUI as the three building types (hotel, hospital and condominium) with 24 hours of operation consume more energy than office and department store with lower operating hours. EUIs of all building types both pre and post-BEC assessment are much lower than the reference EUI.

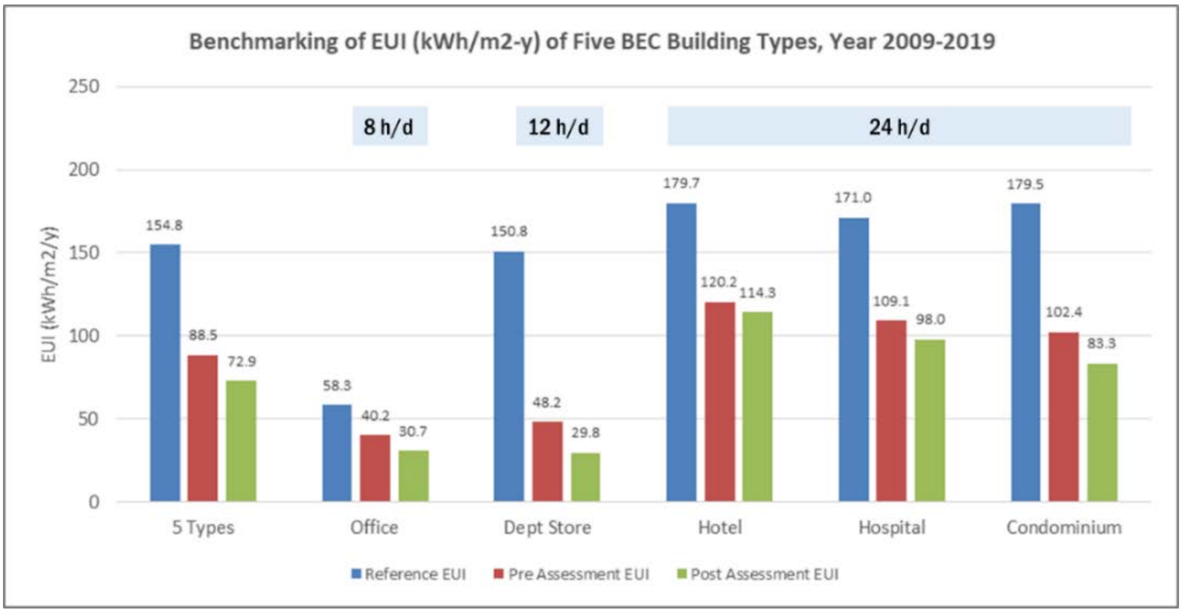


Figure 16: Benchmarking of EUI of Five Building Types, 2009-2019

Table 1: EUI Profile of Five Building Types Benchmarking against Reference EUI, 2009-2019

Building Type	No. of Buildings	EUI Ranges (kWh/m2-y)					Reference EUI
		1%-25%	26%-50%	51%-75%	76%-100%	Average	
Office	114	4.48-31.31	31.66-39.15	39.25-52.56	52.81-102.65	40.19	58.26
Department Store	10	34.35-39.76	40.54-54.42	67.82-90.63	94.58-112.64	48.17	150.81
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

2.3.3 BEC compliance of five building types

The following figures summarize the analysis of overall compliance percentage of five building types over 10-year of BEC assessment database. The scenario of applying previous BEC2009 criteria and recently announced BEC 2020 criteria are compared.

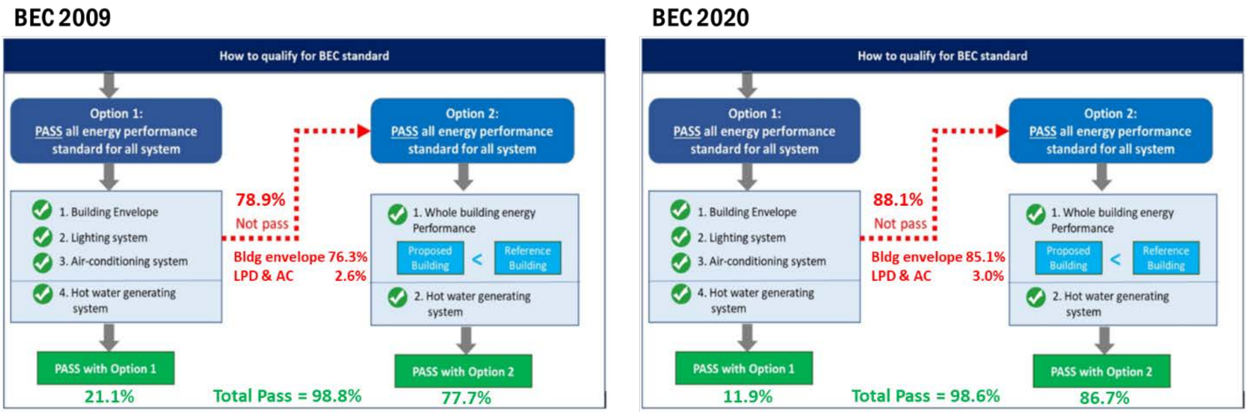


Figure 17: Compliance Percentage of Five Building Types using BEC 2009 and BEC 2020 Criteria, 2009-2019

With both BEC 2009 and BEC 2020 criteria, majority of the buildings fail to comply with the individual requirements of option 1 (21% for BEC 2009 and less than 12% for BEC 2020). However most of the failed buildings from option 1 are able to pass the overall EUI criteria of option 2, making the total passing of both BEC 2009 and BEC 2020 of almost 99%.

Most option 1 non-compliances are due to the building envelope's OTTV and RTTV criteria. Only 3% of the buildings fail the air conditioning (AC) or lighting power density (LPD) criteria.

From detailed checking of building data in recent years from 2013 to 2019 when the BEC processes are fully implemented, the BEC compliance percentages are little improved compared to 2009-2019. Failed percentage of the air conditioning (AC) or lighting power density (LPD) criteria is none for BEC 2009 and 0.8% (only 1 case) for BEC 2020.

The following charts in Figure 18 to Figure 20 benchmarks the average wattage per square meter of OTTV, RTTV and LPD of five building types (pre-BEC assessment) against the BEC 2009 and BEC 2020 criteria. Note the unavailable details of air conditioning data in the BEC assessment database.

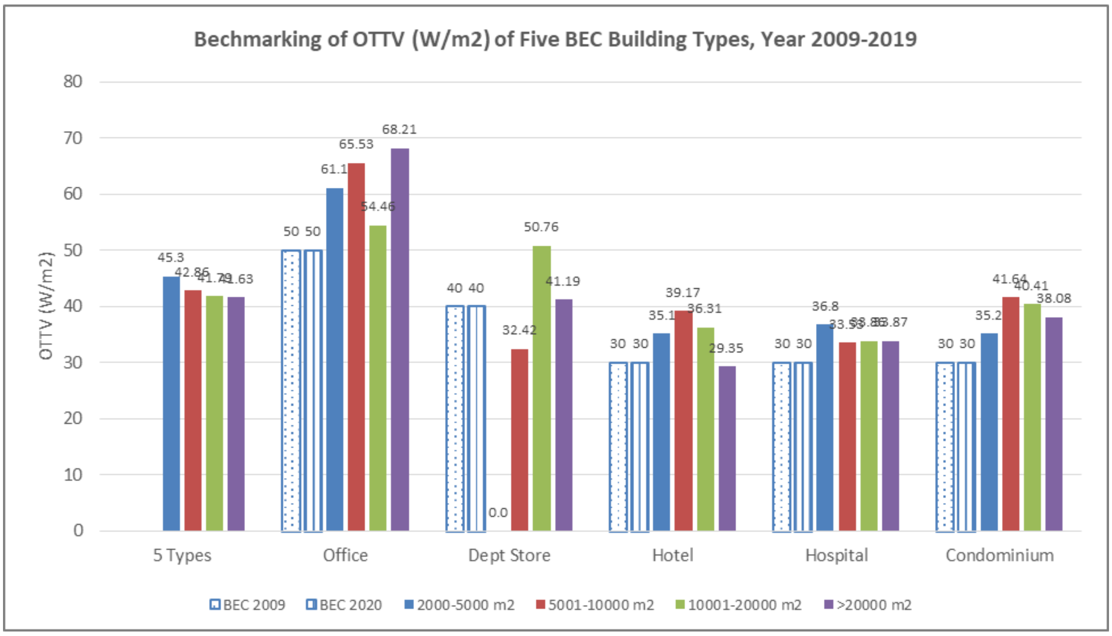


Figure 18: Benchmarking of OTTV of Five Building Types, 2009-2019

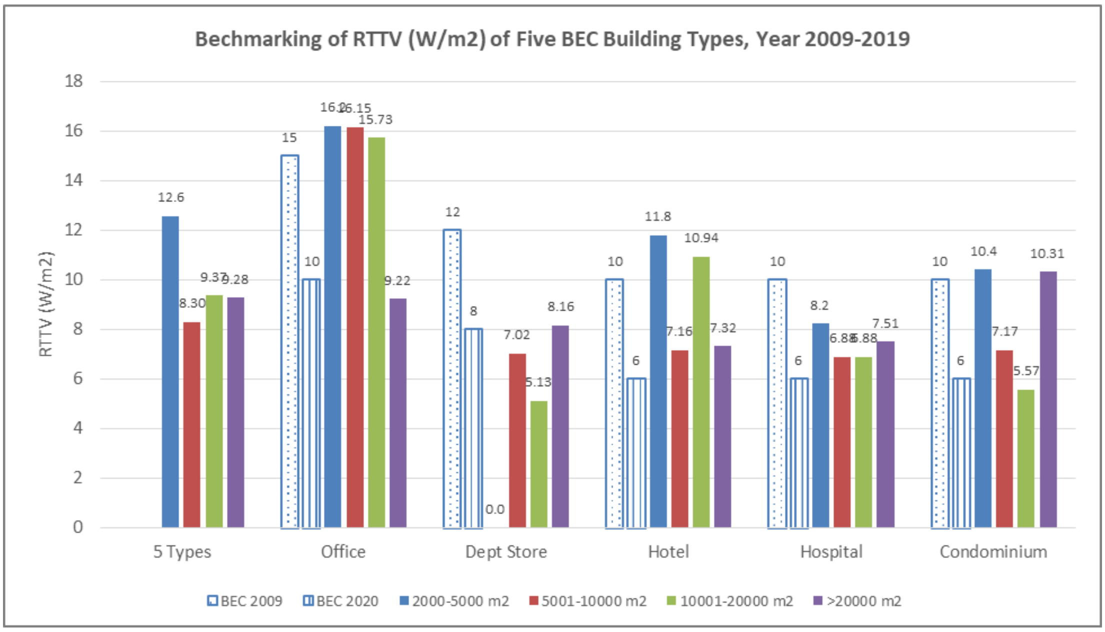


Figure 19: Benchmarking of RTTV of Five Building Types, 2009-2019

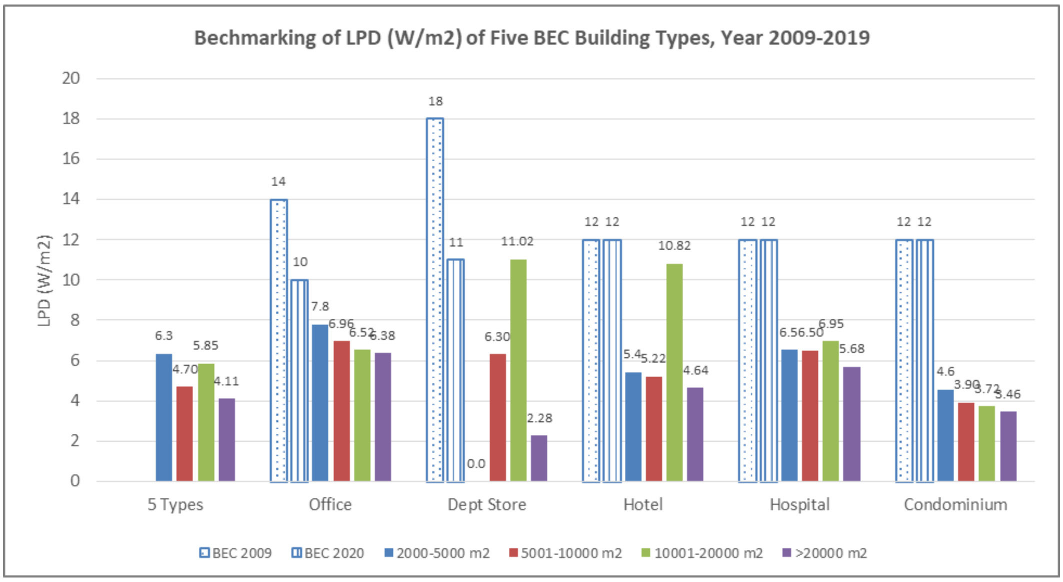


Figure 20: Benchmarking of LPD of Five Building Types, 2009-2019

Noted from the above charts (Figure 18 to Figure 20) the average OTTV of most building types and sizes fail to comply with OTTV criteria. For RTTV only hospital can meet BEC 2009 criteria on all building sizes. With the new RTTV criteria of BEC 2020, most buildings will fail to comply. For the lighting all building types and sizes can pass the LPD criteria despite more stringent BEC 2020.

The following Table 2 show the detailed compliance rate and causes of non-compliance for each of the five building types.

Table 2: Breakdown of BEC compliance and Non-compliance of Five Building Types, 2009-2019

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%**

BEC Compliance of Five Building Types (BEC 2020)	Office	Dept Store	Hotel	Hospital	Condo	Total
BEC Compliance Option 1						
Pass all criteria	13.5%	30.0%	9.1%	17.6%	8.9%	**11.9%**
Pass OTTV-RTTV but fail to AC or LPD	8.1%	0.0%	0.0%	1.2%	1.9%	**3.0%**
Pass OTTV but fail to RTTV	14.4%	20.0%	40.9%	18.8%	8.2%	**13.1%**
Fail OTTV but pass RTTV	21.6%	20.0%	13.6%	27.1%	47.6%	**36.2%**
Fail both OTTV-RTTV	42.3%	30.0%	36.4%	35.3%	33.5%	**35.8%**
BEC Compliance Option 2						
Fail option 1 but pass overall EUI criteria	82.9%	70.0%	86.4%	82.4%	90.3%	**86.7%**
Fail option 1 and fail overall EUI criteria	3.6%	0.0%	4.5%	0.0%	0.7%	**1.4%**
Total BEC compliance buildings	**96.4%**	**100.0%**	**95.5%**	**100.0%**	**99.3%**	**98.6%**

At this point it is clearly seen that the BEC envelope criteria of OTTV and RTTV are the most difficult to comply. Building systems including air conditioning, lighting, hot water and renewable energy have no impact on the BEC compliance. Most systems available in the Thai market have met or even exceeded the BEC energy performance criteria. Energy-efficient air conditioning and lighting are well aware and included in building design.

2.3.4 Gap analysis of OTTV & RTTV compliance

The pre-BEC assessment data of each building types are used for the gap analysis to analyze the OTTV, RTTV passing rates of five building types over 10-year span of 2009-2019.

OTTV compliance of five building types

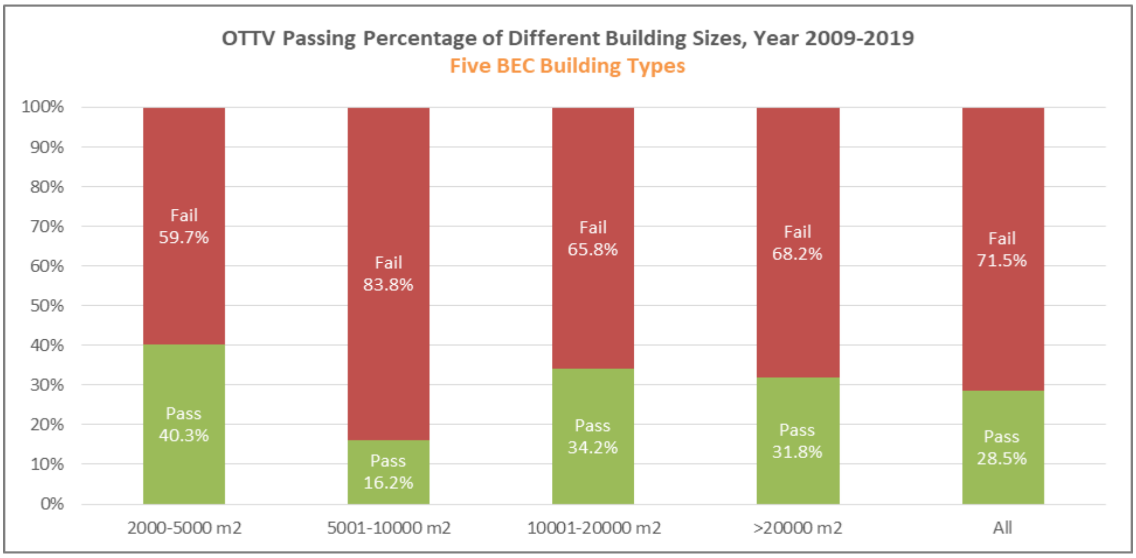


Figure 21: OTTV Compliance of Five Building Types to BEC 2009, 2009-2019

Notes on OTTV compliance of five building types:

- OTTV passing rates are low, below 50% on all sizes.
- From detailed verification, OTTV passing rates of the recent years (2013-2019) drop a few percent compared to overall data of 2009-2019.

OTTV compliance of office

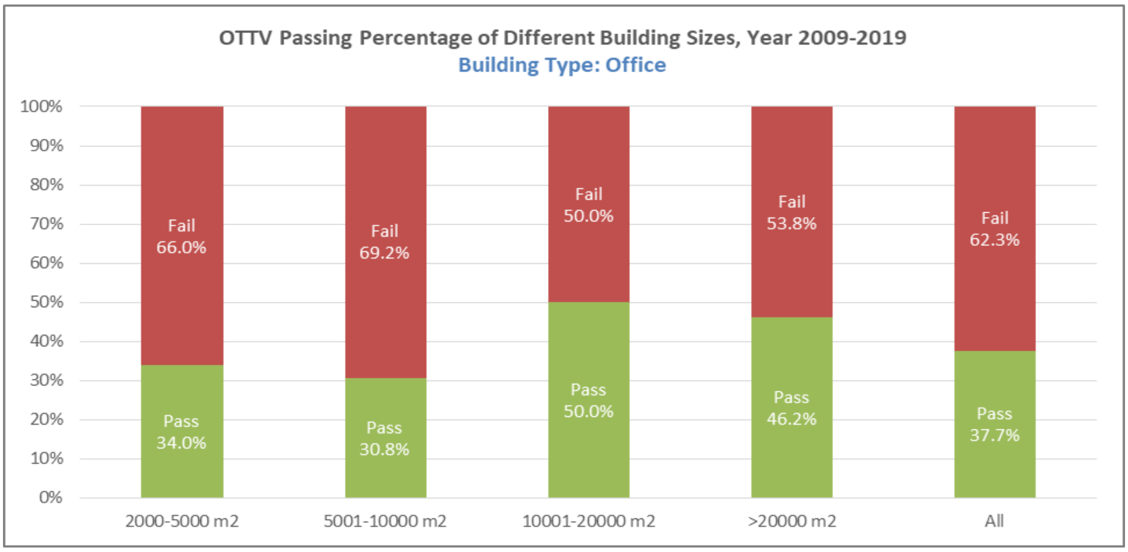


Figure 22: OTTV Compliance of Office to BEC 2009, 2009-2019

Notes on OTTV compliance of office:

- Low OTTV passing rates < 50% on most sizes.

- OTTV passing of medium size (10,001-20,000 m^2) is better than other sizes and significantly improves over recent years.

OTTV compliance of department store

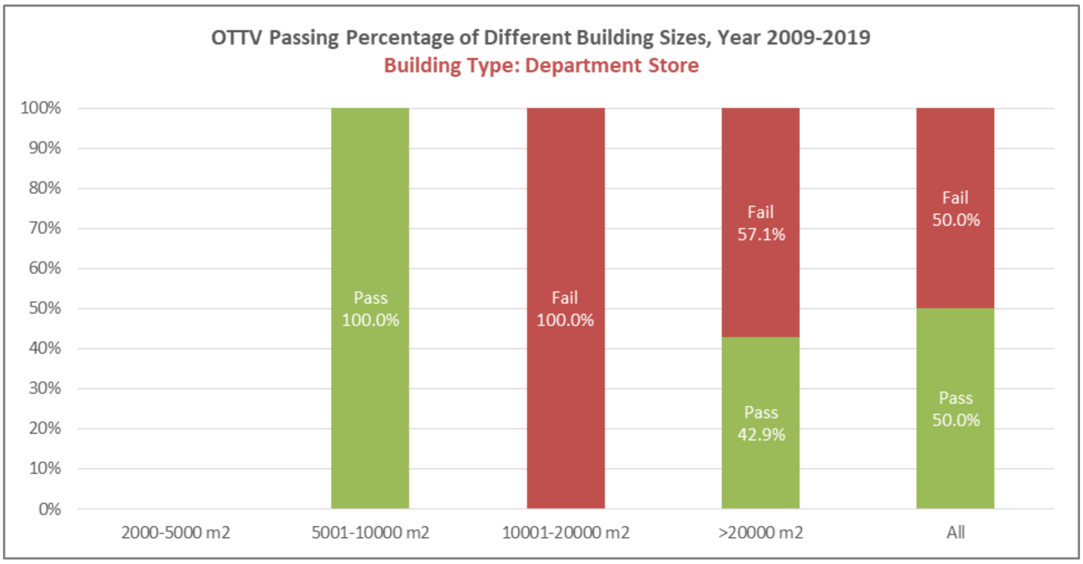


Figure 23: OTTV Compliance of Department Store to BEC 2009, 2009-2019

Notes on OTTV compliance of department store:
- Overall OTTV passing rate is moderate (50%) and improves over recent years.

OTTV compliance of hotel

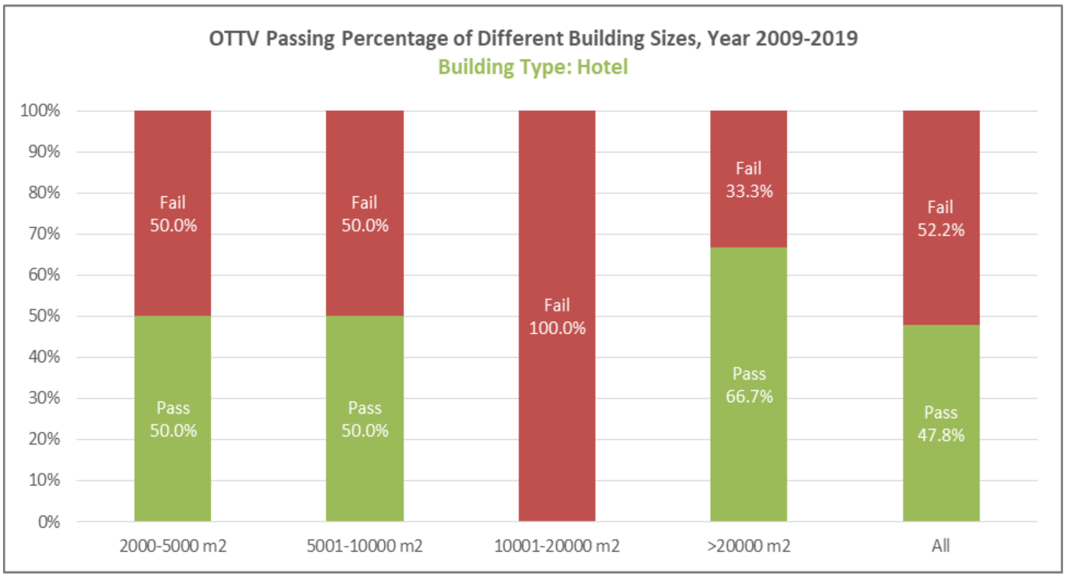


Figure 24: OTTV Compliance of Hotel to BEC 2009, 2009-2019

Notes on OTTV compliance of hotel:
- Overall OTTV passing rate is moderate (50%) and improves over recent years.

OTTV compliance of hospital

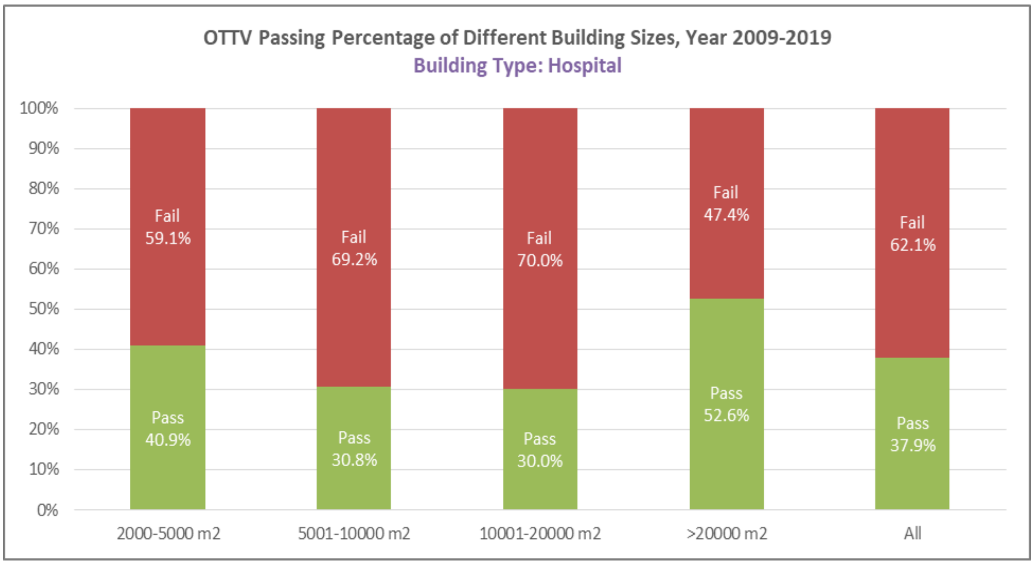


Figure 25: OTTV Compliance of Hospital to BEC 2009, 2009-2019

Notes on OTTV compliance of hospital:

- OTTV passing rates are low on most sizes and unchanged over recent years.

OTTV compliance of condominium

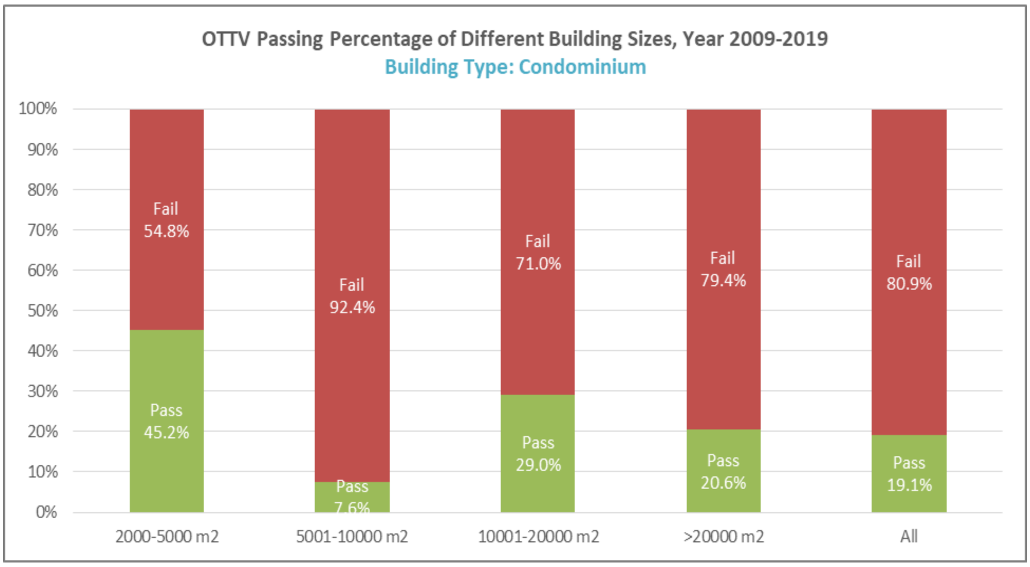


Figure 26: OTTV Compliance of Condominium to BEC 2009, 2009-2019

Notes on OTTV compliance of condominium:

- Overall OTTV passing rates is very low <20%. The lowest of five building types.
- No improvement over recent years.

RTTV compliance of five building types

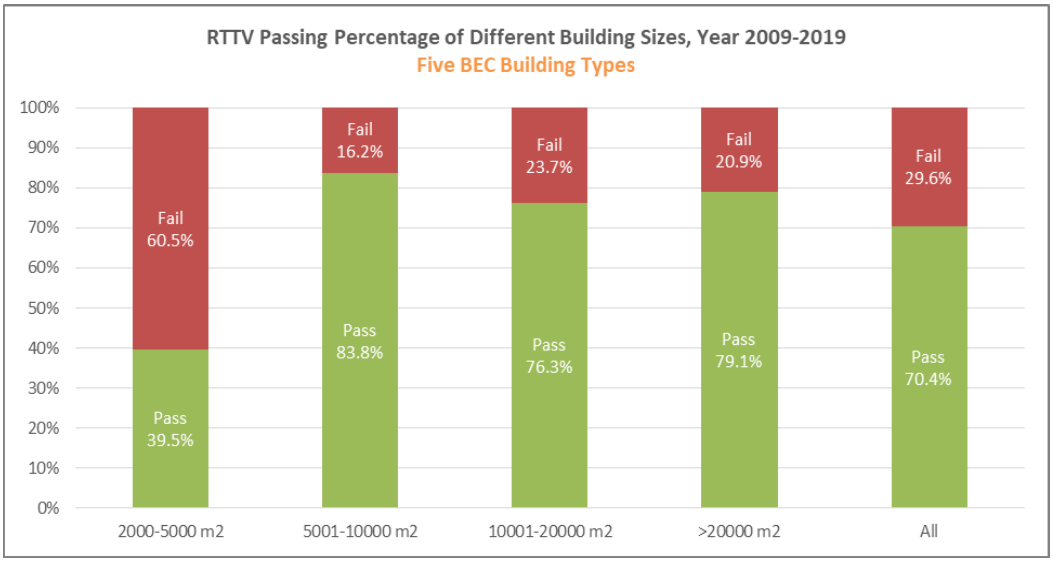


Figure 27: RTTV Compliance of Five Building Types to BEC 2009, 2009-2019

Notes on RTTV compliance of five building types:

- RTTV passing rate are much higher than OTTV.
- RTTV passing rate of small size (2,000-5,000 m^2) is significantly lower than other sizes.

RTTV compliance of office

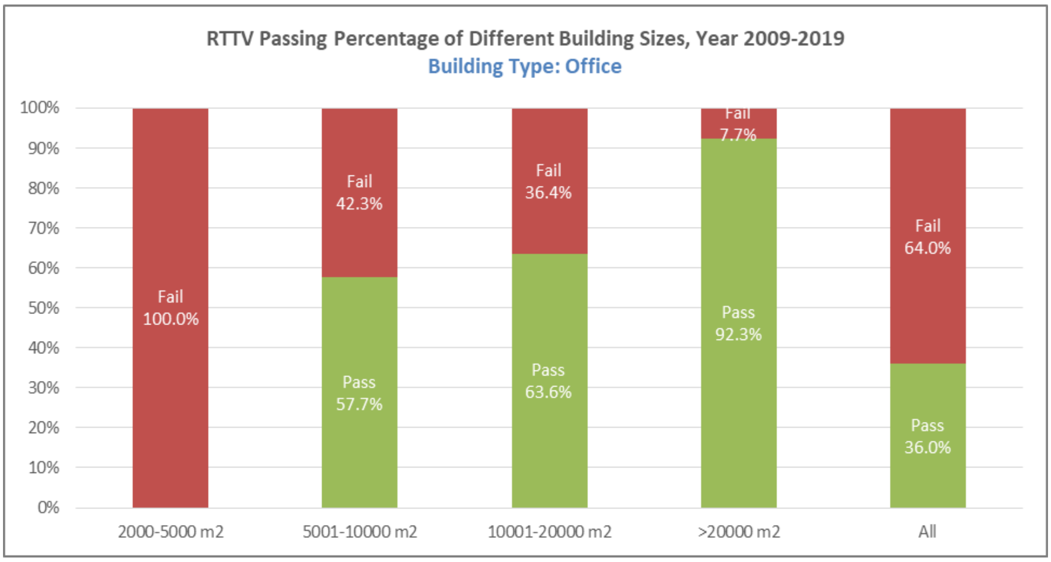


Figure 28: RTTV Compliance of Office to BEC 2009, 2009-2019

Notes on RTTV compliance of office:

- Low RTTV passing rates on small to medium sizes (<20000 m^2).
- All fails on smallest size of 2,000-5,000 m^2.

RTTV compliance of department store

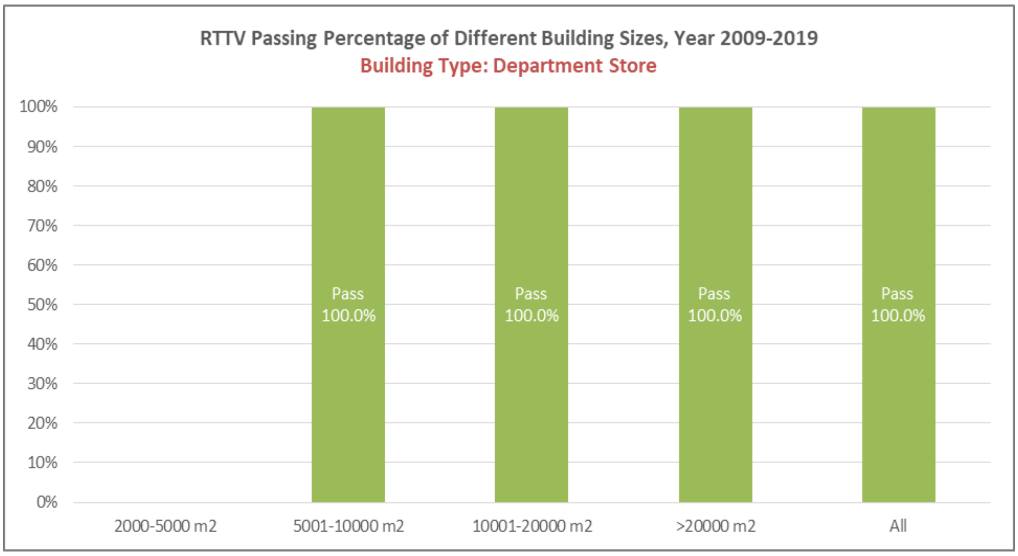


Figure 29: RTTV Compliance of Department Store to BEC 2009, 2009-2019

Notes on RTTV compliance of department store:

- 100% RTTV passing rates on all sizes.

RTTV compliance of hotel

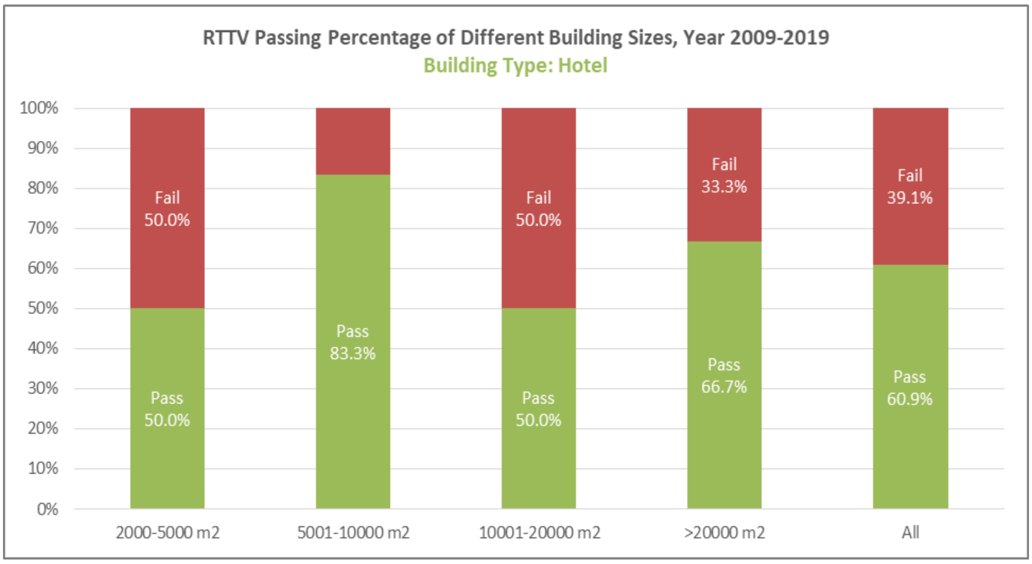


Figure 30: RTTV Compliance of Hotel to BEC 2009, 2009-2019

Notes on RTTV compliance of hotel:

- Moderate RTTV passing rates (>50%) on all sizes.

RTTV compliance of hospital

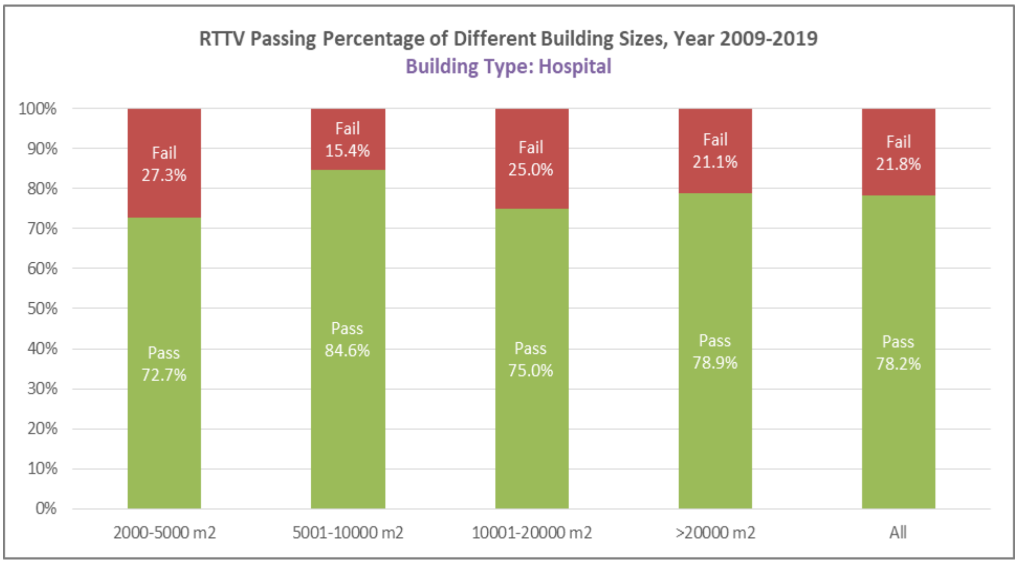


Figure 31: RTTV Compliance of Hospital to BEC 2009, 2009-2019

Notes on RTTV compliance of hospital:

- RTTV passing rates are high (>70%) on all sizes.

RTTV compliance of condominium

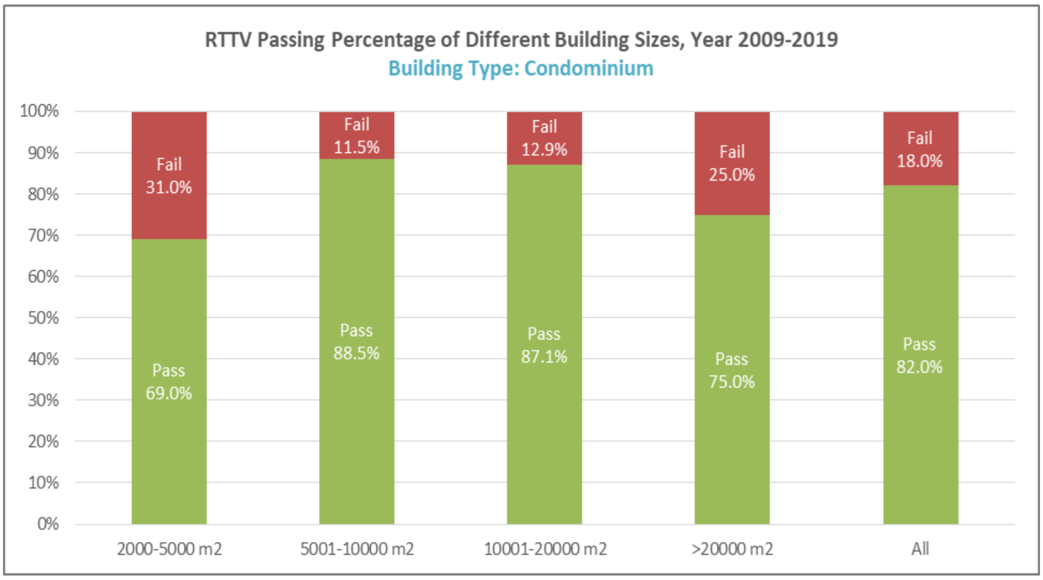


Figure 32: RTTV Compliance of Condominium to BEC 2009, 2009-2019

Notes on RTTV compliance of condominium:

- RTTV passing rates are high (>75%) on most sizes.
- Lower RTTV passing rate on small size (2,000-5,000 m^2) compared with other sizes.

2.3.5 Analysis of OTTV & RTTV distribution profile

Adding to the gap analysis, distribution profiles of the OTTV and RTTV (pre-BEC assessment) of five building types over ten years of BEC implementation are developed (see Figure 33 to Figure 42). The OTTV and RTTV profiles are benchmarked against the BEC 2009 and BEC 2020 criteria to see how these building populations could be improved to meet the BEC requirements.

Each column bar on the profile graphs represents the OTTV or RTTV of each building. The dark bars indicate the values at 25, 50, 75 and 100 percentiles. The red bars mark where the last OTTV, RTTV values just meet the OTTV and RTTV criteria to indicate the compliant percentage of the building population.

OTTV distribution profile

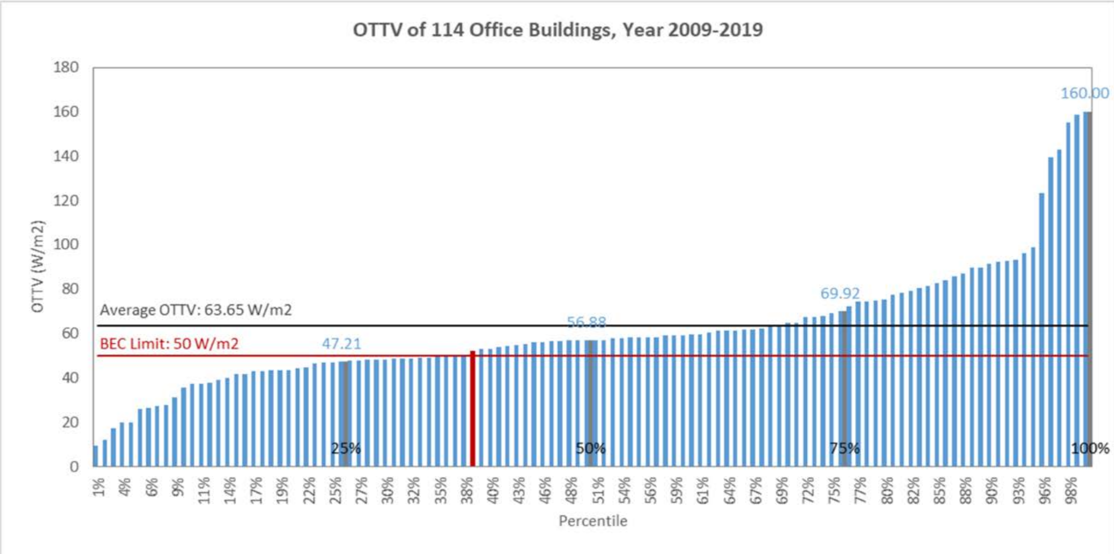


Figure 33: OTTV Profile of Office, 2009-2019

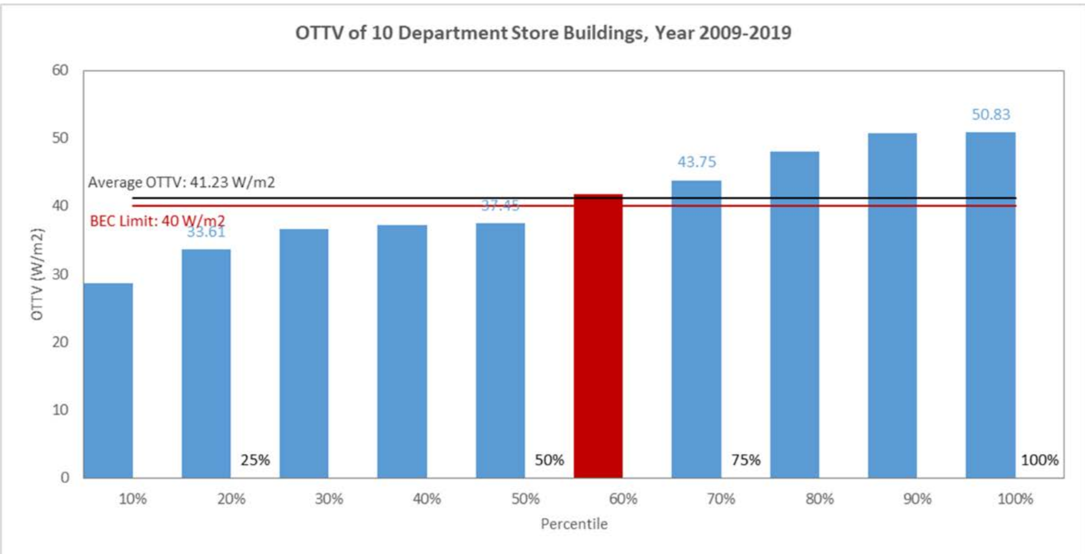


Figure 34: OTTV Profile of Department Store, 2009-2019

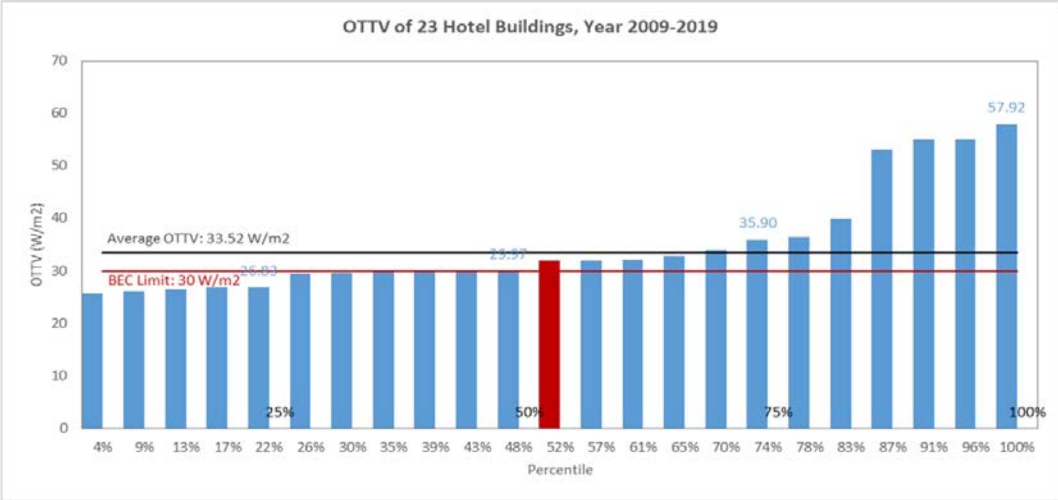


Figure 35: OTTV Profile of Hotel, 2009-2019

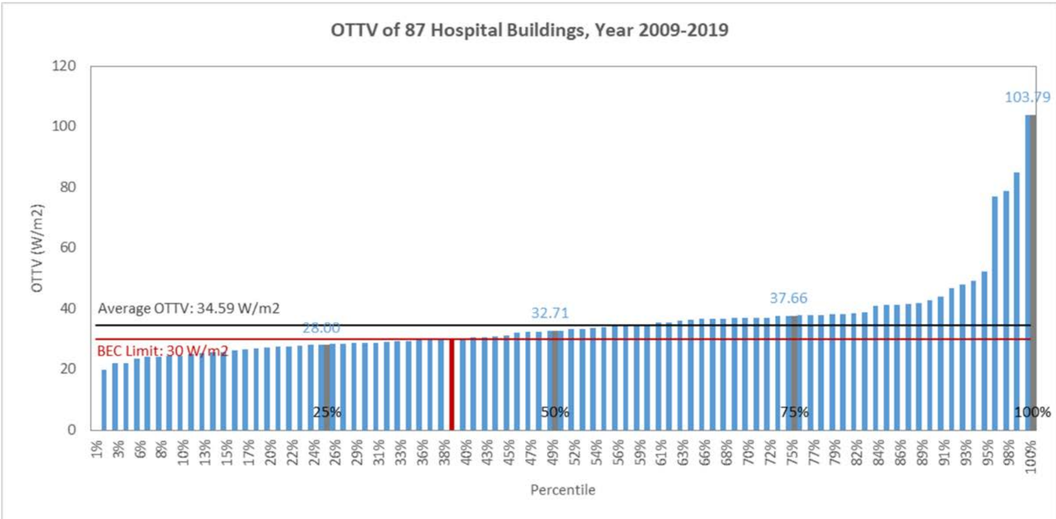


Figure 36: OTTV Profile of Hospital, 2009-2019

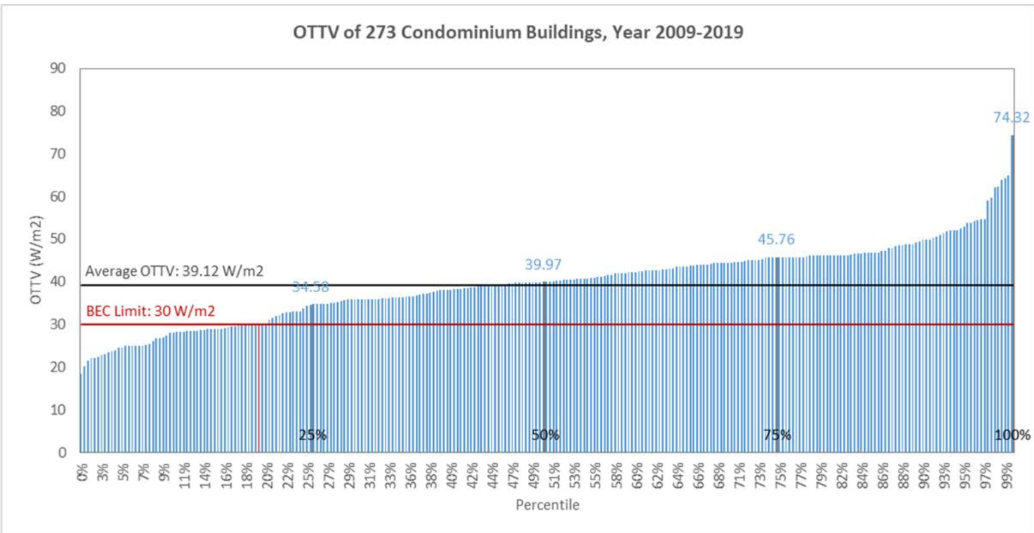


Figure 37: OTTV Profile of Condominium, 2009-2019

RTTV distribution profile

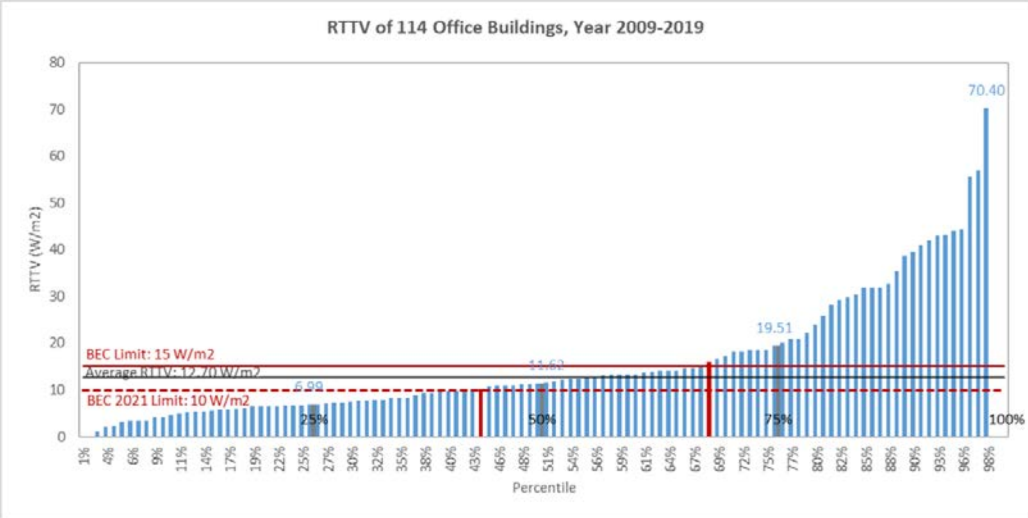


Figure 38: RTTV Profile of Office, 2009-2019

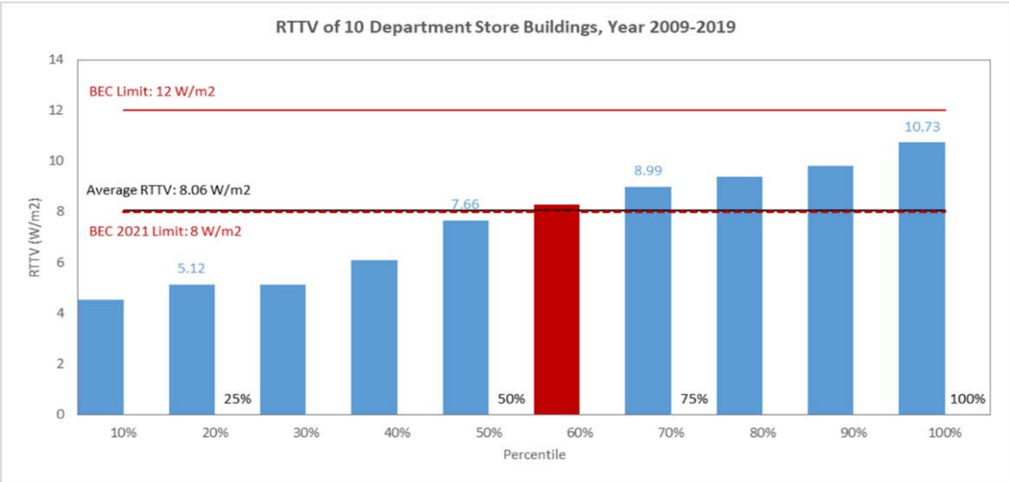


Figure 39: RTTV Profile of Department Store, 2009-2019

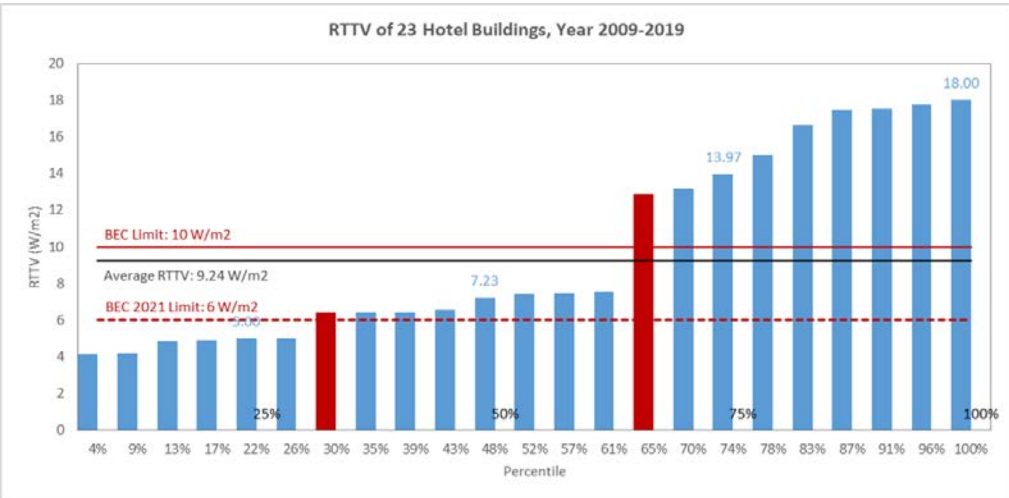


Figure 40: RTTV Profile of Hotel, 2009-2019

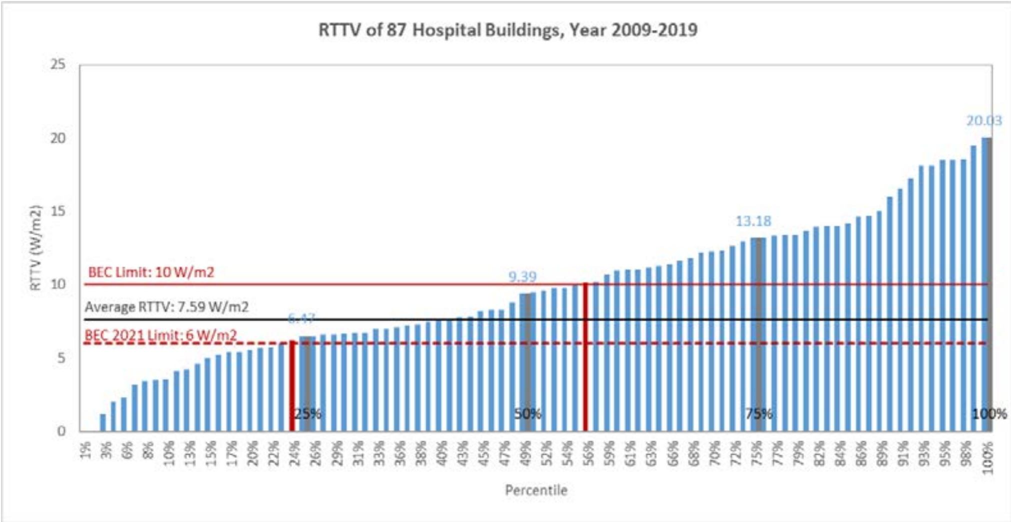


Figure 41: RTTV Profile of Hospital, 2009-2019

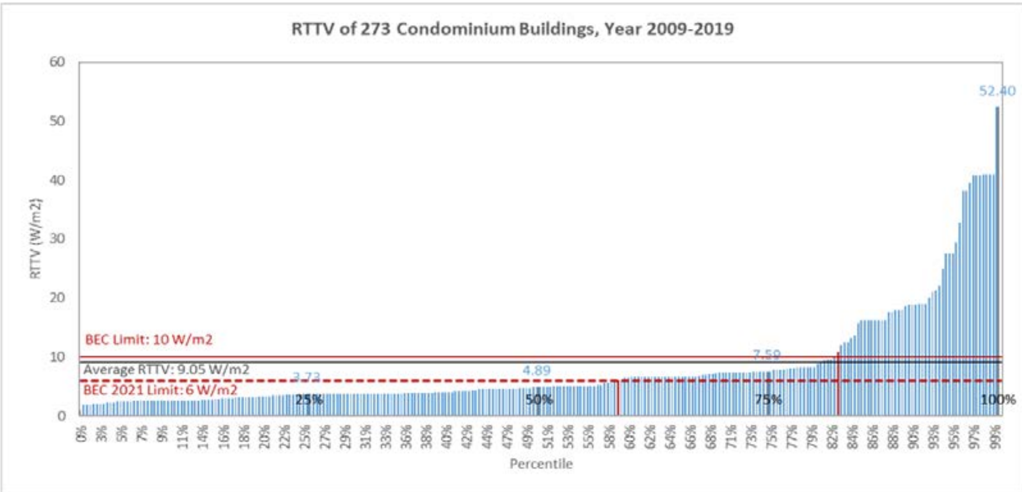


Figure 42: RTTV Profile of Condominium, 2009-2019

Table 3 and Table 4 provide the key summary from the OTTV and RTTV distribution profiles of five building types.

Table 3: Summary of OTTV Profile of Five Building Types, 2009-2019

Building Type	No. of Buildings	OTTV Ranges (W/m^2)					Percentile at BEC Limit	
		1%-25%	26%-50%	51%-75%	76%-100%	Average	BEC2009	BEC2020
Office	114	9.46-47.21	47.90-56.88	56.95-69.92	72.19-160.0	63.65	37.7%	37.7%
Department Store	10	28.70-33.61	36.57-37.45	41.71-43.75	48.03-50.83	41.23	50.0%	50.0%
Hotel	23	25.60-26.83	29.40-29.97	32.00-35.9	36.35-57.92	33.52	47.8%	47.8%
Hospital	87	20.00-28.00	28.26-32.71	32.73-37.66	37.83-103.79	34.59	37.9%	37.9%
Condominium	273	18.39-34.58	34.78-39.97	40.00-45.76	45.77-74.32	39.12	19.0%	19.0%

Table 4: Summary of RTTV Profile of Five Building Types, 2009-2019

Building Type	No. of Buildings	RTTV Ranges (W/m^2)					Percentile at BEC Limit	
		1%-25%	26%-50%	51%-75%	76%-100%	Average	BEC2009	BEC2020
Office	114	1.20-6.99	7.00-11.42	11.62-19.51	20.03-70.4	12.70	67.5%	42.1%
Department Store	10	4.52-5.12	5.13-7.66	8.27-8.99	9.37-10.73	8.06	100.0%	50.0%
Hotel	23	4.12-5.00	5.00-7.23	7.40-13.97	15.00-18.00	9.24	60.9%	26.1%
Hospital	87	1.20-6.47	6.48-9.39	9.46-13.18	13.23-20.03	7.59	55.2%	23.0%
Condominium	273	1.00-3.73	3.73-4.89	4.94-7.59	7.59-52.40	9.05	82.1%	58.2%

2.4 Activity 1.4: Validation of Benchmarks and Stakeholder Consultations

The results of the BEC data analysis and benchmarking of activity 1.1 to 1.3 were consulted with DEDE's BEC working group as the project progresses. The stakeholder consultation workshop was arranged on March 8, 2021 to share the results and validate the established energy and GHG baselines and energy benchmarks for the five building types. The following issues were discussed and noted from the workshop.

2.4.1 Policy-related issues

BEC compliance alternatives: option 1 and option 2

From the analysis of the BEC assessment database on passing rate of both BEC options, majority of the buildings fail to comply with the individual requirements of option 1 and most of the failed buildings from option 1 are able to pass the overall energy consumption criteria of option 2. Of the total of five buildings submitting for BEC assessment from 2009 to 2019, 98.8% can comply with BEC but only 21.1% comply with option 1. 77.7% fail option 1 but comply with option 2. By applying the tighter BEC 2020 criteria to the same data, the total compliance remains at same level at 98.6% with option 1 dropping to 11.9% and option 2 increasing to 86.7%

With this result it seems that the current criteria set on option are ineffective compared with option 2. It is realized from the benchmarking that the average EUIs of all five building types are well below the average EUIs of the reference buildings.

As BEC is targeted for inclusion to the building construction permission, both option 1 and option 2 should be remained. Option 1 is set as the minimum criteria with the intention for every buildings to follow while the option 2 provides flexibility in building design and avoid the complication and reluctance in regulation enforcement. However, it is recommended that the detailed setting of the criteria should be investigated for better balance of both option effectiveness, otherwise further enforcement would be weak.

Mechanism to enhance the BEC implementation

Due to the different nature of the building owners, it is agreed in the workshop that both compliance options should be remained but used in different perspectives.

Option 1 could be used as pulling mechanism for encouraging the building designer and owner to better their building energy efficiency design. The individual building criteria allow comparing of the design to the minimum limit. These limits are subject to revision over regular period i.e. every five years to reflect the improved performance of the new building materials and technology.

Option 2 as the pushing mechanism to force all buildings, including buildings with low energy efficiency awareness to comply with the BEC. The evaluation of the overall energy performance also gives the flexibility to the designer as some components especially building envelope that may have constraints to meet the minimum requirements. Example of such constraints are building shapes and facade aesthetics which are the primary concerns in most commercial building design. With the option 2 the building designer can have their choices to compensate for the deficit with the use of advanced technology or renewable energy.

Nevertheless with its primary objective, BEC should never be treated as the design target but rather as the minimum requirements that every building design should pass.

Using of renewable energy and alternative energy in BEC

Presently the use of renewable energy, heat recovery and alternative energy scheme in building design is still insignificant. The downtrend in the cost of photovoltaic system and availability of technology such as small cogeneration, increase the potential use of renewable and alternative energy in building design in recent years. BEC might consider putting more incentive of using renewable energy or mandate certain extent of renewable or alternative energy in some buildings i.e. buildings with large roof area and high operating hours, which have been proven to be cost effective and applicable in many countries.

Verification of energy performance between BEC assessment and actual operation

BEC evaluates the building energy consumption during its design stage. Currently there have never been verified how buildings are actually constructed to the design and how the buildings actually operate and consume the energy. It is therefore suggested to add some kind of verification mechanism after construction completion and when the buildings are in operation to track actual energy performance in comparison with the calculation estimated during BEC assessment.

Adding of the GHG emission impact to the BEC

It is suggested in the workshop that GHG emission from the building energy consumption be included in the BEC assessment. This would raise more awareness on the environmental impact of the building design and help the country to meet the GHG emission reduction goal.

2.4.2 Technical-related issues

Validity of reference building model

The calculation of the energy consumption of the reference buildings is based on the formula and calculation parameters derived from DEDE energy audit reports of 1,800 designated buildings during 1996-2003. While the calculation formula is still correct, some applied parameters might be outdated and need adjustment to reflect changes in building materials, technology and operation of the present buildings.

Validity of BEC evaluation program

Although the BEC evaluation program applies the same energy calculation formula to the reference building, the calculation components are specified for inputting building design. Some building systems such as lift and escalator, electric equipment and appliances are underestimated making the calculated energy consumption lower than the actual energy consumption.

From the initial review, the average EUI of the 10-year database seems to be very low compared to the country with tropical climate and high efficiency standard like Singapore (See Table 5 and Table 6). Thus the energy calculation in the BEC assessment calculation might also need investigation and verification.

Table 5: EUI Profile of Five Building Types from BEC Assessment Database, 2009-2019

Building Type	No. of Buildings	EUI Ranges (kWh/m²-y)					Reference EUI
		1%-25%	26%-50%	51%-75%	76%-100%	Average	
Office	114	4.48-31.31	31.66-39.15	39.25-52.56	52.81-102.65	40.19	58.26
Department Store	10	34.35-39.76	40.54-54.42	67.82-90.63	94.58-112.64	48.17	150.81
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

Table 6: EUI Profile from Singapore's National Benchmarking for Commercial Buildings (2019)

Building Type	Size	No. of Buildings In 2018	EUI of the top 10%	EUI Ranges (kWh/m2-y)			
				1%-25%	26%-50%	51%-75%	76%-100%
Office Buildings	Large	194	≤113	≤138	138-185	185-246	≥246
	Small	284	≤79	≤131	131-180	180-250	≥250
Hotels	Large	86	≤187	≤223	223-263	263-326	≥326
	Small	217	≤129	≤187	187-257	257-345	≥345
Hospitals	Large	78	≤161	≤239	239-411	411-513	≥513
	Small	99	≤145	≤234	234-349	349-481	≥481
Mixed Developments	All	53	≤156	≤209	209-259	259-335	≥335

Large: Office, Retail, Mixed Developments of GFA ≥ 15,000 m²; Hotels of GFA ≥ 7,000 m²
Small: Office, Retail, Mixed Developments of GFA < 15,000 m²; Hotels of GFA < 7,000 m²

Settings of individual BEC criteria

It is agreed that all settings of BEC criteria have been well accepted as they are based on proper technical and market study. The criteria settings are comparable to international standard and applicable to Thailand. So far there is no objection from the stakeholders.

Enhancement of BEC assessment database for public benchmarking

Despite the numbers of buildings participating the BEC program are still small compared to the total number of new constructed buildings each year, benchmark analysis of the building database provides the good understanding of the building energy efficiency performance situation, which are valuable for further adjustment and design of the policy. The expansion of the database and the analytic capability would also be very useful for public benchmarking and creating the awareness of the energy efficiency design and life-long energy costs of the buildings.

3 PROGRESS BY TASK 2

This chapter reports the work in progress of task 2. The chapter provides the overview of the BEC compliance requirements and parameters that are relevant to technology in building design. Subsequently technologies and their relevance to building energy performance in each BEC components are listed. Analysis of the BEC assessment database reveals materials commonly used in building design and how they affect to the BEC compliance. Possible improvement alternatives are evaluated. Best practice technologies in materials and building systems, uncommon implemented but applicable for Thai building design, are introduced for possible enhancement of building energy efficiency performance.

3.1 ACTIVITY 2.1: ASSESSMENT OF RELEVANT TECHNOLOGIES WITH BEC COMPLIANCE

3.1.1 Overview of technology relevance to BEC compliance

The BEC addresses the technical requirements for the building design in six components for nine building types with 2,000 m^2 building area onward. Nine building types are categorized into three groups of daily operating hours.

The six BEC components and nine building types can be summarized as below.

BEC components:

1. Building envelope: wall (OTTV) and roof (RTTV)
2. Lighting system
3. Air conditioning system
4. Hot water generation system
5. Renewable energy utilization
6. Whole building energy performance

Building types:

Group 1: 8 hours/day operating hours
- Office
- School

Group 2: 12 hours/day operating hours
- Department store
- Exhibition and convention hall
- Entertainment service
- Theater

Group 3: 24 hours/day operating hours
- Hotel
- Hospital
- Condominium

*Note that the project scope covers five building types: office, department store, hotel, hospital and condominium.

The BEC evaluates energy performance of the building construction design based on the minimum energy efficiency criteria given on component 1 to 6 with two options for compliance.

Option 1 compliance

With option 1 the building must pass minimum energy efficiency criteria for each individual system of component 1 to 3. Failing to meet any criteria of each component will result in option 1 noncompliance and option 2 will be used for re-evaluation.

Option 2 compliance

Option 2 evaluates building energy consumption as a whole and allows trade-off among components as long as the overall building energy consumption or component 6 is lower than the consumption of the reference building. In option 2 energy produced from renewable energy utilization or component 5 will be used for compensation of building energy consumption.

Component 4 hot water generation is treated as an independent criterion which building must comply with on both options.

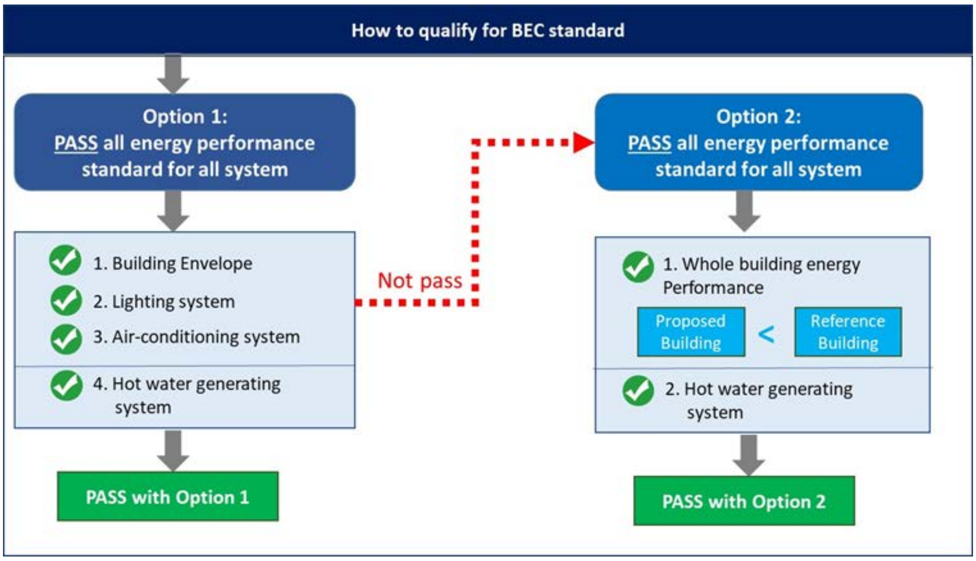


Figure 43: BEC Compliance Options

The evaluation of whole building energy consumption for option 2 compliance is based on the calculation of annual building energy consumption taking into account energy consumption of air-conditioning, lighting, other equipment and energy generation from renewable energy sources.

Annual building energy consumption

= Energy consumption of air conditioning due to heat gain through building envelope (wall and roof)
+ Energy consumption of air conditioning due to cooling loads from lighting, equipment, occupancy and ventilation of the air-conditioned space
+ Energy consumption by lighting and other equipment
- Energy generation from renewable energy including solar PV, heat equivalent renewable energy and other renewable energy sources

The following Table 7 summarizes how six BEC components relate to the BEC compliance option 1 and 2.

Table 7: Six BEC Components and Their Relation to BEC Compliance Options

.BEC Components	Relevant to BEC Compliance	
	Option 1	Option 2
1. Building envelope –OTTV & RTTV	Mandatory with specification of maximum limits for thermal transfer values through walls (OTTV) and roof (RTTV).	Thermal transfer values (OTTV, RTTV) are used in the calculation of annual building energy consumption.
2. Lighting system	Mandatory with specification of maximum limit for lighting power density (LPD).	Light power density (LPD) is used in the calculation of annual building energy consumption.
3. Air conditioning system	Mandatory with specification of minimum energy efficiency (COP, kW/TR) for different kinds of air conditioning systems.	Air conditioning efficiency (COP) is used in the calculation of annual building energy consumption.
4. Hot water generation system	Mandatory with specification of minimum energy efficiency for different kinds of hot water generation systems.	Mandatory with specification of minimum energy efficiency for different kinds of hot water generation systems.
5. Renewable energy utilization	Not specified.	Not specified but used for compensation to annual building energy consumption.
6. Whole building energy performance	Not specified.	Mandatory with specified annual building energy consumption formula and comparison with reference building energy consumption.

3.1.2 Technology assessment by BEC components

3.1.2.1 Component 1: Building envelope

Building envelope consists of opaque walls, transparent walls and windows, opaque and transparent roof. The thermal transfer properties of the building envelope have direct impact on the cooling loads and energy consumption of the air conditioning system. BEC specifies the maximum OTTV (overall thermal transfer value) for walls and windows and RTTV (roof thermal transfer value) for roof to limit the transfer of external heat through building envelope.

Main parameters of building envelope design relevant to the OTTV and RTTV limits are:

For opaque walls

- Thermal transfer coefficient (U-value) of wall in W/(m^2-K). Walls with low U-value allow less heat transfer than walls with higher U-values. The U-value of the wall depends on thermal properties of material (thermal conductance coefficient (k), density, specific heat (Cp)), thickness and composition of the wall layers.
  Typical U-values of brick walls with cement render are 3-5 W/(m^2-K) while the U-values of low mass concrete block walls are 1-4 W/(m^2-K) and the U-values of insulations are as low as 0.3-1 W/(m^2-K).

- Density, specific heat and thickness of the material. These material properties have impacts on the absorption, accumulation and delay of the heat transfer through the building envelope.

- Solar absorption of the wall surface indicated by solar absorption coefficients ranging from 0.3 to 0.9. Walls with lower solar absorption absorb less solar heat and lower the heat transfer. Reflecting or white surface has the lowest solar absorption coefficient of 0.3 and very dark color surface has the highest coefficient of 0.9.

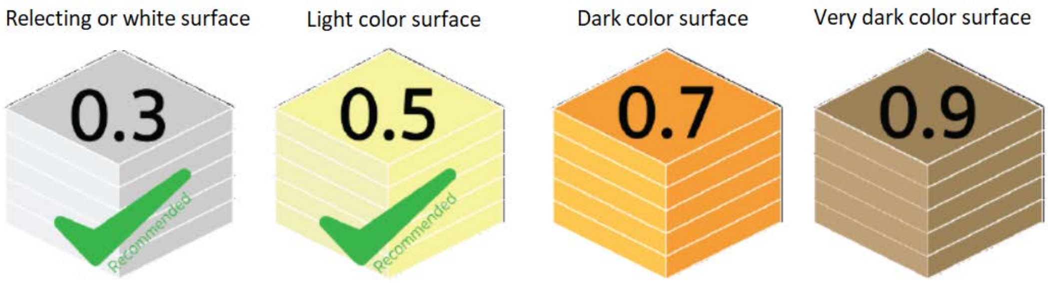


Figure 44: Illustration of Surface Colors and Solar Absorption Coefficients

- Wall orientation, angle and shading. These building design parameters affect how wall surfaces are exposed to the sunlight and solar heat. With Thailand geographic location, walls facing south receive most sunlight and solar energy throughout the day.

For transparent walls and windows

- Thermal transfer coefficient (U-value) of glass in W/(m^2-K) measures heat transfer by conductivity due to the different temperatures between external and internal surfaces. Typical U-values are 5-6 W/(m^2-K) for single glazing windows and are 2.5-3.5 W/(m^2-K) for double glazing. Similar to the opaque wall, U-value of transparent wall and window depends on thermal properties of glass, thickness and glazing layers.

- Solar heat gain coefficient (SHGC). SHGC is the fraction of incident solar radiation admitted through the glass, both directly transmitted and absorbed and subsequently released inward, see Figure 45. SHGC is expressed as a number between 0 and 1. The lower a window's SHGC, the less solar heat it transmits. Types of glass with low SHGC are reflective and low-E coating glass.

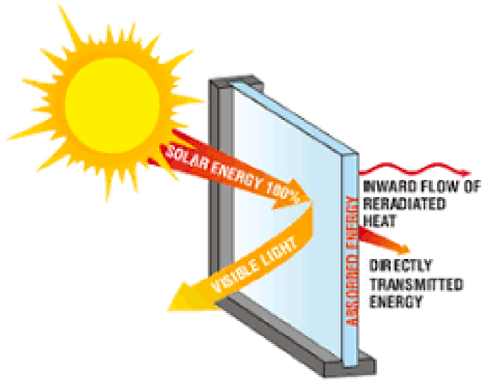


Figure 45: Illustration of Solar Heat Gain Coefficient (SHGC)[1]

- Visible light transmittance (VT) describes the fraction of visible light transmitted through the glass, ranging from 0 to 1. Window with lower VT tends to be better for glare control, while a higher VT is preferred for more natural light. Glass with high VT to SHGC ratio of more than 1 allows more natural light while limits solar heat gain through windows.

- Shading coefficient (SC) is the ratio of solar gain due to direct sunlight passing through a glass unit to the solar energy which passes through 3 mm clear float glass. SC ranges from 0 to 1 (SC =1 for 3 mm clear float glass). It is an indicator of how well the glass is thermally insulating (shading) the interior when there is direct sunlight on the panel or window. Internal or external shading devices can provide shading to direct sunlight and thus reduce the SC of the window.

Figure 46: Illustration of Shading Coefficient by External Shading Device

- Window to wall ratio (WWR) ranging from 0 to 1 (0%-100%) indicates the proportion of windows to the total wall areas. Windows normally allow much more heat gain to the building, sometimes up to 5 times compared to the opaque walls.

Figure 47: Illustration of Window to Wall Ratio

[1] Source: http://www.cspfilm.com/cspfilms/products_g_solar_heat_gain_coefficient(shgc).htm

For roof

- Similar parameters for opaque and transparent walls also apply for the opaque and transparent roofs.

Analysis of building envelope in BEC buildings

The BEC assessment database has collected information on the building design (pre-BEC assessment) since the launch of BEC in 2009 including material use for building envelope. From the BEC assessment database building materials commonly used could be assumed as the representative of the newly constructed building population.

To study the impact of the material use on the BEC compliance, material types are grouped to their similarity while OTTV, RTTV passing rates of each groups are calculated and compared. The passing percentages are categorized by colors for visually display and comparison (see Table 8). For opaque wall and window materials, the ranges of Window-to-Wall Ratio (WWR) are given for reference.

Table 8: Category for OTTV, RTTV Passing Percentage

%Passing	Passing Category
0%	None pass
0.1-24.9%	Rare pass
25.0-49.9%	Few pass
50.0-74.9%	Half pass
75.0-100%	Most pass
100%	All pass

The following analysis shows building materials use for walls, windows and roofs commonly used in five types of BEC buildings from year 2009 to 2019 and their impact on the compliance with individual OTTV and RTTV criteria of option 1.

Opaque Wall

Table 9 summarizes the use of opaque wall materials. The most common materials are brick, concrete, concrete block and low mass concrete block. Brick, concrete and concrete block have low OTTV passing of only 10.4%. The low mass concrete improves the passing rates to 61.4%. From the result only two buildings apply the insulation to the wall and both pass the OTTV criteria.

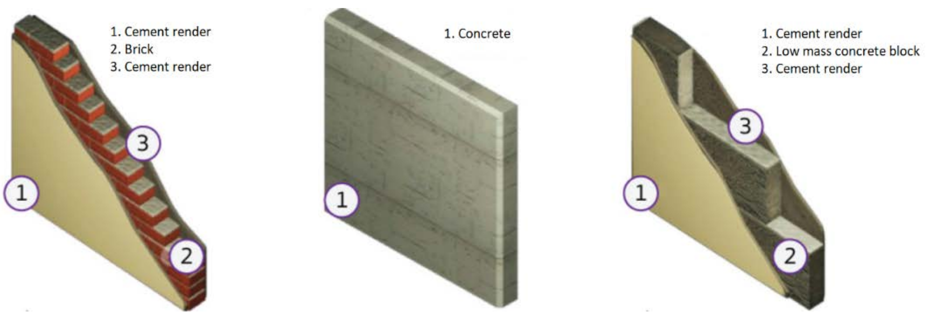


Figure 48: Examples of Common Opaque Wall Materials

Table 9: Opaque Wall Materials and OTTV Compliance, 2009-2019

Wall Material Group	No. of Buildings	Passing Category	OTTV Fail	OTTV %Fail	WWR Min	WWR Max	WWR Avg	OTTV Pass	OTTV %Pass	WWR Min	WWR Max	WWR Avg
Group 1: Single Material	**289**	**Rare pass**	**259**	**89.6%**	**0.05**	**0.92**	**0.36**	**30**	**10.4%**	**0.10**	**0.54**	**0.28**
Brick	63	Rare pass	49	77.8%	0.05	0.92	0.38	14	22.2%	0.10	0.46	0.23
Brick with Aluminium Composite	1	None pass	1	100.0%	0.53	0.53	0.53	0	0.0%			
Concrete Block	34	Few pass	22	64.7%	0.11	0.72	0.38	12	35.3%	0.23	0.54	0.34
Concrete	191	Rare pass	187	97.9%	0.08	0.80	0.35	4	2.1%	0.22	0.36	0.29
Group 2: Low Mass Material	**101**	**Half pass**	**39**	**38.6%**	**0.22**	**0.90**	**0.49**	**62**	**61.4%**	**0.06**	**0.99**	**0.38**
Low Mass Concrete	98	Half pass	39	39.8%	0.22	0.90	0.49	59	60.2%	0.10	0.99	0.39
Low Mass Concrete with Aluminium Composite	2	All pass	0	0.0%				2	100.0%	0.18	0.24	0.21
Low Mass Concrete with Metal Sheet & Fiberglass	1	All pass	0	0.0%				1	100.0%	0.06	0.06	0.06
Group 3: Mixed Materials	**12**	**Half pass**	**6**	**50.0%**	**0.30**	**0.75**	**0.55**	**6**	**50.0%**	**0.04**	**0.47**	**0.28**
Brick + Concrete	6	Half pass	3	50.0%	0.57	0.75	0.68	3	50.0%	0.06	0.45	0.26
Brick + Low Mass Concrete	1	None pass	1	100.0%	0.31	0.31	0.31	0	0.0%			
Concrete + Low Mass Concrete	3	Half pass	1	33.3%	0.30	0.30	0.30	2	66.7%	0.04	0.47	0.26
Concrete + Low Mass Concrete with Aluminium Composite	2	Half pass	1	50.0%	0.66	0.66	0.66	1	50.0%	0.40	0.40	0.40
Group 4: Insulated Walls	**2**	**All pass**	**0**	**0.0%**				**2**	**100.0%**	**0.36**	**0.57**	**0.47**
Concrete with Insulation	1	All pass	0	0.0%				1	100.0%	0.36	0.36	0.36
Low Mass Concrete with Insulation	1	All pass	0	0.0%				1	100.0%	0.57	0.57	0.57

Transparent Walls and Windows

The analysis groups window materials into single, double, triple and mixed glazing. Single glazing are by far the most common windows. Majority of them are single float clear and single float tinted glass. Low percentage of the buildings use double glazing. And only two buildings are designed with triple glazing. Multiple glazing improves OTTV passing from 23.4% on single glazing to 52.6% on double glazing and 100% on triple glazing.

For single glazing, the OTTV passing improve with tinted, laminated, reflective and low-E coating glass. Glazing low SHGC such as reflective and low-E coating significantly improve the passing rates to more than 70% compared to clear glass with passing of less than 15%.

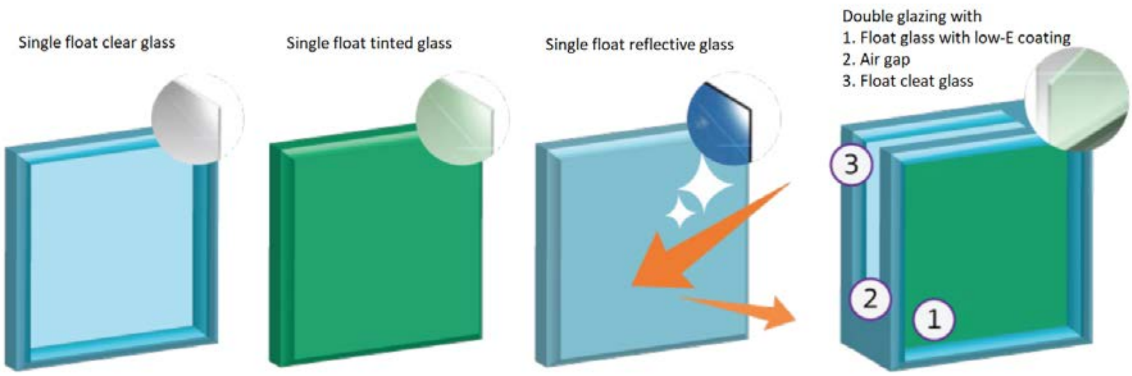


Figure 49: Examples of Window Glazing Materials

Table 10: Window Materials and OTTV Compliance, 2009-2019

Window Material	No. of	Passing	OTTV		WWR			OTTV		WWR		
Group	Buildings	Category	Fail	%Fail	Min	Max	Avg	Pass	%Pass	Min	Max	Avg
Group 1: Single Glazing	**351**	**Few pass**	**267**	**76.1%**	**0.05**	**0.92**	**0.37**	**82**	**23.4%**	**0.04**	**0.61**	**0.32**
Single Float Clear	146	Rare pass	127	87.0%	0.11	0.92	0.30	19	13.0%	0.04	0.46	0.22
Single Float Tinted	146	Few pass	109	74.7%	0.05	0.80	0.39	37	25.3%	0.10	0.61	0.31
Single Float Reflective	6	Half pass	2	33.3%	0.35	0.61	0.48	2	33.3%	0.47	0.57	0.52
Single Float LowE	5	Most pass	1	20.0%	0.43	0.43	0.43	4	80.0%	0.25	0.59	0.87
Single Tempered Clear	2	Half pass	1	50.0%	0.84	0.84	0.84	1	50.0%	0.13	0.13	0.13
Single Laminated Clear	18	Rare pass	14	77.8%	0.30	0.90	0.61	4	22.2%	0.06	0.47	0.23
Single Laminated Tinted	26	Half pass	13	50.0%	0.25	0.80	0.47	13	50.0%	0.21	0.54	0.34
Single Laminated Reflective	1	All pass	0	0.0%				1	100.0%	0.36	0.36	0.36
Single Laminated LowE	1	All pass	0	0.0%				1	100.0%	0.31	0.31	0.31
Group 2: Mixed Single Glazing	**25**	**Few pass**	**22**	**88.0%**	**0.25**	**0.85**	**0.42**	**3**	**12.0%**	**0.27**	**0.55**	**0.41**
Single Float Clear + Single Float Tinted	18	None pass	18	100.0%	0.25	0.46	0.37	0	0.0%			
Single Float Clear + Single Laminated Clear	1	None pass	1	100.0%	0.38	0.38	0.38	0	0.0%			
Single Float Clear + Single Laminated Clear + Single Laminated Clear	1	All pass	0	0.0%				1	100.0%	0.55	0.55	0.55
Single Float Reflective + Single Tempered Reflective	1	All pass	0	0.0%				1	100.0%	0.40	0.40	0.40
Single Laminated Clear + Single Tempered Clear	3	Few pass	2	66.7%	0.57	0.73	0.65	1	33.3%	0.27	0.27	0.27
Single Laminated Clear + Single Laminated Reflective	1	None pass	1	100.0%	0.85	0.85	0.85	0	0.0%			
Group 3: Double Glazing	**19**	**Half pass**	**9**	**47.4%**	**0.23**	**0.88**	**0.42**	**10**	**52.6%**	**0.22**	**0.83**	**0.55**
Double Float Clear	3	Half pass	1	33.3%	0.88	0.88	0.88	2	66.7%	0.31	0.39	0.35
Double Float Tinted	2	All pass	0	0.0%				2	100.0%	0.80	0.83	0.82
Double Laminated Clear	8	Few pass	5	62.5%	0.35	0.46	0.41	3	37.5%	0.65	0.82	0.72
Double Laminated Tinted	6	Half pass	3	50.0%	0.23	0.32	0.29	3	50.0%	0.22	0.46	0.32
Group 4: Mixed Single & Double Glazing	**3**	**None pass**	**3**	**100.0%**	**0.15**	**0.75**	**0.42**	**0**	**0.0%**			
Single Float Clear + Double Laminated Clear	2	None pass	2	100.0%	0.15	0.37	0.26	0	0.0%			
Single Laminated Clear + Double Laminated LowE	1	None pass	1	100.0%	0.75	0.75	0.75	0	0.0%			
Group 5: Triple Glazing	**2**	**All pass**	**0**	**0.0%**				**2**	**100.0%**	**0.62**	**0.99**	**0.81**
Triple Laminated Clear	2	All pass	0	0.0%				2	100.0%	0.62	0.99	0.81

Roof

The most common roof materials are concrete, concrete tile and metal sheet. Using BEC 2009 RTTV criteria majority of buildings (>70%) using with these common roof materials can pass. But with new BEC 2020 the passing percentages reduce to around 50%. Roofs with insulation have almost 100% pass on BEC 2009 but with BEC 2020 the passing rates significantly reduce, meaning that better insulations or air gaps are required to pass the tighter RTTV criteria.

Figure 50: Examples of Roof Materials

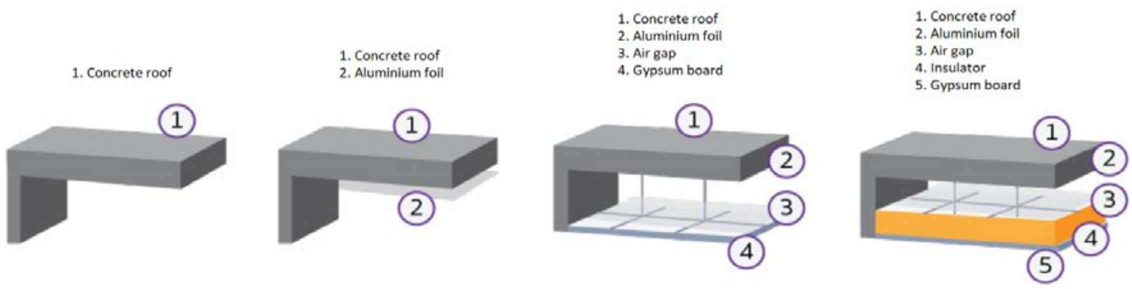


Figure 51: Examples of Roof Components

Table 11: Roof Materials and RTTV Compliance, 2009-2019

Roof Material Group	No. of Buildings	BEC 2009 Passing	RTTV BEC 2009 Fail	RTTV BEC 2009 %Fail	RTTV BEC 2009 Pass	RTTV BEC 2009 %Pass	BEC 2020 Passing	RTTV BEC 2020 Fail	RTTV BEC 2020 %Fail	RTTV BEC 2020 Pass	RTTV BEC 2020 %Pass
Group: Concrete	**308**	**Most pass**	**46**	**14.9%**	**262**	**85.1%**	**Half pass**	**130**	**42.2%**	**178**	**57.8%**
Concrete	98	Half pass	42	42.9%	56	57.1%	Few pass	68	69.4%	30	30.6%
Concrete with Gypsum Board Ceiling	5	Half pass	2	40.0%	3	60.0%	Rare pass	4	80.0%	1	20.0%
Concrete with Foil-covered Gypsum Board Ceiling	1	All pass	0	0.0%	1	100.0%	None pass	1	100.0%	0	0.0%
Concrete with Gypsum Board Ceiling, Air Gap	2	Half pass	1	50.0%	1	50.0%	None pass	2	100.0%	0	0.0%
Concrete with Green Roof	9	All pass	0	0.0%	9	100.0%	Rare pass	7	77.8%	2	22.2%
Concrete with PVC Cover	1	All pass	0	0.0%	1	100.0%	None pass	1	100.0%	0	0.0%
Concrete with Insulator	108	All pass	0	0.0%	108	100.0%	Most pass	23	21.3%	85	78.7%
Concrete with Insulator, Air Gap	1	All pass	0	0.0%	1	100.0%	All pass	0	0.0%	1	100.0%
Concrete with Insulator, Green Roof	4	All pass	0	0.0%	4	100.0%	Most pass	1	25.0%	3	75.0%
Concrete with Insulator, Gypsum Board Ceiling	61	Most pass	1	1.6%	60	98.4%	Most pass	14	23.0%	47	77.0%
Concrete with Insulator, Gypsum Board Ceiling, Air Gap	2	All pass	0	0.0%	2	100.0%	All pass	0	0.0%	2	100.0%
Concrete with Foil-covered Insulator	13	All pass	0	0.0%	13	100.0%	Few pass	7	53.8%	6	46.2%
Concrete with Foil-covered Insulator, Gypsum Board Ceiling	2	All pass	0	0.0%	2	100.0%	None pass	2	100.0%	0	0.0%
Concrete with Foil-covered Insulator, Gypsum Board Ceiling, Air Gap	1	All pass	0	0.0%	1	100.0%	All pass	0	0.0%	1	100.0%
Group: Concrete Tile	**15**	**Half pass**	**5**	**33.3%**	**10**	**66.7%**	**Half pass**	**7**	**46.7%**	**8**	**53.3%**
Concrete Tile	12	Half pass	4	33.3%	8	66.7%	Half pass	5	41.7%	7	58.3%
Concrete Tile with Foil-covered Gypsum Board Ceiling	1	All pass	0	0.0%	1	100.0%	None pass	1	100.0%	0	0.0%
Concrete Tile with Gypsum Board Ceiling, Air Gap	1	None pass	1	100.0%	0	0.0%	None pass	1	100.0%	0	0.0%
Concrete Tile with Insulator	1	All pass	0	0.0%	1	100.0%	All pass	0	0.0%	1	100.0%

Table 12: Roof Materials and RTTV Compliance, 2009-2019 (Continued)

Roof Material Group	No. of Buildings	BEC 2009 Passing	RTTV BEC 2009 Fail	RTTV BEC 2009 %Fail	RTTV BEC 2009 Pass	RTTV BEC 2009 %Pass	BEC 2020 Passing	RTTV BEC 2020 Fail	RTTV BEC 2020 %Fail	RTTV BEC 2020 Pass	RTTV BEC 2020 %Pass
Group: Metal Sheet	**32**	**Most pass**	**7**	**21.9%**	**25**	**78.1%**	**Few pass**	**18**	**56.3%**	**14**	**43.8%**
Metal Sheet	12	Half pass	4	33.3%	8	66.7%	Rare pass	10	83.3%	2	16.7%
Metal Sheet with Ceramic Coating	1	All pass	0	0.0%	1	100.0%	None pass	1	100.0%	0	0.0%
Metal Sheet with Gypsum Board Ceiling, Air Gap	5	Few pass	3	60.0%	2	40.0%	Few pass	3	60.0%	2	40.0%
Metal Sheet with Insulator	5	All pass	0	0.0%	5	100.0%	Most pass	1	20.0%	4	80.0%
Metal Sheet with Foil-covered Insulator	6	All pass	0	0.0%	6	100.0%	Most pass	1	16.7%	5	83.3%
Metal Sheet with Insulator, Gypsum Board Ceiling	3	All pass	0	0.0%	3	100.0%	Few pass	2	66.7%	1	33.3%
Group: Cedar	**5**	**All pass**	**0**	**0.0%**	**5**	**100.0%**	**Rare pass**	**4**	**80.0%**	**1**	**20.0%**
Cedar with Insulator	3	All pass	0	0.0%	3	100.0%	Few pass	2	66.7%	1	33.3%
Cedar with Foil-covered Insulator	2	All pass	0	0.0%	2	100.0%	None pass	2	100.0%	0	0.0%
Group: Mixed Materials	**48**	**Most pass**	**9**	**18.8%**	**39**	**81.3%**	**Few pass**	**27**	**56.3%**	**21**	**43.8%**
Concrete + Concrete Tile	2	All pass	0	0.0%	2	100.0%	Half pass	1	50.0%	1	50.0%
Concrete + Shingle Roof	1	None pass	1	100.0%	0	0.0%	None pass	1	100.0%	0	0.0%
Concrete + Metal Sheet	28	Half pass	8	28.6%	20	71.4%	Few pass	18	64.3%	10	35.7%
Concrete with Foil-covered Gypsum Board Ceiling, Air Gap + Metal Sheet with Foil-covered Gypsum Board Ceiling, Air Gap	1	All pass	0	0.0%	1	100.0%	None pass	1	100.0%	0	0.0%
Concrete with Insulator + Metal Sheet with Insulator	6	All pass	0	0.0%	6	100.0%	Half pass	2	33.3%	4	66.7%
Concrete with Foil-covered Insulator + Metal Sheet with Foil-covered Insulator	5	All pass	0	0.0%	5	100.0%	Most pass	1	20.0%	4	80.0%
Concrete with Insulator, Gypsum Board Ceiling + Metal Sheet with Insulator, Gypsum Board Ceiling	1	All pass	0	0.0%	1	100.0%	None pass	1	100.0%	0	0.0%
Concrete with Insulator + Metal Sheet + Skylight	2	All pass	0	0.0%	2	100.0%	None pass	2	100.0%	0	0.0%
Concrete with Insulator, Green Roof + Metal Sheet with Insulator	1	All pass	0	0.0%	1	100.0%	All pass	0	0.0%	1	100.0%
Concrete Tile + Metal Sheet	1	All pass	0	0.0%	1	100.0%	All pass	0	0.0%	1	100.0%

Table 13: Roof Materials and RTTV Compliance, 2009-2019 (Continued)

Roof Material Group	No. of Buildings	BEC 2009 Passing	RTTV BEC 2009 Fail	RTTV BEC 2009 %Fail	RTTV BEC 2009 Pass	RTTV BEC 2009 %Pass	BEC 2020 Passing	RTTV BEC 2020 Fail	RTTV BEC 2020 %Fail	RTTV BEC 2020 Pass	RTTV BEC 2020 %Pass
Group: Green Roof	**14**	**All pass**	**0**	**0.0%**	**14**	**100.0%**	**Few pass**	**8**	**57.1%**	**6**	**42.9%**
Concrete with Green Roof	9	All pass	0	0.0%	9	100.0%	Rare pass	7	77.8%	2	22.2%
Concrete with Insulator, Green Roof	4	All pass	0	0.0%	4	100.0%	Most pass	1	25.0%	3	75.0%
Concrete with Insulator, Green Roof + Metal Sheet with Insulator	1	All pass	0	0.0%	1	100.0%	All pass	0	0.0%	1	100.0%
Group: Concrete with Insulator	**193**	**Most pass**	**1**	**0.5%**	**192**	**99.5%**	**Most pass**	**47**	**24.4%**	**146**	**75.6%**
Concrete with Insulator	108	All pass	0	0.0%	108	100.0%	Most pass	23	21.3%	85	78.7%
Concrete with Insulator, Air Gap	1	All pass	0	0.0%	1	100.0%	All pass	0	0.0%	1	100.0%
Concrete with Insulator, Green Roof	4	All pass	0	0.0%	4	100.0%	Most pass	1	25.0%	3	75.0%
Concrete with Insulator, Gypsum Board Ceiling	61	Most pass	1	1.6%	60	98.4%	Most pass	14	23.0%	47	77.0%
Concrete with Insulator, Gypsum Board Ceiling, Air Gap	2	All pass	0	0.0%	2	100.0%	All pass	0	0.0%	2	100.0%
Concrete with Foil-covered Insulator	13	All pass	0	0.0%	13	100.0%	Few pass	7	53.8%	6	46.2%
Concrete with Foil-covered Insulator, Gypsum Board Ceiling	2	All pass	0	0.0%	2	100.0%	None pass	2	100.0%	0	0.0%
Concrete with Foil-covered Insulator, Gypsum Board Ceiling, Air Gap	1	All pass	0	0.0%	1	100.0%	All pass	0	0.0%	1	100.0%
Concrete Tile with Insulator	1	All pass	0	0.0%	1	100.0%	All pass	0	0.0%	1	100.0%

Table 14: Roof Materials and RTTV Compliance, 2009-2019 (Continued)

Roof Material Group	No. of Buildings	BEC 2009 Passing	RTTV BEC 2009 Fail	RTTV BEC 2009 %Fail	RTTV BEC 2009 Pass	RTTV BEC 2009 %Pass	BEC 2020 Passing	RTTV BEC 2020 Fail	RTTV BEC 2020 %Fail	RTTV BEC 2020 Pass	RTTV BEC 2020 %Pass
Group: Metal Sheet with Insulator	**14**	**All pass**	**0**	**0.0%**	**14**	**100.0%**	**Half pass**	**4**	**28.6%**	**10**	**71.4%**
Metal Sheet with Insulator	5	All pass	0	0.0%	5	100.0%	Most pass	1	20.0%	4	80.0%
Metal Sheet with Foil-covered Insulator	6	All pass	0	0.0%	6	100.0%	Most pass	1	16.7%	5	83.3%
Metal Sheet with Insulator, Gypsum Board Ceiling	3	All pass	0	0.0%	3	100.0%	Few pass	2	66.7%	1	33.3%
Group: Cedar with Insulator	**5**	**All pass**	**0**	**0.0%**	**5**	**100.0%**	**Rare pass**	**4**	**80.0%**	**1**	**20.0%**
Cedar with Insulator	3	All pass	0	0.0%	3	100.0%	Few pass	2	66.7%	1	33.3%
Cedar with Foil-covered Insulator	2	All pass	0	0.0%	2	100.0%	None pass	2	100.0%	0	0.0%
Group: Mixed Materials with Insulator	**15**	**All pass**	**0**	**0.0%**	**15**	**100.0%**	**Half pass**	**6**	**40.0%**	**9**	**60.0%**
Concrete with Insulator + Metal Sheet with Insulator	6	All pass	0	0.0%	6	100.0%	Half pass	2	33.3%	4	66.7%
Concrete with Foil-covered Insulator + Metal Sheet with Foil-covered Insulator	5	All pass	0	0.0%	5	100.0%	Most pass	1	20.0%	4	80.0%
Concrete with Insulator, Gypsum Board Ceiling + Metal Sheet with Insulator, Gypsum Board Ceiling	1	All pass	0	0.0%	1	100.0%	None pass	1	100.0%	0	0.0%
Concrete with Insulator + Metal Sheet + Skylight	2	All pass	0	0.0%	2	100.0%	None pass	2	100.0%	0	0.0%
Concrete with Insulator, Green Roof + Metal Sheet with Insulator	1	All pass	0	0.0%	1	100.0%	All pass	0	0.0%	1	100.0%

Applicable technology for building envelope improvement

Considering building envelope design parameters explained above, improvement of building envelope to meet the OTTV and RTTV criteria can be achieved by following measures. Many of these measures are confirmed by the revision of building design (post BEC assessment data) from the BEC assessment database.

Opaque Wall

- Using materials with high thermal resistance to lower thermal transfer value (U-value).
- Using low mass materials to reduce heat absorption and accumulation of walls, which will transfer inward to the building. Low mass concrete block can replace conventional concrete or concrete block.
- Using light color or reflective coating to reduce heat absorption of walls.
- Adding insulation or air gap to lower U-value and minimize heat transfer through walls. Most common practice are internal insulation with 3-inch fiberglass insulator and 12-mm gypsum board to walls.

Transparent Wall and Window

- Using glazing with low SHGC to reduce direct solar heat gain which is the main portion of solar heat. This seems to be one of the most effective measures as current glazing development can significantly reduce SHGC while maintaining high VT (visible light transmittance). Many post BEC assessment

buildings can comply the BEC option 1 with the change from clear or tinted glass to reflective or low-E coated glass.
- Increasing glazing thickness to lower U-value.
- Using multiple glazing with air gap such as double or triple glazing to minimize U-value, especially windows with long hours of direct sunlight. Despite the high investment, many new high-end buildings have chosen multiple glazing to minimize the surrounding noise impact in conjunction with energy efficiency purpose.
- Using shading devices. Shading could be considered in the design of building facade to reduce direct sunlight to the windows.

Roof
- Using materials with high thermal resistance to lower thermal transfer value (U-value).
- Using light color or reflective coating to reduce heat absorption of roofs. Some color materials have special solar reflection properties which can be easily implemented to roof.
- Adding insulation or air gap to lower U-value and minimize heat transfer through roofs. This is the most common and cost effective practice for roof improvement. Adding fiberglass insulator and air gap are normally recommended for conventional concrete, concrete tile or metal sheet roof.

Other possible technologies

In additional to the above common improvement measures, present development in building materials and design can be considered. Some of these possible technologies are:

- **External wall insulation**
  External insulation such as PS foam can be applied to improve thermal resistivity of wall especially when installation of internal insulation is more difficult to do. The external insulation may be implemented with aluminum composite or special coating for UV protection and surface finishing.

- **Internal shade glazing**
  Internal shade glazing is the new technology which includes shading devices in the gaps of multiple glazing windows. Many internal shade glazing have included smart feature for adjusting its shading in response to the external sunlight. The technology is applicable to buildings where the architecture design require high window-to-wall ratio.

- **Integrated roof insulation**
  Integrated roof insulator provide alternatives for roof insulation. Metal sheets pre-fabricated with high thermal resistant PU foam insulator have become available in recent years. Other possible option is the spray foam which can be applied to most common roof materials such as concrete, concrete tile and metal sheets. Open-cell or closed-cell foam are both applicable for spraying. Closed-cell has better heat resistance but more expensive than open-cell.

3.1.2.2 Component 2: Lighting system

Lighting is one of the fundamental building system and could consume up to 20-30% of total building energy consumption. Lighting directly consumes electricity and dissipates heat, which adds cooling load to the air conditioning system. BEC specifies lighting energy efficiency criteria expressed by lighting power density (LPD), the ratio of installed wattage of lighting system (W) to the total building area in m^2.

Related design factors to meet the lighting efficiency criteria are:
- Energy efficient lamps with high lighting output (lumen) per watt with the right color rendition. At present LED lamps have become prevalent and common in building design. The light output have significantly improved from 30-80 lumen per Watt on the conventional incandescent, fluorescent, HID lamps to 90-120 lumen per Watt or even more on the new advanced LED technology.

- Energy-efficient luminaire with effective light distribution. With high reflective material and reflector design, energy-efficient luminaires maximizes the light output from the lamps and coverage of the lighting space.
- Space illumination design to suit building function. Lighting design should be incorporated to the design and planning of building spaces for effective lighting to building space functions. Many lighting design software tools are now available for optimizing installation of lighting while ensuring appropriate light level and distribution.
- Daylighting. Daylighting adds natural effect to building interior and reduce lighting consumption. Implementation of daylighting must be considered together with the glazing design to limit heat gain to the air conditioned areas.
- Light zoning and control for management of lighting and avoid lighting waste in the unoccupied building space.

Analysis of lighting system in BEC buildings

The BEC assessment database does not collected the details of lighting system of the individual buildings. However there should be no concern on lighting efficiency of five BEC building types under this study as the result shows high passing on lighting LPD of more than 99% from 2009 to 2019. And the passing are now 100% on recent years (2013-2019) as the LED lighting systems become more commonly used in lighting design.

Applicable technology for lighting system improvement

In addition to on-going development of LED lamps and luminaire technology with more varieties and improved performance, daylighting is an important approach of reducing lighting wattage of the building.

3.1.2.3 Component 3: Air conditioning system

Air conditioning is the most energy consuming building system. For tropical climate like Thailand, air conditioning normally consume 40-60% of total energy consumption. BEC does not require the types of air conditioning to be used but specifies the minimum energy efficiency on all air conditioning types from small spilt type to large chilled water systems.

For split type air conditioner, the new BEC 2020 specifies the minimum efficiency as EER in Btu/h/W in accordance with EGAT No.5 labelling announced in year 2019. For large air conditioning system, BEC 2020 specifies the minimum efficiency in kW/TR and COP for air-cooled and water-cooled chillers by compressor types and cooling capacity. The total efficiency of other air conditioning equipment apart from chiller including cooling system, chiller water system and air handling units must have the minimum COP of 7.03 or 0.5 kW per ton of chiller cooling capacity. The BEC also specifies the minimum COP for absorption chillers of both single and double stage types.

Analysis of air conditioning system in BEC buildings

From the BEC database, all types of air conditioning system from small split-type units to large central chiller systems are used in the five BEC building types. The use of air conditioning depends on building areas and functions. No specific details are provided on the database. Similar to lighting system the result from BEC assessment database shows high passing on air conditioning of more than 99% on five BEC building types from 2009 to 2019. And the passing are now 100% on recent years (2013-2019). In fact most air conditioning system available in the market have better efficiency than the BEC requirements and most Thai design engineers are well aware of and take energy efficiency as an important factor in chiller selection. The use of absorption chiller in BEC buildings is still very rare due to the unavailability of low cost energy sources such as waste heat or city gas.

Applicable technology for air conditioning system improvement

Further improvement on energy efficiency are possible with more advanced technology air conditioning system including:

- **Split type air-conditioner**
  New technology of refrigerant, compressor including variable speed and advanced control such as variable refrigerant volume (VRV) and inverter type are becoming commonly used in the new buildings.

- **Electric chiller**
  The new oil free magnetic bearing chiller and variable speed compressor chillers have improved energy efficiency by at least 10-20% compared with conventional chillers and BEC criteria.

- **Absorption chiller**
  New generation absorption chillers can produce chilled water and hot water simultaneously at COP more than 1.65.

- **Energy recovery ventilator (ERV)**
  Building air conditioning system requires air change by the new fresh air to remove CO_2 from the air conditioned space. Conventional air conditioning uses natural ventilation with no control of fresh air from the external ambient, adding considerable amount of cooling loads to the air conditioning system.

  The new technology of Energy Recovery Ventilator (ERV) can control and clean fresh air supply to the space. The unit is equipped with energy recovery feature to exchange the cool from the exhaust air to pre cool fresh air intake. The technology can save 10%-30% of air conditioning consumption.

3.1.2.4 Component 4: Hot water generation system

Hot water and steam is used in some BEC buildings such as hotel, hospital and condominium. Some application examples are 50-60 C hot water for showering in hotel and condominium, 70-90 C hot water for washing in the kitchen in hotel and hospital, 100C hot water or steam for laundry in hotel and hospital. However the portion of energy use by the water generation system in buildings are relatively small compared to air conditioning and lighting.

The BEC specifies minimum efficiency for central hot water and steam boiler including gas-fired, oil-fired and heat pump system. However it does not specify the efficiency of electric hot water heaters.

Analysis of hot water generation system in BEC buildings

There is no data record on the hot water generation system in the BEC assessment database. And there is no noncompliance from the hot water generation criteria over 10-year database. The most common hot water generation system for hotels and hospitals are central oil-fired and LPG boiler to produce hot water for central laundry, kitchen and room services. Small electric hot water heater are also prevalent in small to medium sized hotels and condominiums as they are convenient and cost effective. Heat pump systems have also been implemented for more than 10 years in many hotels and hospitals, especially large chain and international-owned business with energy efficiency awareness. However they are still not common in most local buildings although the technologies are proven on their high efficiency and cost effectiveness.

3.1.2.5 Component 5: Renewable energy

The BEC does not require utilization of renewable energy but allow using of renewable energy produced for compensation of the whole building energy consumption in option 2 evaluation. The new BEC 2020 prescribes the use of renewable energy taking into account three following alternatives:

1. Electricity from photovoltaic (PV) system. Electricity produced from the PV system can directly reduce the amount of electricity required from the grid.
2. Utilization of renewable heat source to replace the use of electricity. Renewable energy sources such as solar, biogas can be used for heat production such as hot water or steam. The heat energy produced can be calculated to the equivalent electricity and subtract from the building energy consumption.
3. Utilization of other renewable energy. Using other renewable energy sources can be included for compensation of building energy consumption. Example of such applications are wind turbine electricity, solar air conditioner and etc.

Analysis of renewable energy utilization in BEC buildings

The BEC assessment database has no record on any renewable energy utilization in BEC buildings. However the downtrend of the price per performance (THB/kW) of the PV system has created the high awareness in the Thai market. The potential for inclusion of the PV system in current building design are high especially buildings with large roof areas. Other renewable energy utilization are still low and unaware by most buildings.

3.1.2.6 Component 6: Whole building performance

The BEC component 6 considers the whole building energy consumption in comparison with the reference building for evaluation of option 2 compliance. Energy consumption of all building systems are taken for calculation of building energy consumption and the amount of renewable energy use can cancel some portion of energy consumption. Although the component 6 does not require specific requirements for individual building systems, it allows trade-off of among building design components which provides more flexibility in building design.

Analysis of whole building energy performance of BEC buildings

The analysis of the whole building energy performance of five BEC building types are presented in the previous chapter. Most BEC buildings can easily comply with the whole build energy performance evaluation. The gap differences between current BEC building design and reference building model make the component ineffective in driving better building energy efficiency compared with component 1 to 4.

Applicable technology for whole building energy performance improvement

Additional to the trade-off between individual building systems there are still potential technologies for increasing the whole building energy performance which would be worth considering.

- **Building Energy Management System (BEMS)**
  BEMS manages building functions and optimizes energy consumption of building systems including electricity distribution, air conditioning, lighting and etc.

- **Combined Cooling Heating and Power (CCHP)**
  The combined cooling heating and power (CCHP) sometimes called tri-generation utilizes one energy source usually natural gas or LNG to produce electricity, cooling and heat energy. The system consists of a gas engine, an electricity generator, a heat exchanger and an absorption chiller. The gas-fired generator produces electricity and heat. This exhaust heat is transported to the absorption chiller to produce chilled water. The system has the overall energy efficiency of 80-95%, which are very high compared to individual production of electricity, cooling and heating energy.

3.1.3 Summary Listing of Applicable Technologies for BEC Buildings

The following Table 15 summarizes the listing of applicable technologies for six BEC components as described above.

Table 15: Listing of Applicable Technologies for Six BEC Components

Technology	Target Building	Current Status
Component 1: Building Envelope		
Opaque Walls and Roof		
Using materials with high thermal resistance to lower thermal transfer value (U-value) for wall.	All buildings	Common
Using low mass materials to reduce heat absorption and accumulation of wall.	All buildings	Common
Using light color or reflective coating to reduce heat absorption of wall and roof	All buildings	Uncommon
Adding insulation or air gap to lower U-value and minimize heat transfer through wall and roofs	All buildings	Common
External wall insulation	All buildings	Common
Integrated roof insulation	All buildings	Uncommon
Transparent Wall and Window		
Using glazing with low SHGC to reduce direct solar heat gain	All buildings	Common
Increasing glazing thickness to lower U-value.	All buildings	Common
Using multiple glazing with air gap such as double or triple glazing to minimize U-value	Large office, hotels, hospitals, condominiums	Uncommon
Internal shade glazing	Large office, hotels, hospitals, condominiums	Uncommon
Component 2: Lighting System		
LED lamps with high lighting output (lumen) per watt	All buildings	Common
Energy-efficient luminaire with effective light distribution.	All buildings	Common
Daylighting	All buildings	Common
Component 3: Air Conditioning System		
Split-type air conditioner		
Inverter split type	Small to medium sized buildings Condominiums	Common
Variable refrigerant volume (VRV) split-type and packaged unit	Small to medium sized buildings	Common

Technology	Target Building	Current Status
Electric chiller		
Oil free magnetic bearing chiller	Large buildings	Uncommon
Variable speed compressor chiller	Large buildings	Uncommon
Absorption chiller		
High efficiency absorption chiller	Large hotels and hospitals	Uncommon
Ventilation		
Energy recovery ventilator (ERV)	Large buildings	Uncommon
Component 4: Hot Water Generation System		
Heat pump hot water heater	Large hotels and hospitals	Uncommon
Component 5: Renewable Energy Utilization		
Photovoltaic system	All buildings	Uncommon
Heat generation from biomass/biogas	Large hotels and hospitals	Uncommon
Solar heating	Hotels, hospitals, condominium	Uncommon
Solar cooling/air conditioner	All buildings	Uncommon
Component 6: Whole Building Energy Performance		
Building Energy Management System (BEMS)	Large buildings	Uncommon
Combined Cooling Heating and Power (CCHP)	Large hotels and hospitals	Uncommon

4 STAKEHOLDER CONSULTATIONS

4.1 STAKEHOLDER CONSULTATION MEETING WITH DEDE

Following the detailed review and assessment of BEC's database on energy consumption baselines and benchmarks (Activities 1.1 to 1.3), the IIEC team organized and conducted the consultation meeting with the key stakeholders to share the results. IIEC presented the fact-findings of BEC's ten-year data assessment on the energy consumption baselines, benchmarks, and GHG emissions of the five building types to the BEC working grourp comprising DEDE and the Coordinating Center for Energy Conservation Building Design (2e-Building Center) consultants, for validation and comments. The two small stakeholder consultation meeting with DEDE and the consultants was held on Wednesday 18th February 2021 and Tuesday 23th February 2021.

The project team also prepared the stakeholder consultation workshop outline in consultation with DEDE, to identify target stakeholders and finalize the workshop program. For Activity 1.4 of the validation and stakeholder consultation workshop, DEDE recommended to combine two workshops of technical and policy groups into one integrated stakeholder workshop due to limited numbers of the stakeholders who involved to BEC policy and technical design. Other technical stakeholders including DPT staff and Local authorities' officers, BEC-certified engineer/auditor could invite to participate in the subsequent activities.

The project team had conducted a consultation with NDE and CTCN and gain acceptance on the proposed consultation workshop arrangement.

4.2 SUMMARY OF VALIDATION OF BENCHMARKS AND STAKEHOLDER CONSULTATION WORKSHOP

The first stakeholder consultation workshop for the 'Enabling Readiness for Up-Scaling Investments in Building Energy Efficiency for Achieving NDC Goals in Thailand'' project was successfully organized in Bangkok, on Monday, March 8th, 2021. The face-to-face consultation workshop aims at presenting the fact-findings from the analysis of ten-year operational data of BEC, and seeking comments and suggestions from stakeholders to strengthen the BEC implementation.

The workshop was attended by 26 participants, representing local building energy efficiency experts from 12 key national organizations, such as Department of Alternative Energy Development and Efficiency (DEDE), Office of Natural Resources and Environmental Policy and Planning (ONEP), Office of National Higher Education Science Research and Innovation Policy Council (NXPO), Thai Green Building Institute (TGBI), and academic institutions. The list of participants and workshop agenda are given in Annex 2.

OPENING REMARKS

The virtual welcome remark was given via online video message by CTCN representative, Ms. Clara landeiro - Regional Manager-CTCN. The welcome speech was given by the NDE representative- Ms. Sirinya Lim.

Figure 52: Stakeholder Consultation Workshop

4.3 SUMMARY OF PRESENTATIONS

The workshop schedule was designed to update the new BEC 2020 and support implementation measures and activities under the DEDE and 2e-Building center. Following the introduction session, the project team presented the fact-finding and analysis results of Task 1. The presentation provided BEC benchmarking data and gap analysis of BEC performance, which lead to the focus areas for policy discussion and recommendation for further enhancement of the BEC program.

As most of the participants are Thai, all the presentations were prepared and conducted in Thai language. According to the COVID-19 pandemic situation worldwide, the international experts from DEM and IIEC could not participate in this stakeholder consultation workshop due to limited travelling, cannot join via teleconference due to the different time zones.

The keynote of each presentation are summarized as follows:

SESSION 1: OVERVIEW OF THE ENERGY EFFICIENCY PLAN AND THE BEC IMPLEMENTATION TARGET, AND BEC CURRENT STATUS

Following the opening remark, DEDE provided a presentation to share an update of energy policy direction under the National Energy Efficiency Plan (EEP 2015), and the BEC implemented measures and targets in the fiscal year 2021, including the enforcement status of the revised BEC 2020.

The revised BEC enforcement process is continuing through an inter-ministerial collaboration between DEDE and DPT. To date the new revised BEC 2020 enforcement is still under consideration by DPT. The first DPT-building control board meeting was held on 21st January 2021. It is expected for the draft of new Ministerial regulation of the building control will be approved and announced by MOI in September 2021, and scheduled for the new BEC to be implemented by the local administrative organizations by December 2021.

Under the BEC implementation mechanism implemented in 2021 and 2022, DEDE will support the BEC training program for BEC certified auditor, which targets 4,300 certified auditors by 2022. In the pipeline, DEDE will set up the technical working group to review the BEC compliance system and develop the monitoring and evaluation (M&E) system, including support for enhancing the BEC level by demonstrating the new zero energy building (NZEB).

SESSION 2: PROJECT BACKGROUND AND INTRODUCTION

IIEC briefly introduced the project background, objectives, expected outputs and project timelines. The audience acknowledged the overall objective of this GCF readiness project as to support Thailand in achieving national targets for energy efficiency in the building sector, prescribed in the Energy Efficiency Plan of 2015, NAMAs, and Thailand's NDC. The project period is 12 months, from September 2020 to August 2021.

The project team informed the project coverage of five building types: offices, hotels, department stores, medical centers and condominiums. The summary of the six-component of project activities was presented by an infographic shown in Figure 53..

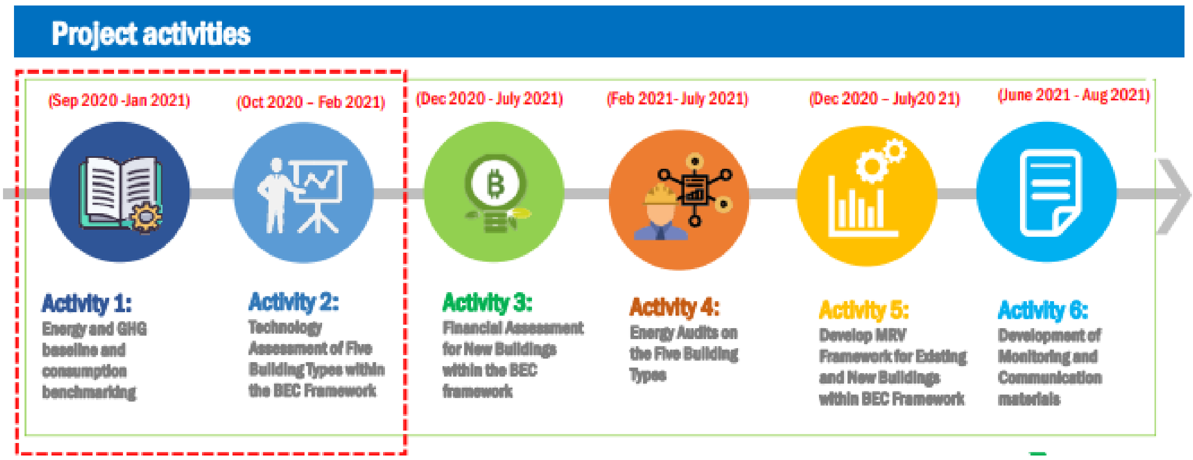


Figure 53: Summary of the Six-Components of Project Activities

SESSION 3: PROMOTING ACTIVITIES AND SUPPORTING TOOL AND IMPLEMENTATION FOR BEC COMPLIANCE UNDER 2E-BUILDING CENTER

This session was presented by the representative consultant from KMITL who is in charge of running the Coordinating Center for Energy Conservation Building Design (2e-Building Center) for DEDE. The 2e-Building Center was established in 2010 to support building designs and implementation of the BEC 2009. The presentation aimed to provide information on their role, activities and achievements over the past decade.

From the result of BEC 2009 implementation, an accumulated total of 861 buildings was applied for building construction permit under BEC compliance from 2009 to 2020; 522 buildings for government buildings and 399 private buildings. It accounted for an estimated accumulation of energy saving of 630.35 GWh in 2020, equivalent to saving of 54.20 ktoe and 338.5 million ton CO_2.

The 2e-Building Center has developed the BEC manual handbook and BEC calculation toolkit to support the building designer and owner to verify the building design condition to comply with BEC requirements. In 2019, the BEC calculation program was updated and launched as the web-based version, and the program has been used for training the BEC-certified auditor. Up to date, the 2e-Building Center has conducted the BEC training program for BEC's trainees and issuance of 650 BEC certificates for BEC auditors.

The consultant also presented the new BEC 2020 criteria of six technical components and the two options of compliance with the BEC requirements. It is noted that the existing BEC web-based calculation program is still using the previous criteria of the BEC 2009. DEDE has planned to revise and update the program software once the new BEC 2020 become effective.

SESSION 4: BEC PERFORMANCE BENCHMARKING AND TECHNOLOGY ASSESSMENT

In this session, the analysis results in this report Chapter 2 were summarized and presented to the audience. The project team presented the methodology for analyzing BEC energy consumption and benchmarking assessment using the consolidation from the ten-year BEC assessment database, from 2009 to 2019.

The results under the three scenarios of BEC reference baseline, Pre-BEC assessment and Post-BEC assessment were presented. The EUI profiles of five building types benchmarking against the reference EUI and the gap analysis of BEC performance over 10-year of implementation were also presented.

Summary of the keynote of the presentation are as follows:

- From the BEC analysis under three scenario models, the results indicate the decreasing trend of the average EUI of all five building types; the overall average of five building EUI reduces by 15% from 93.3 kWh/m^2-y to 79.6 kWh/m^2-y.
- The current BEC reference baselines, established since the launch of the BEC program in 2009, have been using as the basis for BEC energy and performance reference in option 2 compliance.
- It is observed that EUIs of all building types, both PRE and POST-BEC assessment, are much lower than the reference EUI.
- With BEC 2009 criteria applying from 2009 to 2019, 98.8% of the five building types can comply, only 21.1% comply with option 1, and 77.7% fail option 1 but comply with option 2.
- Most of the non-compliances under option 1 are due to the building envelope's OTTV and RTTV criteria. Only 3% of the buildings fail the air conditioning (AC) or lighting power density (LPD) criteria.
- Most of the failed buildings from option 1 criteria can still pass the overall EUI criteria of option 2.
- Applying the tighter BEC 2020 criteria to the same data, the total compliance remained at the same level at 98.6%, with option 1 dropping to 11.9% and option 2 increasing to 86.7%.

SESSION 5: BEC TECHNOLOGY ASSESSMENT OF FIVE BUILDING TYPES WITHIN THE BEC FRAMEWORK

In this session, the preliminary analysis results in this report Chapter 3 were summarized and presented. The BEC compliance requirements and parameters relevant to the BEC criteria and building design were presented. Analysis results of the BEC assessment database revealed the material commonly used in the buildings and how they affect the BEC compliance.

The distribution profiles of the OTTV and RTTV (Pre-BEC assessment) of the five building types over ten years of BEC implementation were presented. The overall pass/fail conditions of all buildings based on material categories against the OTTV and RTTV criteria of the BEC 2009 were given, indicating the compliance percentage of the building population distribution profiles.

Summary of the key note of the presentation are as follows:

- Most building types and sizes fail to comply with the OTTV criteria.
- For RTTV only hospital can meet BEC 2009 criteria on all building sizes.
- It is clearly that the BEC envelop criteria of OTTV and RTTV are the most difficult to comply.
- Building system including air conditioning, lighting, hot water and renewable energy have no impact on the BEC compliance. Most system available and applied with BEC compliance could be met or even exceed the BEC performance criteria.
- Subsequently the preliminary technologies assessment for building design and their relevance to building envelop and other BEC component are listed.

4.4 SUMMARY OF DISCUSSION AND RECOMMENDATION

The analysis results of the energy consumption baseline, benchmark and GHG emission assessment, and the technical assessment results provided the common ground for discussing the policy-related issue for BEC program enhancement and recommendation on relevant technical issues from the participants. The following discussion issues were discussed and noted from the workshop.

POLICY-RELATED ISSUES:

- The benchmark analysis of the building database provides a good understanding of the building's energy efficiency performance situation, which are valuable for further adjustment and design of the policy.
- With BEC primary objective, BEC should be treated as the minimum requirements that every building design should comply with, rather than the building design.
- For BEC compliance alternatives, option 1 and option 2 the stakeholders agreed with the presented results that the current criteria set on option 1 are ineffective compared with option 2.
- As BEC is targeted for inclusion to the building construction permit, it is agreed in the workshop that both compliance options should be remained but used in different perspectives. Option 1 could be used as a pulling mechanism for encouraging the building designer and owner to better their building energy efficiency design. Option 2 should be strengthened as the pushing mechanism to force all buildings, especially buildings with low energy efficiency awareness, to comply with the BEC.Option 1 sets the minimum criteria with the intention for every building to follow, while option 2 provides flexibility in building design and avoids the complication and reluctance in regulation enforcement.
- It is recommended that the detailed setting of the criteria should be investigated for better balance of both option effectiveness, otherwise further enforcement would be weak.

- The BEC criteria should be revised over a regular period, i.e. every five years, to reflect the improved performance of the new building materials and technology.
-
- DEDE should consider using policy-driven incentive to promote the investor/building owner to investment in improvement of building energy performance.
-

TECHNICAL-RELATED ISSUES:

- The calculation of the energy consumption of the reference buildings is based on the formula and parameters derived from DEDE energy audit reports of 1,800 designated buildings during 1996-2003. Although the calculation formula is still correct, some applied parameters might be outdated and need adjustment to reflect changes in building materials, technology and operation of the present buildings.
- It is realized from the benchmarking that the average EUIs of all five building types are well below the average EUIs of the reference buildings.
- It is agreed that the setting of the BEC criteria is comparable to international standard and applicable to Thailand. So far, there is no objection from the stakeholders.
- Although the BEC evaluation program applies the same energy calculation format to the reference building, the components to the calculation are specified for inputting building design. Some building systems such as lift and escalator, electric equipment and appliances are omitted, making the estimated energy consumption lower than the actual energy consumption.
- The use of renewable energy, heat recovery and alternative energy scheme in building design is still insignificant. BEC might consider putting more incentive or criteria of using renewable energy or mandate a certain extent of renewable or alternative energy.
- It is a suggestion to add some verification mechanism after construction completion and when the buildings are in operation to track actual energy performance compared to the calculation estimated during BEC assessment.
- The workshop suggested that GHG emissions from the building energy consumption should be included in the BEC assessment. This would raise more awareness of the environmental impact of the building design and help the country meet the GHG emission reduction goal.

4.5 WORKSHOP EVALUATION

Following the completion of the workshops, the evaluation was conducted through the workshop satisfaction assessment form with three aspects.

1) Knowledge and Suitability of the Content.
2) Information, Usefulness and Consultation.
3) Quality of Workshop Organization

The results are summarized as follows:

The overall respondents on the workshop satisfaction based on a five Likert scale satisfaction score are shown in Figure 54 to Figure 55.

KNOWLEDGE AND SUITABILITY OF CONTENT:

More than 60% of participants are directly or partially involved in the BEC implementation activities and have been working with DEDE for a long time. More than 65% of the respondents satisfied with the overall workshop arrangement, the provided content, including the Q&A session. However, as most of the participants are BEC experts, knowledge gained before and after are not much different.

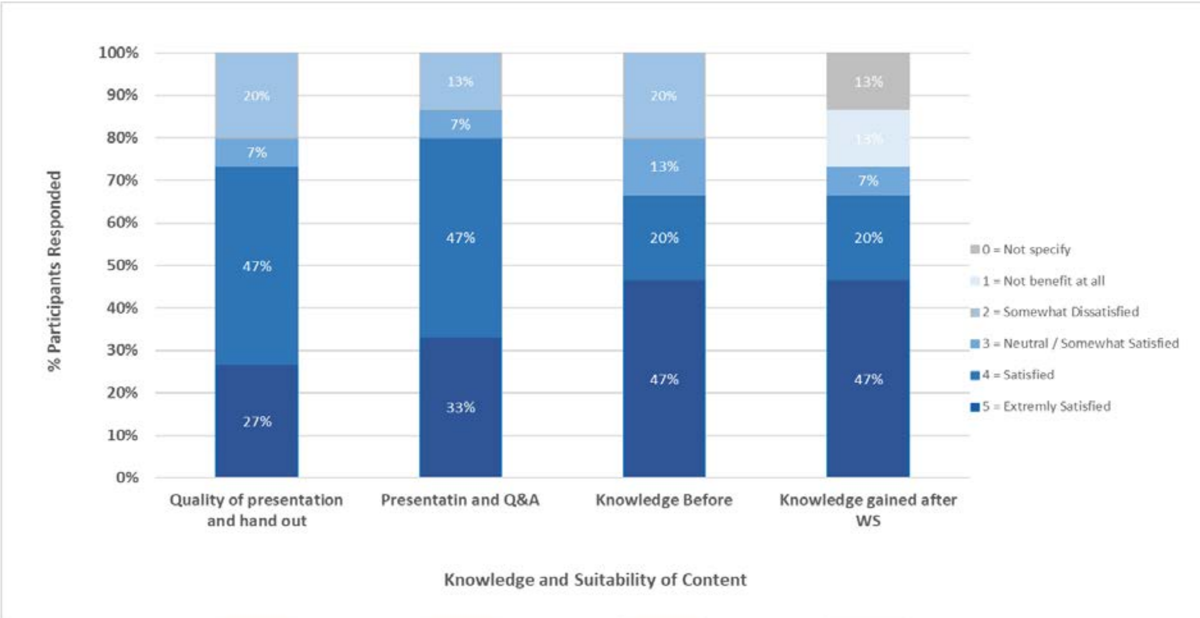


Figure 54: The Participants' Responses on the Knowledge Gain and Suitability of Workshop Content

INFORMATION, USEFULNESS AND CONSULTATION:

The participants viewed the content's information and usefulness. More than 80% of the respondents were satisfied with the presented information and discussion topics, and realized the benefits on BEC implementation and policy development. 67% of respondents were happy with the stakeholder consultation process, and 67% satisfied with gender equality; everyone had the same opportunity to express their opinion.

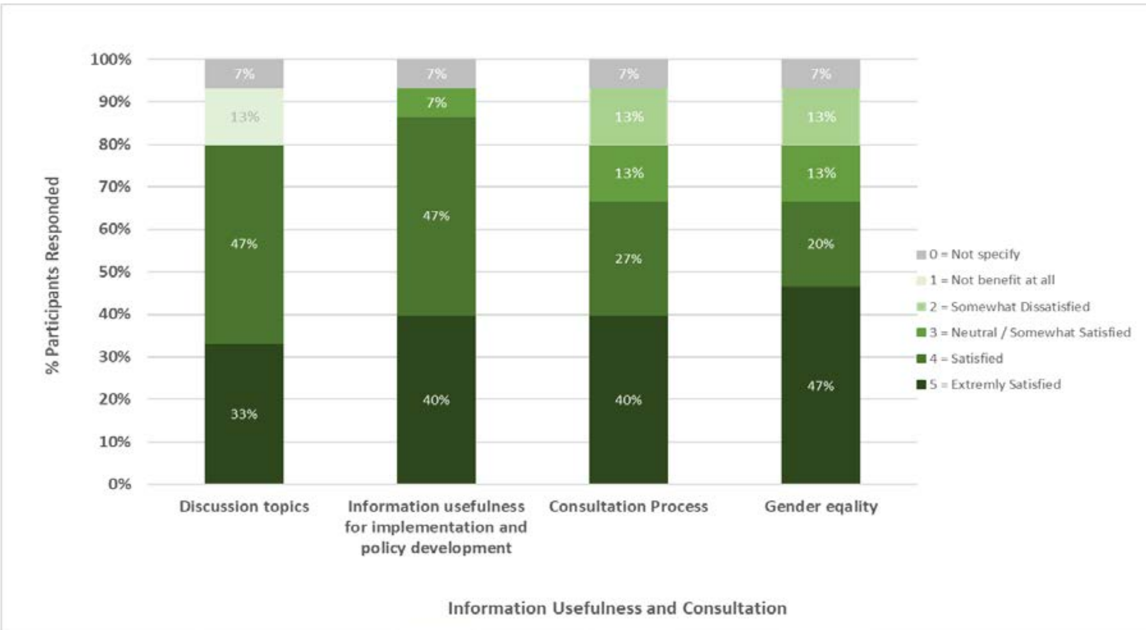


Figure 55: The Participants' Responses on the Information Usefulness and Consultation Process

Quality of Venue, Food and Time:

More than 80% of participants felt satisfied with the quality of venue and food, function room and materials, workshop organization and coordination. However, some participants were somewhat dissatisfied with time (20%) as the open discussion time was too short. The detailed evaluation results toward the quality of venue and workshop organization arrangement is shown in Figure 56.

Figure 56: The participants' Responses on the Quality of Venue and Workshop Organization Arrangement

5 LESSONS LEARNT AND IMPLEMENTATION CHALLENGES

From the previous progress report the collaboration process for data acquisition have been greatly improved thanks to the excellent support from DEDE working group and KMITL BEC team. However as most of the work in this progress report 2 involves detailed data analysis for the completion of task 1, the main challenges faced in this progress are on the quality of data received. Additionally, the impact of recently widespread of COVID-19 pandemic may affect the work of the incoming project activities. These challenges are summarized below.

1. Non-standardized data

From further analysis of the data extracted from the BEC assessment database, it is found that data stored in many categories were not standardized. For example fifteen names with different words or word orders were used to represent the same concrete wall with plaster finish. Considerable efforts were taken to clean, interpret and standardize the names in order to classify the data before detailed gap analysis and benchmarking could be performed.

2. Incomplete and non-systematic details of BEC components

Apart from building envelope materials, data extracted from the database does not provide enough details of other BEC components such as sizes, types and energy consumption of lighting and air conditioning. Many building records have incomplete details while others were completely missing. There is no breakdown of energy consumption of building air conditioning and lighting from the calculation. With the incomplete details, benchmarking analysis of these components are therefore limited to only comply/not comply.

From the analysis experience, the project team still sees the use of the BEC assessment database as the powerful tools for analysis and planning of the BEC program. To make it fully usable it is suggested that parts of this BEC assessment database be reviewed and sanitized. Adding automatic data export and analysis tools are worth considering to lower the efforts use in the future, especially for the full enhancement and enforcement of BEC in the coming years.

3. Uncontrollable of COVID-19 pandemic may effect to the next step activities

Since the beginning of March 2021, the third round of COVID-19 pandemic situation in Thailand has shown a resurgence of COVID-19 infections around the country. Presently the Thai Government is putting a lot of efforts to control this outbreak to avoid the widespread lockdown the whole country. However, if the current situation worsens, it would possible affect to the upcoming activities of Task 2 and 3, the stakeholder workshop consultation, and energy audit of Task 4. This would likely result in project delays as all project partners and the stakeholders especially the building owner are hardly cooperate and allow visiting.

Foreseeing this happening the following alternative plans will be put in place for conduct the stakeholder consultation:

- Setting up the regular monthly online meetings with the project team and review of the situation as needed.
- Maintaining regular dialogue and meetings with all project partners and stakeholders through appropriate communication channels or remote online platforms.
- Mobilizing the stakeholder engagement process, proactive stakeholder management and health safety precautions are needed. The stakeholder meetings will be conducted though teleconference applications, e.g., zoom meeting.

CTCN will be notified if there is any change to the existing COVID-19 restrictions.

6 ANNEX-1 SUMMARY OF BEC TECHNICAL REQUIREMENTS

The BEC addresses the technical requirements for the building design in six components for nine building types of three operation categories. The six BEC components and nine building types are:

BEC components:

1. Building envelope: wall (OTTV) and roof (RTTV)
2. Lighting system
3. Air conditioning system
4. Hot water generation system
5. Renewable energy utilization
6. Whole building energy performance

Building types:

Group 1: 8 hours/day operating hours

- Office
- School

Group 2: 12 hours/day operating hours

- Department store
- Exhibition and convention hall
- Entertainment service
- Theater

Group 3: 24 hours/day operating hours

- Hotel
- Hospital
- Condominium

*Note that the project scope covers five building types: office, department store, hotel, hospital and condominium.

The component 1 to 4 specify minimum criteria for individual building system to comply with option 1. Failing to meet any criteria of component 1 to 3 will result in option 1 noncompliance and option 2 will be used for evaluation of the whole building consumption or component 6 against the reference building consumption. In option 2 evaluation, renewable energy use or component 5 will be considered as the credit to reduce the building consumption. Component 4 hot water generation is treated as an independent criterion which building must comply with on both options.

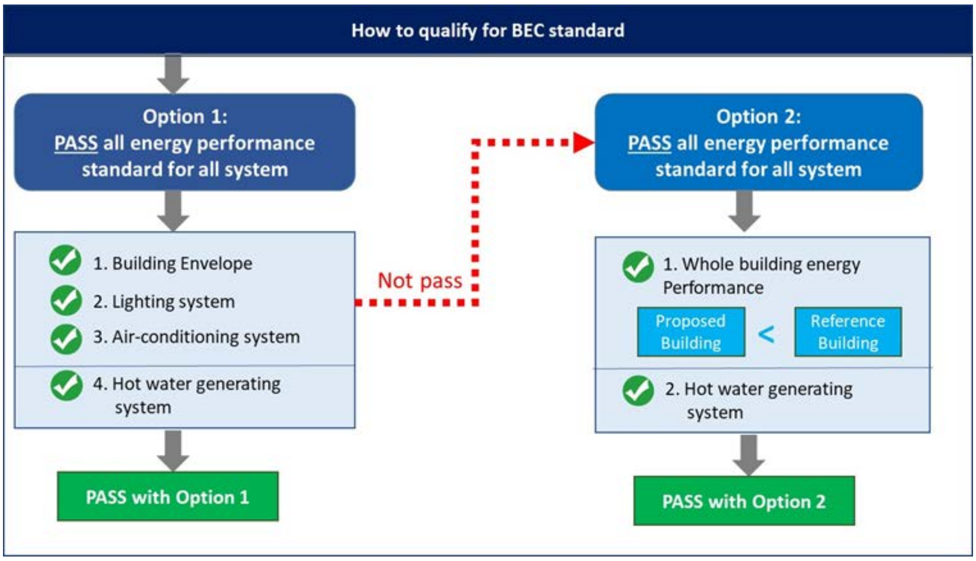


Figure 57: BEC Compliance Options

Option 1 compliance

Table 16 to 22 show the minimum criteria for the individual system of component 1 to 4. It is required that the building system and equipment must pass these minimum criteria.

Component 1: Building envelope: OTTV and RTTV

Table 16: Criteria for Building Envelope OTTV and RTTV

Type of target building	OTTV (W/m²)		RTTV (W/m²)	
	BEC 2009*	BEC 2020	BEC 2009*	BEC 2020
Group 1: Office building, and School	≤ 50	≤ 50	≤ 15	≤ 10
Group 2: Exhibition building, Theater, Entertainment service, and Department store	≤ 40	≤ 40	≤ 12	≤ 8
Group 3: Hotel, Hospital, Condominium	≤ 30	≤ 30	≤ 10	≤ 6

Component 2: Lighting system

Table 17: Maximum Allowable Rated Lighting Power Density (LPD) for Lighting System

Type of target building	LPD (W/m²)	
	BEC 2009*	BEC 2020
Group 1: Office building, and School	≤ 14	≤ 10
Group 2: Exhibition building, Theater, Entertainment service, and Department store	≤ 18	≤ 11
Group 3: Hotel, Hospital, Condominium	≤ 12	≤ 12

Component 3: Air conditioning system

Table 18: COP and EER Standards for Small Air-conditioning System (Split Type)

Type of Split Type AC	Size of Cooling Capacity	BEC 2009*		BEC 2020**	
		COP (W/W)	EER (Btu/hr/Watt)	COP (W/W)	SEER (Btu/hr/Watt)
Fixed-speed	Cooling Capacity (CC) ≤ 8,000 Watt	≥ 3.22	≥ 11.0	≥ 3.76	≥ 12.85
	8,000 > CC ≤ 12,000 Watt	≥ 3.22	≥ 11.0	≥ 3.63	≥ 12.40
Variable Speed/Inverter	Cooling Capacity (CC) ≤ 8,000 Watt	≥ 3.22	≥ 11.0	≥ 4.39	≥ 15.0
	8,000 > CC ≤ 12,000 Watt	≥ 3.22	≥ 11.0	≥ 4.10	≥ 14.0

Remark: * Refer to the Ministry of Energy Notification Prescribing Minimum standard of COP, EER and CHP for air conditioning system installed in Building in 2009 (B.E. 2552).
** Refer to the latest minimum requirement of the EGAT No.5 labelling announced in year 2019.

Table 19: CHP Standard for Large Air-conditioning System (Chiller)

Type of Chiller		Refrigeration capacity, at Full load(Ton of refrigeration)	CHP (kW/Ton of refrigeration)	
Type of Condenser	Type of Compressor		BEC 2009	BEC 2020*
Air-cooled chiller	All type	≤ 300 ≤ 300	≤ 1.33 ≤ 1.31	≤ 1.12
Water-cooled chiller	Reciprocating	All type	≤ 1.24	≤ 0.88
	Rotary, Screw	All type	≤ 0.89	≤ 0.70
	Scroll	All type	≤ 0.78	≤ 0.89
	Centrifugal	≤ 300 ≤ 300	≤ 0.76 ≤ 0.62	≤ 0.67 ≤ 0.61

Remark: * The CHP standard for large air conditioning system (chiller) in the new revision BEC code is reference to the Ministry of Energy Notification Prescribing the High Energy Efficiency Standard (HEPS) for large air conditioning system (Chiller) installed in Building in 2009 (B.E. 2552).

Table 20: CHP Standard for Large Air-conditioning System (Absorption Chiller)

Type of Absorption Chiller	Rated capacity					CHP (kW/Ton of refrigeration)	
	Chilled-Water Temperature		Condenser-Cooling water				
	Inlet (°C)	Outlet (°C)	Inlet (°C)	Outlet (°C)	Water flowrate (L/s/kW)	BEC 2009	BEC 2020
a) Single stage	12.0	7.0	32.0	37.5	0.105	0.65	0.65
b) Double stage	12.0	7.0	32.0	37.5	0.079	1.10	1.10

Component 4: Hot water generation system

Table 21: Standard of Boiler Efficiency

Type of boiler	Boiler efficiency (%)	
	BEC 2009	BEC 2020
a) Oil fired steam boiler	≥ 85%	≥ 85%
b) Oil fired hot water boiler	≥ 80%	≥ 80%
c) Gas fired steam boiler	≥ 80%	≥ 80%
d) Gas fired hot water boiler	≥ 80%	≥ 80%

Table 22: COP Standard of Air-source Heat Pump Water Heater

Type of design	Standard Condition of performance			COP of Heat pump*	
	Temperature of water inflow (°C)	Temperature of water outflow (°C)	Temperature of ambient (°C)	BEC 2009	BEC 2020
a) Type 1	30.0	50.0	30.0	≥ 3.5	≥ 3.0
b) Type 2	30.0	50.0	30.0	≥ 3.0	≥ 3.0

Option 2 compliance

The option 2 considers the building energy consumption as a whole and allows trade-off among building system components as long as the overall building energy performance are met.

Component 5: Renewable energy utilization

BEC has no mandatory requirement for using renewable energy. But energy generated from renewable energy sources including photovoltaic system can be taken into account in the option 2 compliance by subtracting the amount produced from the calculation of whole building energy consumption in component 6.

Component 6: Whole building energy performance

The evaluation of whole building energy consumption in component 6 is based on the calculation formula for annual building energy consumption.

$$E_{pa} = \sum_{i=1}^{n} \left[\begin{array}{c} \dfrac{A_{wi}(OTTV_i)}{COP_i} + \dfrac{A_{ri}(RTTV_i)}{COP_i} \\ + A_i \left\{ \dfrac{C_i(LPD_i) + C_e(EQD_i) + 130C_o(OCCU_i) + 24C_v(VENT_i)}{COP_i} \right\} \end{array} \right] n_h$$

$$+ \sum_{i=1}^{n} A_i(LPD_i + EQD_i)\, n_h - (PVE + HEE + ORE)$$

Where E_{pa} is the annual energy consumption of the whole building in kWh/y

$OTTV_i$ is the overall thermal transfer value of external walls of air conditioned space i in w/m^2

$RTTV_i$ is the roof thermal transfer value of air conditioned space i in w/m^2

COP_i is the minimum coefficient of performance of air conditioning system of space i

A_i is the area of air conditioned space i in m2

A_{wi} is the wall area including opaque walls and glazing of air conditioned space i in m^2

A_{ri} is the roof area including opaque and transparent roof of air conditioned space i in m^2

LPD_i is the lighting power density of space i in W/m^2

EQD_i is the equipment power density of space i in W/m^2

$OCCU_i$ is the occupancy density of space i in person/m^2

$VENT_i$ is the air ventilation rate of space i in l/s

n_h is the nominal operating hours of the building in hours/y

PVE is the average annual electricity generation from solar photovoltaic system in kWh/y

HEE is the average annual thermal energy generation from energy recovery system in kWh/y

OEE is the average annual electricity generation from other renewable energy sources in kWh/y

C_i, C_e, C_o, C_v are the coefficients of thermal power contribution to the load of the air-conditioning systems by lighting, equipment, occupants and ventilation

The first summation of the above equation above accounts for energy consumption of the air conditioning system. The second summation accounts for the energy consumed directly by lighting and other equipment. The last part of the equation is the contribution of renewable energy in replacing some amount of energy use in the building.

The largest portion of the building energy use is the air conditioning system, accounting for around 60% of total energy use. The major contribution to the air conditioning consumption is the heat gain through the building envelope, which can be reduced with the improvement of OTTV and RTTV. Further reduction of air conditioning load can be done by improved lighting efficiency (LPD), high efficiency equipment (EQD), optimized occupancy (OCCU) and optimized ventilation (VENT) of the air conditioned spaces. Reduction of air conditioning cooling load in the building design will decrease the size and investment in air conditioning system and ongoing energy expenses thus normally proven to be cost effective. Together with the high efficient air conditioning (COP), the energy consumption of the building will be significantly reduced.

The reduction of the energy use in the unconditioned spaces can be done by improved lighting (LPD) and energy efficient building system and equipment (EQD). The use of renewable energy and energy recovery (PVE, HEE, OEE) will directly replace consumption of electricity and increase building energy efficiency.

7 ANNEX-2 STAKEHOLDER WORKSHOP AGENDA AND PARTICIPANT LIST

7.1 AGENDA

Stakeholder Consultation Workshop # 1

Project "Enabling Readiness for Up Scaling Investment in Energy Efficiency for Achieving NDC Goals in Thailand"

Monday, 8th March 2021

Marriott Executive Apartments-Sukhumvit Park, Gallery Room, Bangkok

Agenda	
08.30 – 09.00	**Registration**
09.00 – 09.10	**Welcome Remark and Opening** *By: Representative of CTCN and* NXPO
09.10 – 09.20	**Overview of the Energy Efficiency Plan and the BEC Implementation target, and BEC current status** *By: Representative of DEDE*
09.20 – 09.30	**Project Background and Introduction** *By: IIEC*
09.30 – 09.45	**Promoting Activities and Supporting tool and Implementation for BEC compliance under 2e-Building Center** *By: Project manager of the Coordinating Center for Energy Conservation Building Design (2e-Building Center), DEDE*
09.45 – 10.30	**Ten-years BEC Performance Benchmarking and Technology Assessment** *By IIEC*
10.30 – 10.45	Coffee break
10.45 – 11.30	**Technology Assessment of Five Building Types within the BEC Framework** *by IIEC*
11.30 – 12.00	**Q&A and Discussion**
12.00 – 13.00	Lunch
Remark:	Please scan QR Code for registration or confirmation through the email attached here. Email: swachirapuwadon@iiec.org

7.2 PARTICIPANT LIST

Total 26 persons from 12 organization as list below:

No.	Participants	Title	Organization
1	Dr. Kittisak Prukkanone	Director of Climate Change Management and Coordination Division	Office of Natural Resources and Environmental Policy and Planning (ONEP)
2	Mr. Worapon Mathurosmatanee	Environmentalist-Senior Professional	
3	Ms. Sirinya Lim	Division Director of Innovation Economy	Office of National Higher Education Science Research and Innovation Policy Council (NXPO)
4	Ms Sirinporn Daengphuang	Policy analyst	
5	Mr. Prakob Eamsa-Ard	Head of Building standard regulation and enforcement group	Department of Alternative Energy Development and Efficiency (DEDE)
6	Mr. Wistikorn Nimnual	Senior Professional Engineer	
7	Ms. Chalermluk Jitrumpueng	Senior Professional Engineer	
8	Dr. Apichit Therdyothin	Director, Energy Conservation Laboratory	King Mongkut's University of Technology Thonburi (KMUTT)
9	Assoc. Prof. Dr. Atch Sreshthaputra	Associate Professor	Faculty of Architecture, Chulalongkorn University (CU)
10	Mr. Danu Katunyutanunt	Researcher	
11	Mr. Supakiat Thongtub	General Manager	GIGAJOULE CO., LTD
12	Ms. Parnleykha Promta	Engineer	
13	Asst. Prof. Dr.Kiattisak Roonpradang	Assistant Professor	King Mongkut's Institute of Technology Ladkrabang (KMITL)
14	Prof. Dr. Surapong Chirarattananon	Professor of Joint Graduate School of Energy and Environment (JGSEE)	King Mongkut's University of Technology Thonburi (KMUTT)
15	Asst. Prof. Dr. Kuskana Kubaha	Dean of School of Energy Environment and Materials	King Mongkut's University of Technology Thonburi (KMUTT)
16	Assoc. Prof. Dr. Chanikarn Yimprayoon	Associate Professor,	Faculty of Architecture, Kasetsart University (KU)
17	Assoc. Prof. Dr. Prakob Surawattanawan	Associate Professor	Faculty of Engineer, Kasetsart University (KU)
18	Assoc. Prof. Dr. Pantuda Puthipiroj	Associate Professor,	Faculty of Architecture, Silpakorn University (SU)
19	Assoc. Prof. Dr. Prechaya Mahattanatawe	Associate Professor	

No.	Participants	Title	Organization
20	Asst. Prof. Dr. Pimolsiri Prajongsan	Assistant Professor	
21	Dr. Preecha Maneesatid	Professional Consultant	Thailand Green Building Institute (TGBI)
22	Mr. Sommai Phon-Amnuaisuk	Director, Asia-Pacific,	International Institute for Energy Conservation (IIEC)
23	Mr. Sran Sribhibhadh	Senior consultant, M&E Expert	
24	Mr. Preecha Preedavichit	Senior consultant, Building EE Expert,	
25	Ms. Sopin Wachirapuwadon	Senior project manager	
26	Ms. Wilaiwan Kunchansombut	Communication and Graphic Design Specialist	