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)

TASK 2: REPORT ON TECHNOLOGY ASSESSMENT OF FIVE BUILDING TYPES WITHIN BEC FRAMEWORK

(Activity 2.1)

Prepared for

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Leading the Transition to Clean Energy

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Acronyms

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

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

1 Progress by Activity 2.1: Assessment of Relevant Technologies with BEC Compliance

This reports provides the complete result of activities 2.1 - assessment of relevant Technologies. The result 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.

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.

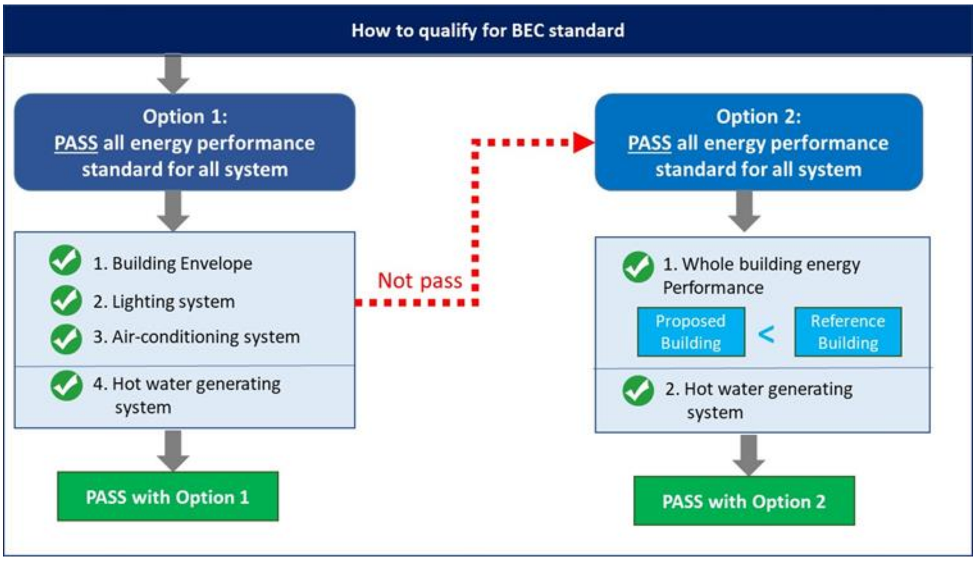

Figure 1: BEC Compliance Options

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 1 summarizes how six BEC components relate to the BEC compliance option 1 and 2.

Table 1: 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.

1.2 Technology Assessment by BEC Components

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.

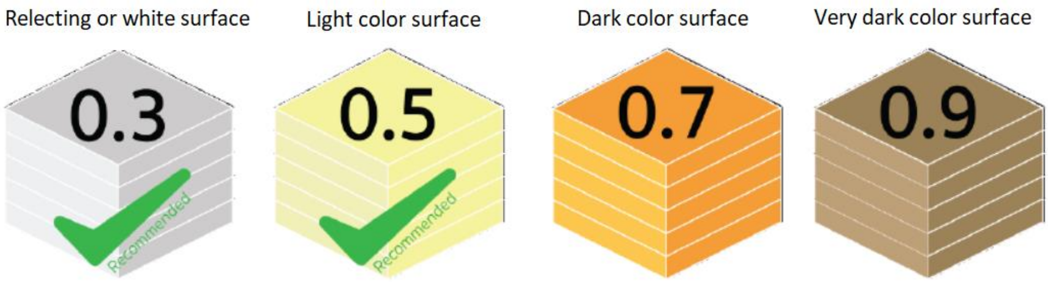

Figure 2: Illustration of Surface Colors and Solar Absorption Coefficients

- 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 3. 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.

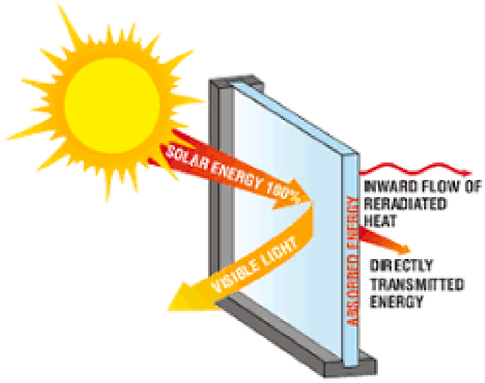

Figure 3: Illustration of Solar Heat Gain Coefficient (SHGC)[1]

- 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 4: 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.

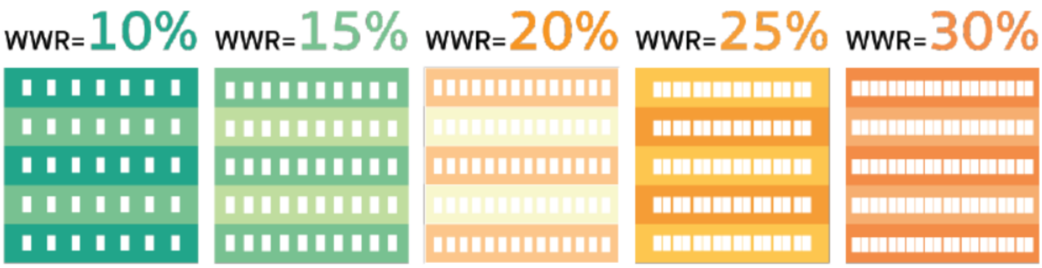

Figure 5: Illustration of Window to Wall Ratio

[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 2). For opaque wall and window materials, the ranges of Window-to-Wall Ratio (WWR) are given for reference.

Table 2: 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 3 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.

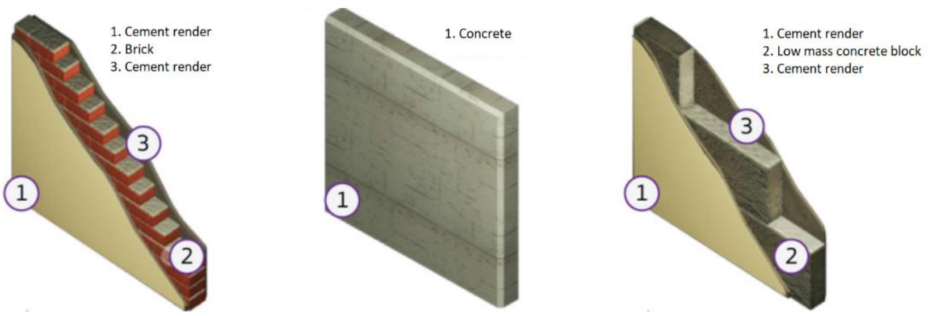

Figure 6: Examples of Common Opaque Wall Materials

Table 3: Opaque Wall Materials and OTTV Compliance, 2009-2019

Wall Material Group	No. of Buildings	Passing Category	OTTV Fail	%Fail	WWR Min	WWR Max	WWR Avg	OTTV Pass	%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%.

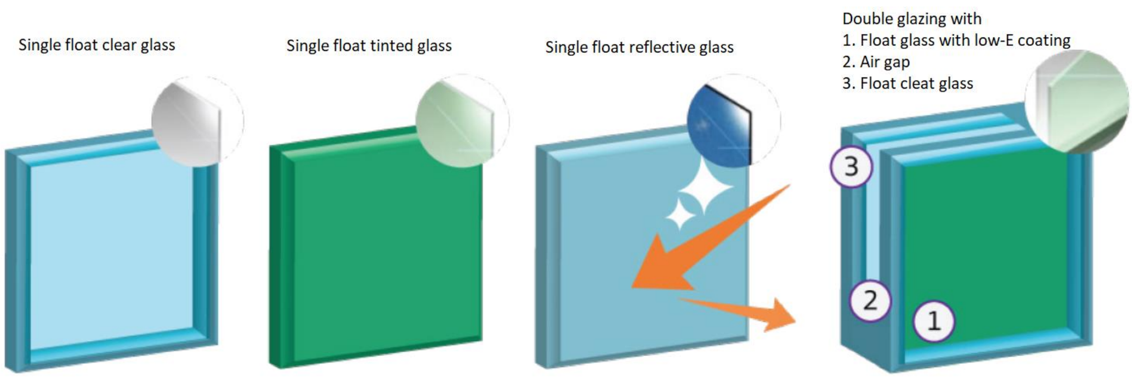

Figure 7: Examples of Window Glazing Materials

Table 4: 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 8: Examples of Roof Materials

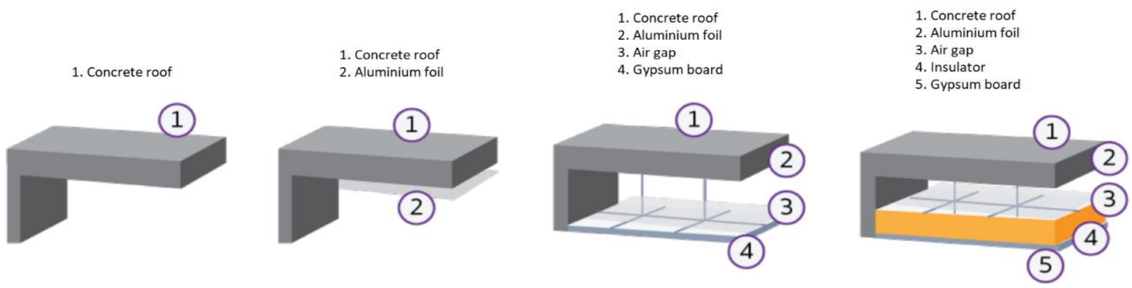

Figure 9: Examples of Roof Components

Table 5: Roof Materials and RTTV Compliance, 2009-2019

Roof Material	No. of	BEC 2009	RTTV BEC 2009		RTTV BEC 2009		BEC 2020	RTTV BEC 2020		RTTV BEC 2020	
Group	Buildings	Passing	Fail	%Fail	Pass	%Pass	Passing	Fail	%Fail	Pass	%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 6: Roof Materials and RTTV Compliance, 2009-2019 (Continued)

Roof Material	No. of	BEC 2009	RTTV BEC 2009		RTTV BEC 2009		BEC 2020	RTTV BEC 2020		RTTV BEC 2020	
Group	Buildings	Passing	Fail	%Fail	Pass	%Pass	Passing	Fail	%Fail	Pass	%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 7: Roof Materials and RTTV Compliance, 2009-2019 (Continued)

Roof Material	No. of	BEC 2009	RTTV BEC 2009		RTTV BEC 2009		BEC 2020	RTTV BEC 2020		RTTV BEC 2020	
Group	Buildings	Passing	Fail	%Fail	Pass	%Pass	Passing	Fail	%Fail	Pass	%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 8: Roof Materials and RTTV Compliance, 2009-2019 (Continued)

Roof Material	No. of	BEC 2009	RTTV BEC 2009		RTTV BEC 2009		BEC 2020	RTTV BEC 2020		RTTV BEC 2020	
Group	Buildings	Passing	Fail	%Fail	Pass	%Pass	Passing	Fail	%Fail	Pass	%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.

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.

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.

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.

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.

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.

1.3 SUMMARY LISTING OF APPLICABLE TECHNOLOGIES FOR BEC BUILDINGS

The following Table 9 summarizes the listing of applicable technologies for six BEC components as described above.

Table 9: 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

Technology	Target Building	Current Status
Variable refrigerant volume (VRV) split-type and packaged unit	Small to medium sized buildings	Common
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

2 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.

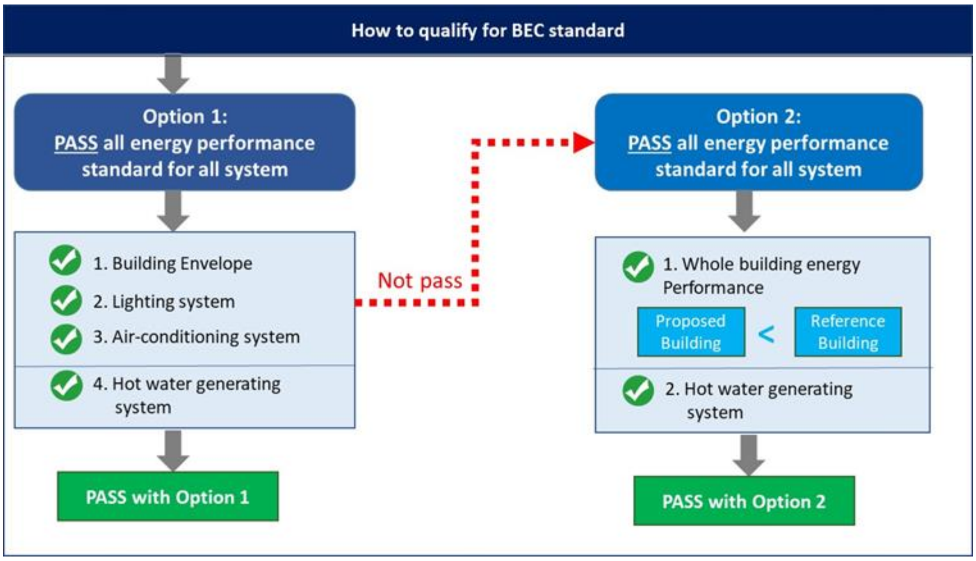

Figure 10: BEC Compliance Options

Option 1 compliance

Table 10 to 16 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 10: 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 11: 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 12: 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 13: 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 14: 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 15: 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 16: 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.

3 ANNEX-2 DETAILS OF LONG LIST POTENTIAL TECHNOLOGIES FOR IMPROVING ENERGY PERFORMANCE OF BEC BUILDINGS

3.1 COMPONENT 1: BUILDING ENVELOPE

Heat transfer by thermal conductance from the external ambient to the building can be reduced by using building envelope materials with low thermal transfer coefficients or U-values. U-value indicates how well the materials can transfer the heat with temperature difference across them. U-values are measured in watts per square meter per kelvin (W/(m²-K)). For example, a concrete wall with a U-value of 3.0, for every degree difference in temperature between the inside and outside of the wall, 3 watts will be transmitted every square meter.

U-values can be used to describe the thermal transfer properties of single or composite materials such as walls made up of concrete, insulator and gypsum board layers. The lower the U-value of building envelope, the more slowly heat is able to transmit through it, and so the better it performs as the heat insulator. Along with U values are R-values. The R-value is a measure of thermal resistance rather than thermal transmission, often described as being the reciprocal of U-values but excluding surface heat transfers.

Thermal properties of the materials including thermal conductance coefficient (k), density and specific heat (Cp) in conjunction with thickness and the composition of envelope layers have direct impacts on the U-values. With similar composition layers and thickness, building envelope with lower thermal conductance, density and specific heat materials will have lower U-values.

The following Table 17 compares thermal properties of common building envelope materials for opaque walls and roofs.

Table 17: Thermal properties of some common building envelope materials[2]

Materials	Thickness (cm)	Density (kg/m³)	Thermal conductance coefficient (W/m-K)	Specific heat (kJ/kg-K)
Concrete	10.0	2,400	1.422	0.92
Concrete	25.0	2,400	0.993	0.79
Brick	3.0 - 6.0	1,760	0.807	0.79
Low mass concrete block	7.5 - 20.0	500 - 1,280	0.099 - 0.476	0.84
Concrete roof tile	6.0	1,500 - 2,000	0.202 - 0.395	1 - 1.88
Metal sheet	0.25 - 1.0	7,840	47.6	0.5
Fiber glass insulator	2.54	10 - 40	0.037	0.96
Mineral wool insulator	2.54	40 - 140	0.033 - 0.042	0.98
PU foam insulator	2.54	35 - 45	0.02	1.59

Opaque Walls

3.1.1 Low mass wall materials

Recent development have introduced wall materials that are reasonably strong, light weight and with improved thermal properties compared to the conventional materials such as concrete or brick. The most common low

[2] Source: DEDE

mass materials which can replace the conventional concrete or brick are Autoclaved Aerated Concrete (AAC), Cellular Light Weight Concrete (CLC) and Glass Fiber Reinforced Concrete (GFRC).

Autoclaved Aerated Concrete Blocks (AAC)

Aerated concrete is a versatile, lightweight building material. Compared to solid dense concrete blocks, aerated concrete blocks have lower density and better insulation properties. They are durable and have good resistance to sulfate attack and damage by fire and frost. Compared to concrete blocks, they are lighter and easier to handle and install. Aerated concrete block has dry bulk density around 400-700 kg/m^3, equivalent to one-third of the clay brick and one-fifth of the common concrete and thermal conductivity around 0.09-0.22 W/m K, only one-fourth to one-fifth of the clay brick and one fifth to one-tenth of normal concrete. [3]

Figure 11: Autoclaved Aerated Concrete (AAC) blocks[4]

Cellular Light Weight Concrete Blocks

Cellular Light Weight Concrete or CLC blocks are made from a slurry of cement, fly ash, and water, to which pre-formed stable foam is added in an ordinary concrete mixer under ambient conditions. The addition of foam to the concrete mixture creates millions of tiny voids or cells in the material, hence improves insulation property. The density of CLC ranges from 400 kg/m^3 to 1,800 kg/m^3 compared to regular concrete at 2,400 kg/m^3.

The low densities (400-600 kg/m^3) are ideal for thermal and sound insulations. The medium densities (800-1,000 kg/m^3) are for non-load-bearing brickwork. And the high densities (1200-1800 kg/m^3) are for structural-grade material used for load-bearing walls and ceilings of low rise structures. Thermal conductivity of the low density CLC are around 0.10 W/m-K while the medium and high densities have the thermal conductivities of 0.17-0.30 and 0.38-0.66 W/m-K respectively.[5]

[3] Ministry of Housing and Urban-Rural Construction of the People's Republic of China. Technical Specification for Application of Autoclaved Aerated Concrete. China Building Industry Press; Beijing, China: 2008. JGJ/T17-2008.

[4] Source: Linyi

[5] Erwin S., et al., Effect of Cement Variation on Properties of CLC Concrete Masonry Brick, MATEC Web of Conferences 159, 01008 (2018).

Figure 12: Cellular Light Weight Concrete (CLC) blocks[6]

Glass Fiber Reinforced Concrete cladding

Glass Fiber Reinforced Concrete (GFRC) is an alternative to pre-cast concrete for building facades. Because of its strength, this type of cladding can be produced in thinner sections to meet complex architectural specifications, and is three to five times lighter than standard concrete. GFRC has excellent weather-proof and fire-retardant qualities, and is also more water and pollution-proof than standard concrete. Glass reinforced concrete offers greater versatility due to its superior compressive strength and flexibility. It is also easy to handle and fast to erect and mount on support systems due to its light weight. Thermal conductivity of a typical glass fiber reinforced concrete with density of 1,900 – 2,100 kg/m^3 is in the range of 0.5 to 1.0 W/m-K.

Figure 13: Glass fiber reinforced concrete[7]

[6] Source: https://theconstructor.org/

[7] Source: Rieder Group

3.1.2 Wall Insulation

Adding insulation to building walls lowers heat transfer caused by the temperature difference between indoors and outdoors. Insulation reduces unwanted heat gain and energy consumption of the air conditioning systems. Insulation materials range from fiber materials such as fiberglass, rock and slag wool, to rigid foam boards to sleek foils. Fiber materials resist conductive and convective heat flow in a building cavity. Rigid foam boards trap air or another gas to resist heat flow. Highly reflective foils in radiant barriers and reflective insulation systems reflect radiant heat away from the building envelope.

Fiberglass

Fiberglass consists of extremely fine glass fibers. It is one of the universal insulation materials. The most common type of fiberglass for building insulation comes in the form of blanket: batts or rolls. Standard fiberglass blankets and batts have a thermal resistance or R-values between R-2.9 and R-3.8 per inch of thickness. High-performance (medium-density and high-density) fiberglass blankets and batts have R-values between R-3.7 and R-4.3 per inch of thickness.

Mineral Wool

The term "mineral wool" typically refers to two types of insulation material: rock wool, a man-made material consisting of natural minerals like basalt or diabase, and Slag wool, a man-made material from blast furnace slag (the waste matter that forms on the surface of molten metal). Mineral wool contains an average of 75% post-industrial recycled content. It doesn't require additional chemicals to make it fire resistant, and it is commonly available as blanket (batts and rolls) and loose-fill insulation.

Polystyrene

Polystyrene is a colorless, transparent thermoplastic, widely used in products from toys and packaging to automobile parts and electronics. Polystyrene expanded into a foam material, called Expanded Polystyrene (EPS) or Extruded Polystyrene (XPS), are used as insulation. EPS and XPS contain millions of air pockets trapped within the foam. Because the polystyrene itself is also highly resistant to heat, the result is a great thermal insulator. In addition to this, XPS is often lined with aluminum foil on at least one side, causing radiant heat to be reflected and blocked simultaneously.

Polyurethane

Polyurethane is a foam insulation material that contains a low-conductivity gas in its cells. Polyurethane foam insulation is available in closed-cell and open-cell formulas. With closed-cell foam, the high-density cells are closed and filled with a gas that helps the foam expand to fill the spaces around it. Open-cell foam cells are not as dense and are filled with air, which gives the insulation a spongy texture and a lower thermal resistance (R-value).

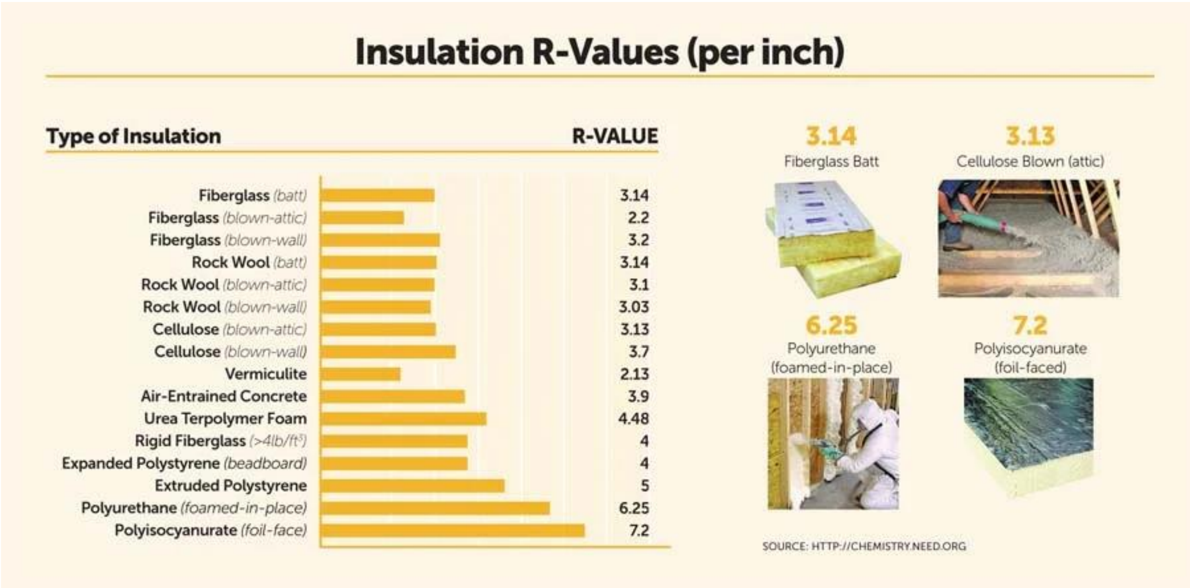

Figure 14: Comparison of thermal resistance (R-value) of insulation material[8]

Wall insulation can be implemented in various forms including external wall insulation, internal wall insulation or composite insulated panels.

External Wall Insulation

External wall insulation adds a layer of insulating material to the outside walls of a building and coating this with a protective render or cladding. The main components of the external wall insulation system are thermal insulator with expanded polystyrene, mineral wool, polyurethane foam or phenolic foam, topped off with a reinforced cement based, mineral or synthetic finish and plaster. Depending on the types of materials and insulation used, external insulated wall can have very low U-value as low as 0.25-0.3 W/m^2-K. The external materials can be designed to the required appearance and durability.

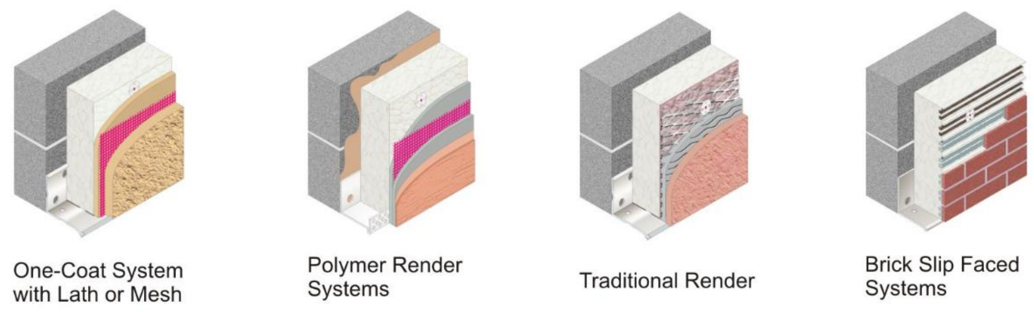

Figure 15: Examples of external wall insulation[9]

[8] Source: https://www.greenbuildermedia.com/blog/insulation-r-values-chart

[9] Source: https://en.wikipedia.org/wiki/External_wall_insulation

Internal Wall Insulation

Internal wall insulation adds a layer of thermal insulator to the building walls. It may be suitable for buildings made from brick, stone or concrete construction. Internal solid wall insulation is particularly appropriate where the external appearance of the building, e.g. in a heritage look, is needed to be maintained. The internal wall insulation however reduce the internal usable areas of the building. Consideration must be made in design and selection of insulation materials to avoid moisture trapping inside the wall which could lead to damp, mould and damage to the building envelope.

3.1.3 Composite insulated panels

Composite insulated panels consist of insulation core covering by external sheets. In most cases, the outer shell consists of a galvanized steel or aluminum sheet. The inner shell can be made of galvanized steel sheet, thin aluminum sheets, stainless steel or GRP (glass-fiber reinforced plastic). The core is mostly made of insulating material such as polyurethane, polyisocyanurate (PIR), or rock wool. Composite insulated panels are factory-manufactured by order and can be used as wall, ceiling and roof. They can be attached to a support structure and are simultaneously stable walls or roofs with excellent insulation properties.

Figure 16: Composite insulated panels[10]

Transparent Wall and Window

Heat gain through glass consists of solar radiation and conduction. Solar radiation comprises direct and diffuse radiation. Direct radiation is energy directly radiated from the sun and diffuse radiation is the solar radiation that is absorbed, stored and scattered in the atmosphere. Conduction heat gain occurs due to the difference in temperature on either side of the glass. Conduction heat gain is positive if the outdoor air temperature is greater than indoor air temperature and it is negative (heat loss from the space) if the indoor air temperature is greater.

[10] Source: Kingspan

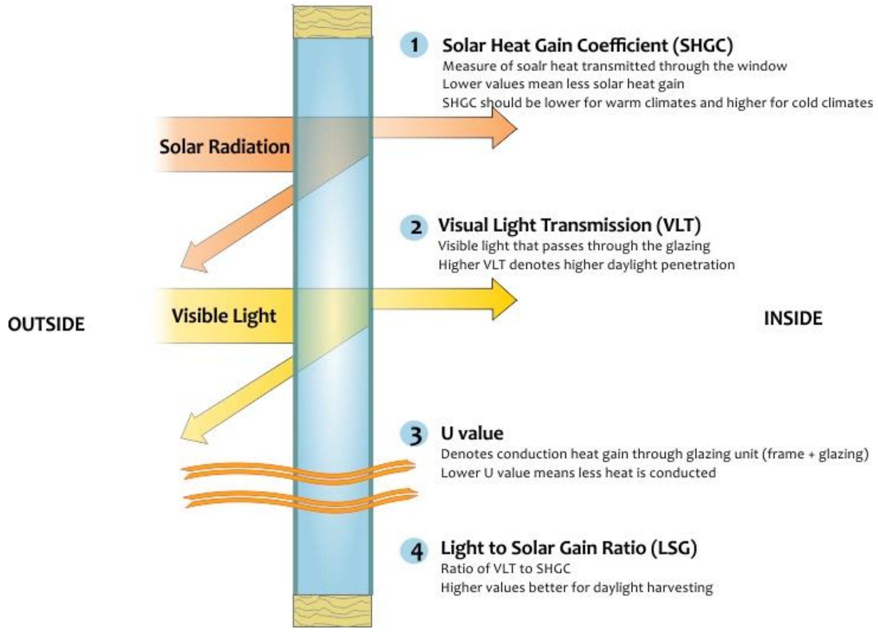

Figure 17: Components of heat gain through glass[11]

For building energy efficiency, the most favorable glasses are the ones minimize heat gain through solar radiation and heat conduction while admitting more visible light to the building spaces. These properties are expressed by Solar Heat Gain Coefficient (SHGC), U-Value and Visible Light Transmittance (VT). As the guideline BEC recommends glass with low SHGC below 0.4 and high VT over 0.7. Two common types of energy efficient coated glass are reflective and low emissivity (low-e) glass.

Table 18 compares the properties of different glass types for building windows

Table 18: Properties of different glass types[12]

Glass Materials	Thickness (mm)	Visible Light Transmittance (VT)	Solar Heat Gain Coefficient (SHGC)
Clear glass	2 - 19	0.16 - 0.91	0.7 - 0.88
Tinted glass (green)	5 - 12	0.63 - 0.78	0.47 - 0.64
Laminated glass	3 - 8	0.15 - 0.88	0.41 - 0.79
Reflective glass	6 - 8	5.4 - 64.2	0.21 - 0.66
Low-e glass	5 - 12	50.8 - 74.7	0.28 - 0.59

3.1.4 Energy efficient coated glass

Energy efficiency coated glass applies spectrally selective coatings to reflect particular wavelengths, but remain transparent to others. Such coatings are commonly used to reflect the ultraviolet and infrared (heat) portion of the solar spectrum while admitting more visible light. They help create a window with a low U-factor and SHGC but a high VT.

[11] Source: http://nzeb.in/knowledge-centre/passive-design/fenestration/

[12] Source: DEDE

Reflective Glass

Reflective glass is clear or tinted glass that has a very thin layer of metal or metallic oxide on the surface. The coating is applied to only one side of the glass making it a mirror-like appearance. This reflective coating is applied during the float process to enhance the amount of heat reflected by the glass. It can absorb and reflect UV and infrared rays of the sun, but allows natural visible light to pass through. It also prevents excessive solar glare.

Low-Emissivity Coatings

Low-emissivity (low-e) coatings on glazing or glass control heat transfer through windows with insulated glazing. Windows manufactured with low-e coatings typically cost about %10 to %15 more than regular windows, but they reduce energy loss by as much as 30% to 50%.

A low-e coating is a thin, virtually invisible, metal or metallic oxide layer deposited directly on the surface of glass. The low-e coating lowers the U-value of the window, and different types of low-e coatings have been designed to limit the amount of solar gain. A special type of low-e coating is designed to reflect particular wavelengths, but remain transparent to others. Such coatings are commonly used to reflect the infrared (heat) portion of the solar spectrum while admitting more visible light. They help create a window with a low U-value and SHGC but a high VT.

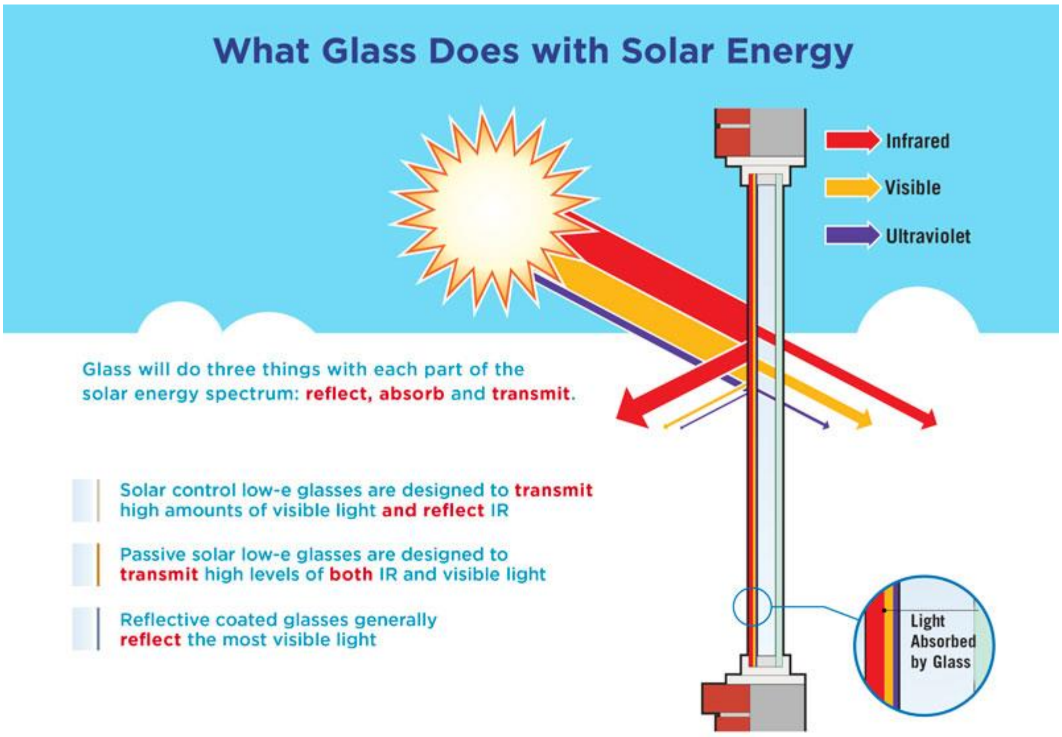

Figure 18: How different types of glass coatings prevent solar energy into the building[13]

[13] Source: Vitro

3.1.5 Insulating glass

Insulating glass consists of two or more glass window panes separated by a vacuum or gas-filled space to reduce heat transfer across a part of the building envelope. A window with insulating glass is commonly known as double glazing or a double-paned window, triple glazing or a triple-paned window, or quadruple glazing or a quadruple-paned window, depending upon how many panes of glass are used in its construction.

Insulating glass units are typically manufactured with glass in thicknesses from 3 to 10 mm (1/8" to 3/8"). Laminated or tempered glass may also be used as part of the construction. Most units are produced with the same thickness of glass on both panes but special applications such as acoustic attenuation or security may require different thicknesses of glass to be incorporated in a unit. Insulating glass primarily lowers the heat transfer due to the temperature differences (U-value), but is also lowers the solar heat gain through radiation (SHGC)

Figure 19: Different types of insulating glass[14]

3.1.6 Window shading

Shading is one of the most effective way to reduce heat gain through windows and transparent walls. Exterior shading can block the sunlight before it hits the glass and can block up to 95% of the sun's heat. The variety of shading strategies can be effective at accomplishing the goal. Windows facing south can be shaded from above with roof overhangs or awnings. For windows facing West or East, louvered shutters or other types of shades that cover the entire glass area are most effective.

Some exterior shades are partially transparent, so some of the incident radiation passes through them to the window. The rest is absorbed by the shade material. Heat absorbed by the exterior shade is largely carried away from the window by radiation and air convection. Some exterior shades are operable, can be raised, lowered or altered their coverage and degree of window protection. Shading effectiveness is rated by a number called a Shading Coefficient which represents the percent of the sun's heat that passes through the shading devices. The lower the number, the more heat will be blocked.

[14] Source: Saida Glass

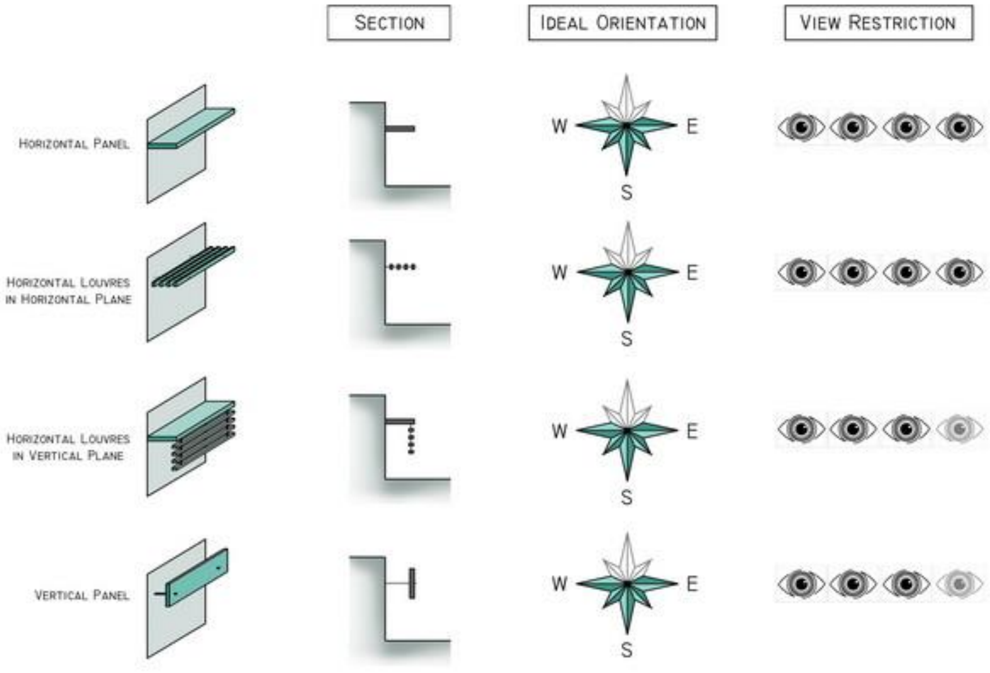

Figure 20: Horizontal shading devices for southern exposures[15]

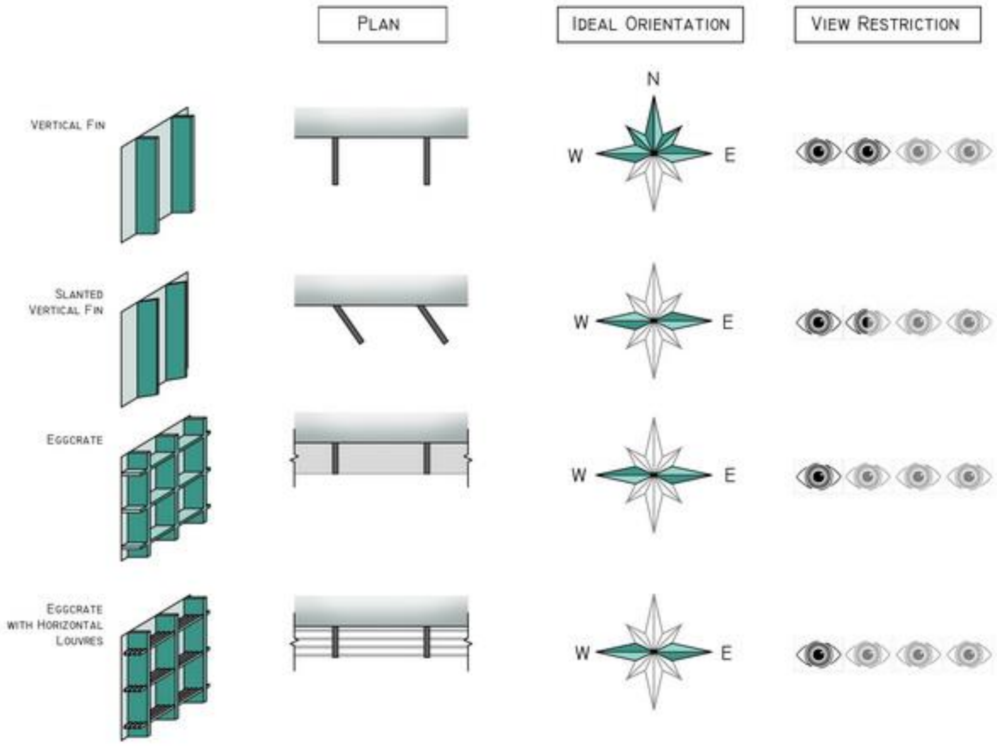

Figure 21: Shading devices for non-southern exposures[16]

[15] Source: the American Institute of Architects

[16] Source: the American Institute of Architects

Roof

3.1.7 Roof insulation

Thermal insulation is one of the most important components to reduce heat gain from the roof. The insulation materials are very similar to wall insulation but forms of insulation are slightly different.

Air gap

In principle, the use of cavities is similar to the use of an insulating material. As air is a poor conductor of heat, still air trapped in air space between two layers of roof acts as a barrier to heat transfer. However, gaps larger than 100 mm encourage convection and are not effective.

Insulation batts with fiberglass or mineral wool

Insulation batts is one of the more popular types for roofing. It is relatively inexpensive and available in a wide variety of different R-values and thickness. Many roof insulation blankets are contained in the foil to protect insulation damage from moisture accumulation.

Rigid foam board

Rigid foam board is more expensive than batt insulation because the R-values of foam board are much higher. Foam boards are good at soundproofing and have excellent heat insulation.

Composite roof panels

It is the ready-made insulation roof panel which is strong and can prevent heat better than other general roofs with the properties of insulation preventing the heat from sunlight to penetrate the building.

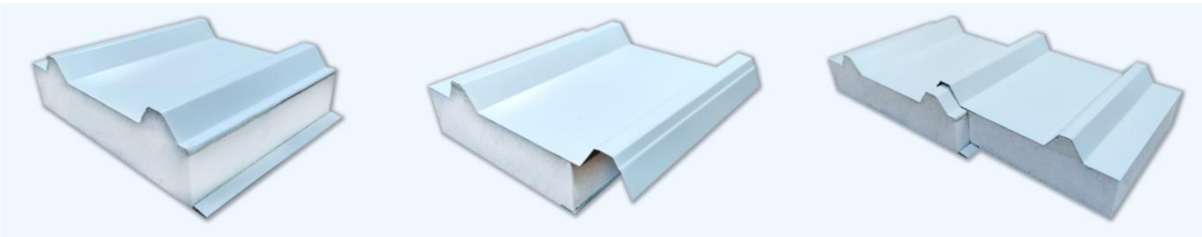

Figure 22: Composite roof panels[17]

Spray foam insulation

Spray foam insulation is an alternative to traditional building insulation. Polyurethane and polyisocyanurate are two types of foam used in this application. The foam is applied to the underside of the roof deck and directly onto the slates and tiles. The spray foam insulation then bonds the slates and tiles together to prevent unwanted moisture, wind, heat, and hot air from seeping in. Spray foam comes in two forms: closed-cell and open-cell. Open-cell spray foam is less expensive but provides a lower R-value. Conversely, closed-cell insulation is more costly but provides better insulation. Apart for its good insulation, spray foam can be applied to both new installation and renovation.

[17] Source: Fatek Group

3.1.8 High solar reflective coating

The innovation in painting has offered the high solar reflective paint which reduces heat transfer into the building. The high solar reflective paint incorporates a composition of reflectivity and refractivity pigment such as: Titanium dioxide, IR reflective and microsphere ceramic. These materials increase reflection of sunlight, ultraviolet and infrared rays of the external surface of the building envelope. Many research experiments[18] show lower surface temperatures of the building walls and roofs from 4 to 10 degrees C and reduction of air conditioning energy consumptions in some cases up to 20% when comparing with conventional color coated

Table 19 provides the comparison examples of the high reflective solar paint and the conventional paint with similar color.

Table 19: Optical properties of high solar reflective and conventional paints

Paint Product	Solar Reflectance (%)		
	UV	Visible Light	Infrared
High solar reflective paint	8.3	14.6	60.0
Conventional paint	8.0	13.5	12.7

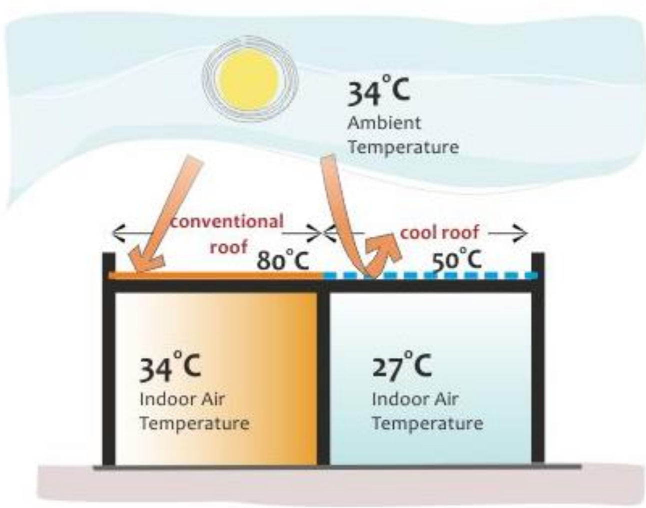

Figure 23: Solar reflectance to cool down the roof[19]

[18] Chalakorn C., et.al, Energy Consumption Reduction by High Solar Reflective Paint, ENGINEERING JOURNAL Volume 25 Issue 2, Published 28 February 2021.

[19] Source: https://nzeb.in/knowledge-centre/passive-design/cool-roofs/

3.2 Component 2: Lighting System

3.2.1 High efficiency LED lamps

Light emitting diodes (LEDs) are a type of solid-state lighting -- semiconductors that convert electricity into light. Nowadays LEDs become one of the most energy-efficient and rapidly-developing lighting technologies. The highest luminous efficacy of commercially available LED lights has raised to the level of 200 lm/W (lumen per watt) in the last few years.

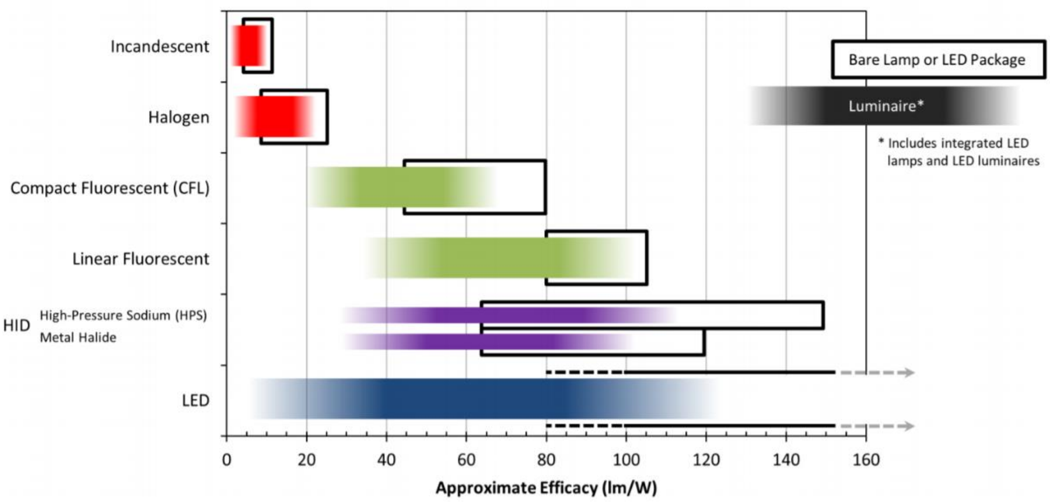

Figure 24: Comparison of light efficacy of common lightings[20]

LED lights come in different forms, brightness levels and color temperatures. LED light bulbs come in every shape, size, and flavor – from the long tubes for office ceiling, to standard-looking bulbs that power wall lights, desk task lights, lamps, and even oven and refrigerator lights. LED light can last very long in the range of 10,000-50,000 operating hours, significantly longer than traditional incandescent, halogen and florescent lamps.

Figure 25: Different forms of LED lamps[21]

[20] Source: Energy Efficiency of LEDs, Building Technologies Program, U.S. Department of Energy, 2013.

[21] Source: Elstar

3.2.2 Energy efficient luminaires

Energy-efficient luminaire can deliver high percentage of the light output from the light source, provide proper distribution and effective lighting impact of the building space. Many of these high efficient luminaires are equipped with reflective materials such as pure anodized aluminum with designed shapes for high reflection and proper light distribution forms. Selection of the right luminaires can optimize the number of lighting installation to fit the area functions while comply with the lighting standard and reduce lighting wattages.

Figure 26: Example of high efficiency luminaire with highly reflective material[22]

3.2.3 Lighting controls

Energy consumption for lighting can be saved with a lighting controls system. They vary from basic wall switch to a sophisticated computerized control by building management system. A combination of a lighting controls, energy-efficient lamps and luminaires maximizes the lighting performance of the building. In most cases lighting controls systems can furtherly save 20 to 40 percent of lighting consumption. They constantly monitor usage and light levels, and only run lighting when needed. Some of the strategies for lighting controls systems include:

• Schedule control and photocells offer simple, reliable and cost-effective basic of controls of a lighting system;

• Occupancy sensors as well as sound and heat-sensing technology detects the presence of people and turn the lights off when the space is unoccupied. Some systems incorporate intelligence into the designs to avoid false or too frequent turning off for the light fixtures. Occupancy sensors can gather data to optimize building utilization;

• Dimming technologies including manual dimming switches and more sophisticated technology automatically reduces light output according to the availability of daylight or other ambient light. Dimming of some lamps and luminaires (e.g. CFLs, LEDs) can be accomplished with dimming enabled devices;

• Day lighting sensors adjust luminaire light output levels in the near window areas in response to natural outdoor light. Day lighting controls are available in continuous dimming and stepped reduction of lighting levels;

[22] Source: Vivoson

• Lighting management systems with centralized computer control of lighting systems to automate lighting characteristics to individual building areas;

• Personalized lighting setting via mobile apps to enhance comfort and user experience.

3.2.4 Daylighting

Daylighting is the controlled admission of natural light, direct sunlight, and diffused-skylight into a building to reduce electric lighting and saving energy. Daylighting helps create a visually stimulating and productive environment for building occupants. Daylighting requires an integrated design approach and involve decisions about the building form, siting, climate, building components such as windows and skylights, lighting controls, and lighting design criteria.

In addition to normal glass walls and windows the following devices can be utilized in daylighting design.

Skylights

Skylights provide top lighting or admitting daylight from the above. Skylights can be either active or passive. Passive skylights use a clear or diffusing medium such as acrylic for daylight to penetrate to the roof openings. They are often designed with double layers for increased insulation. Active skylights have a mirror system within the skylight to track the sun and channel the sunlight into the skylight well.

Tubular daylight

Tubular daylight devices are another type of top lighting device. These devices employ a highly reflective film on the interior of a tube to channel light from a lens at the roof, to a lens at the ceiling plane.

Daylight redirection devices

Daylight redirection devices take incoming direct sunlight and redirect it, generally onto the ceiling of a space. These devices serve two functions: glare control, where direct sun is redirected away from the eyes of occupants, and daylight penetration, where sunlight is distributed deeper into a space that would not be allowed otherwise. Daylight redirection devices generally take one of two forms: a large horizontal element, or louvered systems. Horizontal daylight redirection devices are often called light shelves.

3.3 Component 3: Air Conditioning System

3.3.1 High efficiency inverter split-type air conditioners

Inverter air conditioners are the most energy-efficient split-type air conditioner in the market. They are commonly available and usually used in small air conditioning areas. Inverter technology is an innovative method in controlling the operation of the electric compressor. The inverter increases the compressor operating frequency to reach the desired temperature rapidly. When this is achieved, it adjusts the compressor frequency to maintain the temperature without consuming excess power efficiently. The compressor runs at full power to achieve the desired temperature; then runs at part load to retain it, thereby using less power than a non-inverter air conditioners.

The inverter split-type air conditioners with energy-efficient label 5 and three-star rating could offer very high efficiency more than 21.5 SEER. These savings are over 40% of energy consumption of the normal fixed speed label 5 split-type air conditioners and would give short payback period on the premium when using for high daily operating hours.

3.3.2 VRF/VRV air conditioning system

Variable refrigerant flow (VRF), also known as variable refrigerant volume (VRV) is an air conditioning technology invented by Daikin Industries, Ltd. in 1982. VRFs use refrigerant as the cooling medium. This refrigerant is conditioned by a single or multiple condensing units which may be outdoors or indoors and is circulated within the building to multiple indoor units. VRF systems, unlike conventional chiller-based systems, allow for varying degrees of cooling in more specific areas. Unlike the chiller system, VRFs use only smaller indoor units with no air handing units and large air ducts. The installations are more flexible with low ceiling space required and less structural impact due to smaller refrigerant pipes instead of ducts.

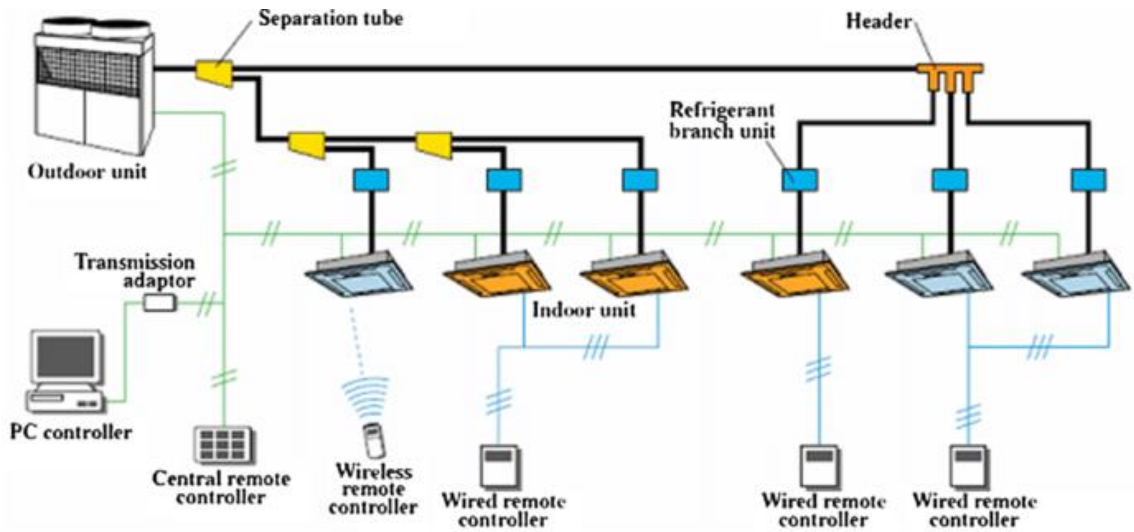

Figure 27: Components of VRF air conditioning system[23]

VRF systems may be air or water cooled. If air cooled, VRF condensing units are exposed to outside air normally outdoors. For water cooled, the condensing units are placed indoors and are much smaller and cooled with water by a closed type cooling tower or dry cooler. The VRFs are normally used in midsize office buildings up to 6,500 m^2 and but could be applied in some larger commercial buildings.

3.3.3 Oil-free magnetic bearing chiller

Magnetic-bearing chillers are chillers equipped with magnetic bearing, variable speed centrifugal compressors. Magnetic bearings apply the magnetic field with internally controlled sensors to support the rotating shaft without physical contact, reducing friction and eliminating the need for oil lubrication. The compressors are soft started and speed controlled by the inverter to the required cooling loads.

[23] Source: Fujitsu

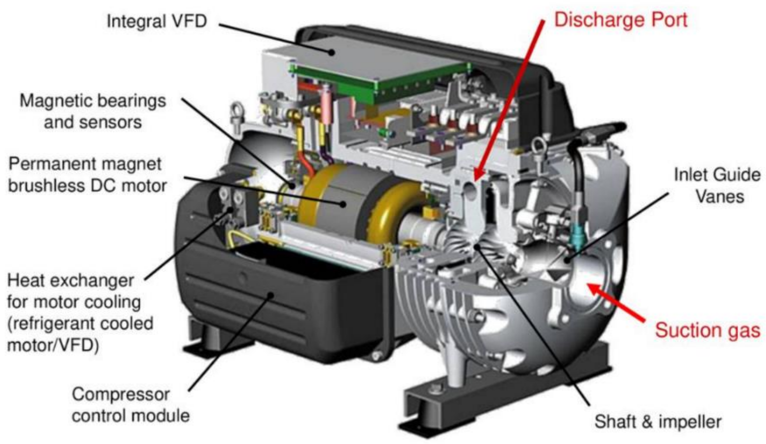

Figure 28: Components of oil-free magnetic bearing compressor[24]

The magnetic bearing centrifugal chillers can operate at low level of 20 to 40% of load and having electricity consumption lower than 0.55 kW/TR when compared with large air-conditioning water chiller with centrifugal compressor or screw compressor that the system will not be able to run with load below 40%.

A magnetic-bearing chiller compressor can be installed as part of a new chiller installation or a retrofit on an existing chiller when the existing evaporator and condenser are in good condition. The technology can be applied to air-cooled and water-cooled chillers but may require upgrade of the control system.

The technology is ideally suited for chillers that run at partial load for most of the time as energy savings are reduced when operate at or near full load. In addition to energy efficiency, magnetic bearing chillers have fewer moving parts, require no oil, nor oil-circulation equipment, and therefore require less maintenance and service throughout their operating life.

3.3.4 Absorption chiller

Absorption chillers use heat instead of electricity to produce cooling. The electric-driven compressor is replaced by a thermal compressor that consists of an absorber, a generator, a pump, and a throttling device. The refrigerant vapor from the evaporator is absorbed by a solution mixture in the absorber. This solution is then pumped to the generator where the refrigerant is evaporated using a waste heat source. The refrigerant-depleted solution is then returned to the absorber via a throttling device. The two most common refrigerant/absorbent mixtures used in absorption chillers are water/lithium bromide and ammonia/water.

[24] Source: Daikin

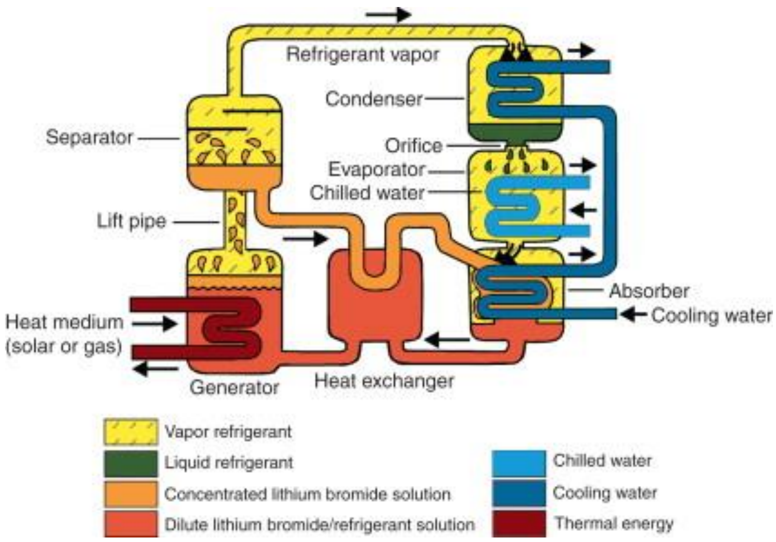

Figure 29: Absorption chiller components[25]

Compared to electric chillers, absorption chillers have a low coefficient of performance (COP). Nonetheless, they can substantially reduce operating costs because they are energized by low-grade waste heat, while normal electric chillers must use electricity. Absorption chillers are available in capacities ranging from 100 to 1,500 tons. Absorption chillers come in two commercially available designs: single-effect and double-effect. Single-effect machines provide a thermal COP of 0.7 and require about 18 pounds of 15-pounds-per-square-inch-gauge (psig) steam per ton-hour of cooling. Double-effect machines are about 40% more efficient, but require a higher grade of thermal input, using about 10 pounds of 100- to 150-psig steam per ton-hour.

Absorption chillers can be utilized as a component in the combined heat and power (CHP) system to take the exhaust heat from the electricity generator to produce cooling. They can also integrate with the solar thermal collecting system to convert solar energy to cooling energy in supplement to normal chilled water system.

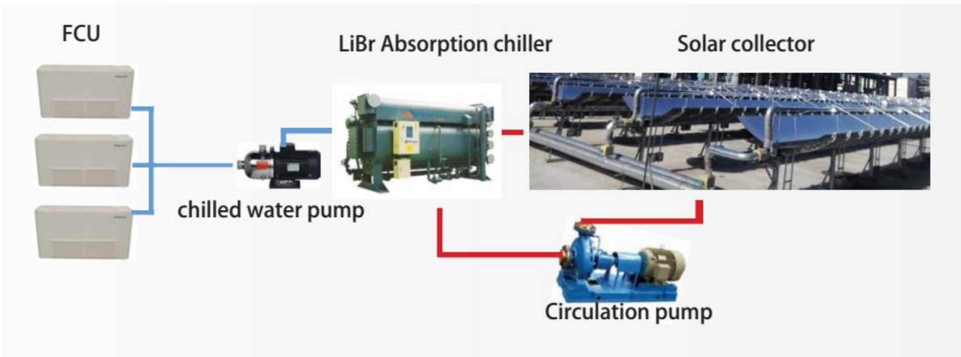

Figure 30: An example of solar absorption chiller system[26]

[25] Source: http://www.yazakienergy.com

[26] Source: Viscot.cm.cn

3.3.5 Energy Recovery Ventilation (ERV)

Energy recovery ventilation (ERV) is the energy recovery process in HVAC systems that exchanges the energy contained in exhausted air of a building or conditioned space to treat the incoming fresh air. The ERV system pre-cools and dehumidifies the incoming fresh air. Many ERV units are equipped with air filter to screen out the suspended particulates. With the measurement of CO_2 in building area, ERV can optimize the amount of fresh air in accordance with area occupancy.

In conclusion ERV systems help improve indoor air quality while reduces the cooling load from fresh air, thereby reducing energy consumption of the HVAC.

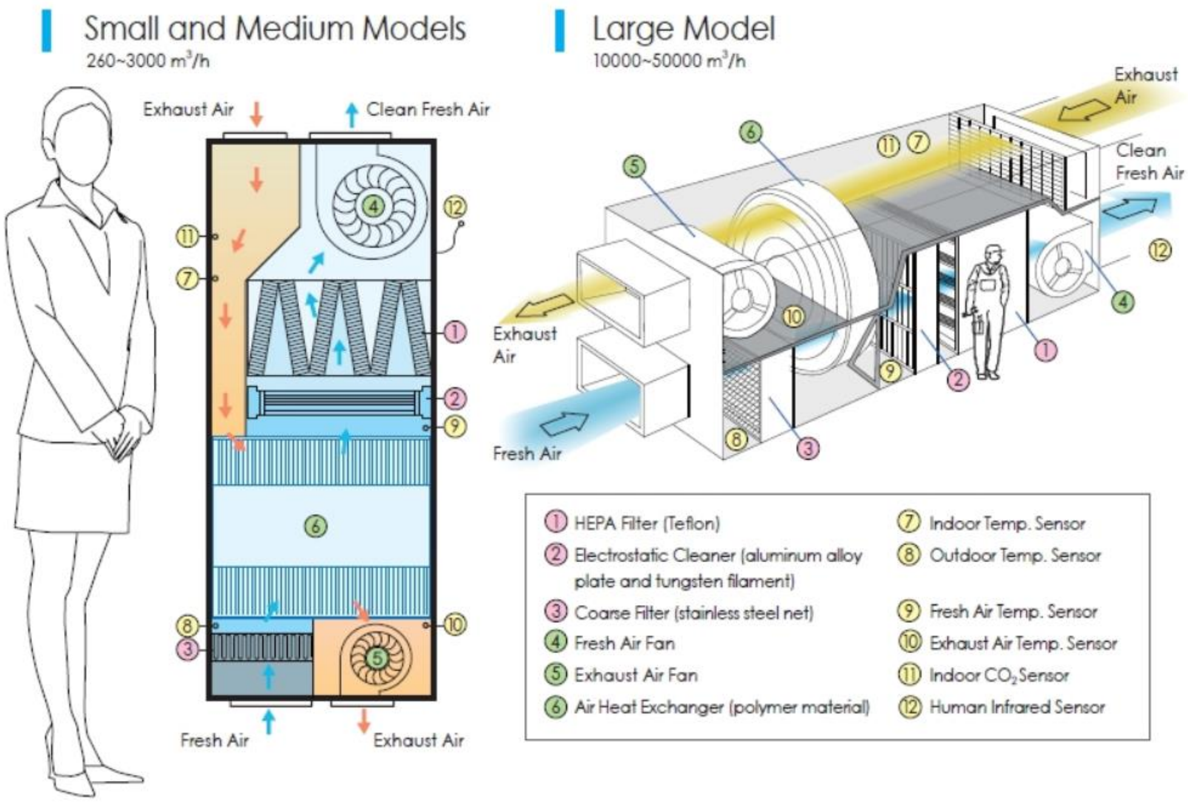

Figure 31: Energy Recovery Ventilator[27]

[27] Source: Broad Clean Air Technology

3.4 COMPONENT 4: HOT WATER GENERATION SYSTEM

3.4.1 Heat pump hot water generation

A heat pump moves, or 'pumps', heat from one medium into another. Common forms of heat pumps are air conditioners and refrigerators. Heat pump hot water systems use refrigerant as the medium to concentrate low-grade heat from the air and transfer it to the water instead of generating heat directly. They are two to three times more efficient than conventional hot water boilers using electricity or fuels such as fuel oil or LPG as the energy source.

Heat pump water heater can be installed as a stand-alone or as an integrated unit to the conventional hot water system. Heat pump water heater works very well in the hot climate like Thailand. The system can generate hot water around 55 to 60 degree C which is suitable for general washing and bathing.

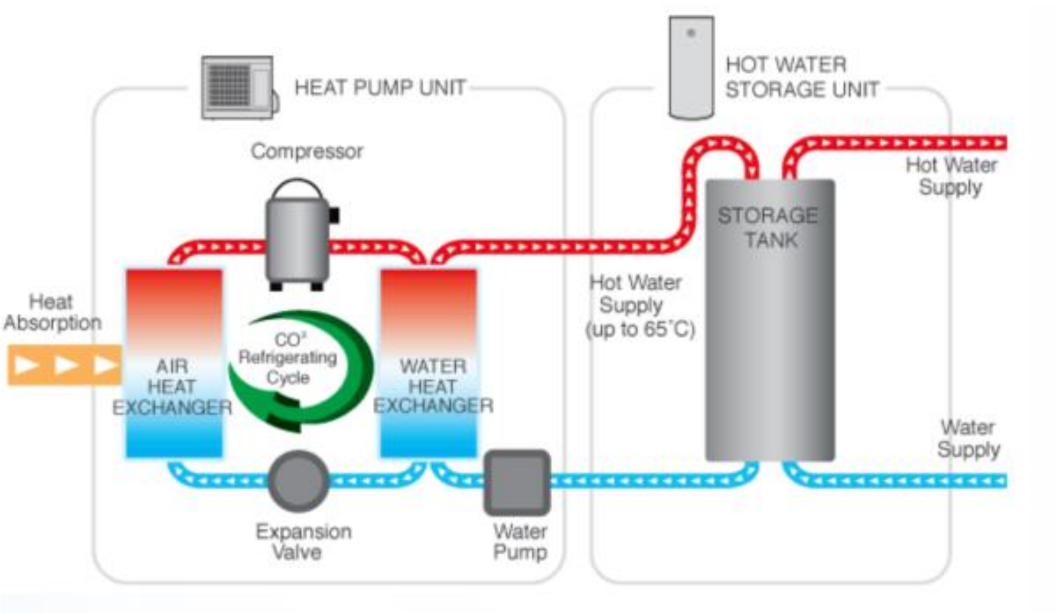

Figure 32: Heat pump hot water generator system[28]

[28] Source: Sanden

3.5 Component 5: Renewable Energy Utilization

3.5.1 Solar power generation

Solar energy is currently the most feasible source of renewable energy for buildings to offset their energy consumption for Thailand. Around 64% of the country has a daily solar exposure of around 18-20 $MJ/m^2/day$. This solar energy can be utilized through photovoltaic (PV), by converting sunlight into electricity, and solar thermal, producing hot water.

Rooftop solar power generation system can be installed to most residential houses, commercial buildings, factories and carpark buildings. The system produces electricity for use in conjunction with the electricity from the grid and helps reduce monthly electricity bill effectively. With participation to the government program, the surplus electricity generated can be sold to the electricity authority.

Major components of the rooftop solar power generation systems are photovoltaic (PV) panels, mounting systems, cables, solar inverters and other electrical accessories.

Photovoltaic or solar panels produce electricity when irradiated with sunlight. Often made of Silicon, solar panels are made of numbers of smaller solar cells. Multiple photovoltaic panels strung together make up a solar array. PV panels are generally protected by tempered glass and secured with an aluminum frame. Three most common types of PV panels are monocrystalline, polycrystalline, and thin-film. Each of these types has a different characteristics and aesthetic appearance.

Monocrystalline

Monocrystalline solar panels are the oldest type of solar panel and the most developed. These monocrystalline solar panels are made from about 40 of the monocrystalline solar cells. These solar cells are made from pure silicon. Monocrystalline solar cells appear black because of the way sunlight interacts with pure silicon. While the cells are black, there is a variety of colors and designs for the back sheets and frames. The monocrystalline cells are shaped like a square with the corners removed, so there are small gaps between the cells. Monocrystalline silicon cells are highly efficient in the range of 17% to 22%, but their manufacturing process is slow and labor intensive, making them more expensive than their polycrystalline or thin film counterparts.

Polycrystalline

Polycrystalline solar panels are a newer development, but they are rising quickly in popularity and efficiency. Just like monocrystalline solar panels, polycrystalline cells are made from silicon. But polycrystalline cells are made from fragments of the silicon crystal melted together. Polycrystalline cells are blue in color because of the way sunlight reflects on the crystals. Sunlight reflects off of silicon fragments differently than it does with a pure silicon cell. Usually the back frames and frames are silver with polycrystalline, but there can be variation. The shape of the cell is a square, and there are no gaps between corners of cells.

Polycrystalline panel efficiencies typically range from 15% to 17%. New technology polycrystalline panels are now much closer in efficiency to monocrystalline solar panels than they have been in the past. Polycrystalline solar panels are cheaper to produce than monocrystalline panels, which allowed them to make up a significant market share.

Thin-film

Thin-film solar panels are an extremely new development in the solar panel industry. They can be made from a variety of materials, including cadmium telluride (CdTe), amorphous silicon (a-Si), and Copper Indium Gallium Selenide (CIGS). These solar cells are created by placing the main material between thin sheets of conductive material with a layer of glass on top for protection. Thin-film panels are easy to identify by their thin appearance. These panels are approximately 350 times thinner than those that use silicon wafers. Thin-film cells can be black or blue, depending on the material they were made from.

A few years ago, thin film efficiencies were in the single digits, but now thin film panels that are commercially available generally have efficiency in the 10 to 13% range. Thin film solar panels have the lowest cost out of the three solar panel types because of their low performance. Because of their light weight and flexibility, they are easier to install than crystalline silicon panels.

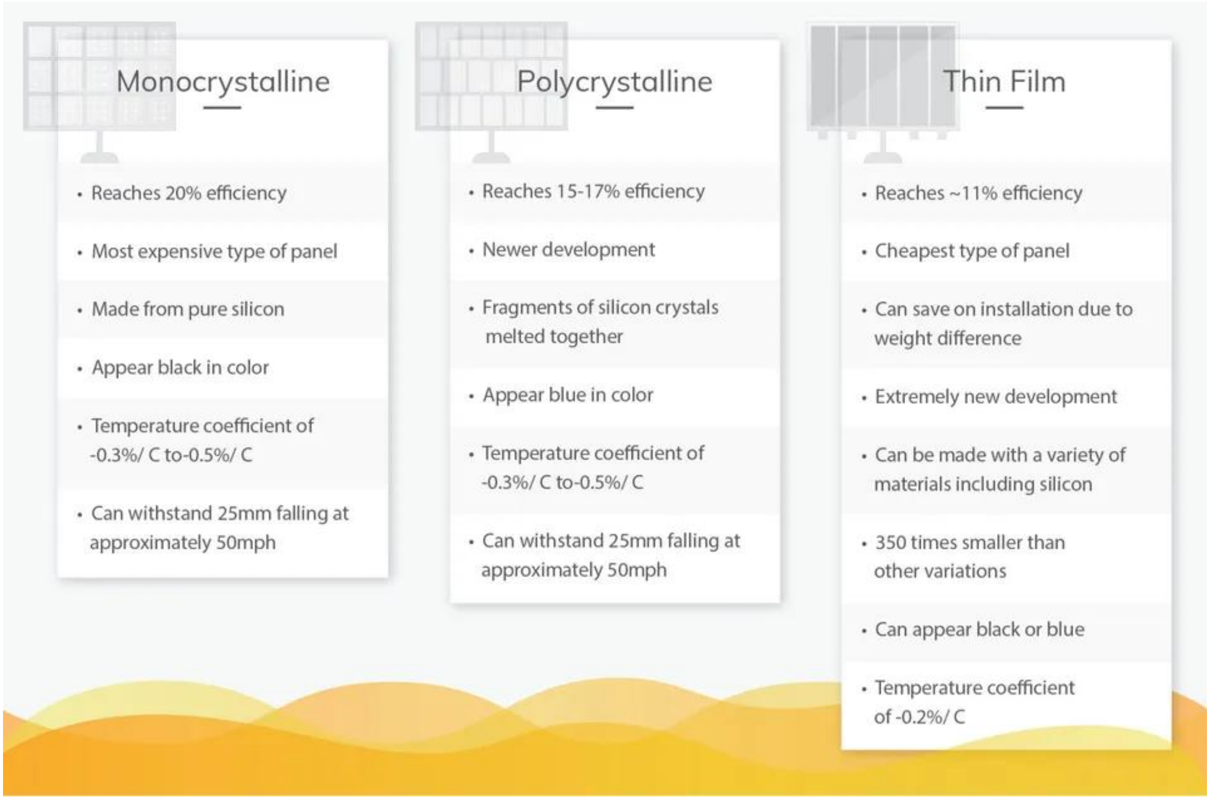

Figure 33: Comparison of three common types of PV panels[29]

Solar Inverter

In addition to PV panels, solar inverter is an integral part of the solar power generation system. Solar Inverter converts DC electricity from solar panels to AC electricity that can be connected to the electrical system. Generally solar inverters are high efficient with the conversion efficiency between 95% and 98%. The state-of-the-art inverters can reach even higher efficiency of more than 98%. Many advanced inverters are equipped with power optimizer to get the maximum possible power from the PV array at any given environmental conditions.

[29] Source: https://www.8msolar.com/types-of-solar-panels

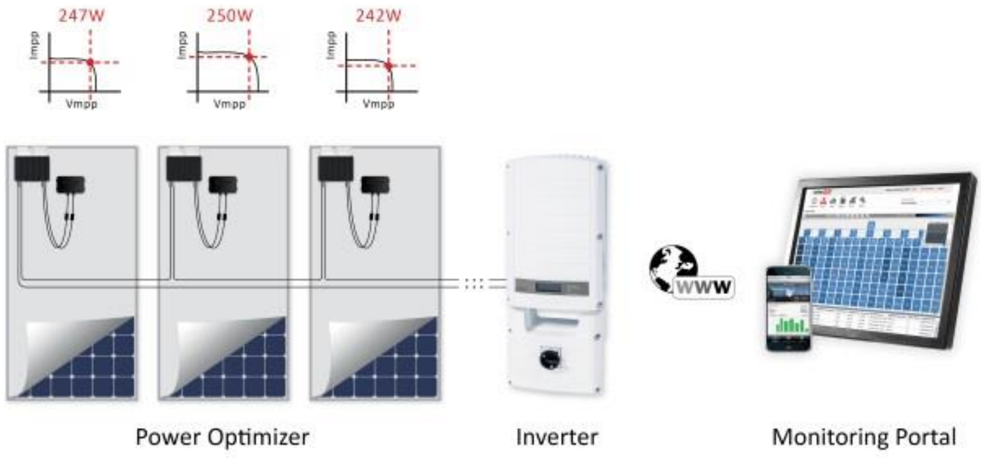

***Figure 34: Solar inverter with power optimizer*[30]**

3.5.2 Solar hot water generation

Solar water heater convert energy from sunlight to heat water. They can be used to generate hot water for building. Solar water heating systems include storage tanks and solar collectors. There are two types of solar water heating systems: active, which have circulating pumps and controls, and passive, which do not have circulating pumps. The solar water heating system can be incorporated with the economizer and the heat recovery system. This combination is called the solar hybrid system; it combines the sunlight with the excess heat from air conditioners and boilers. The solar water heater becomes the alternative in the energy saving installed in households, schools, industries, hotels, resorts & spas, restaurants, and beauty shops.

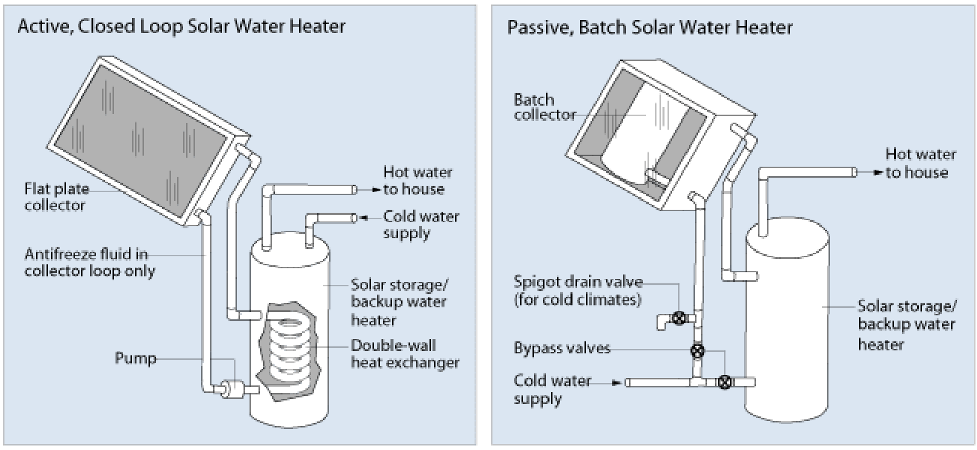

***Figure 35: Two type of solar water heating system*[31]**

A large 5-star hotel, the Shangri-La, Bangkok, has installed a 938 m^2 rooftop solar water heating system since 2011 for supply hot water for its 802 guestrooms. This makes it the largest solar heating system ever installed in a Thai hotel.

[30] Source: SolarEdge

[31] Source: https://www.energy.gov/energysaver/water-heating/solar-water-heaters

3.6 COMPONENT 6: WHOLE BUILDING ENERGY PERFORMANCE

3.6.1 Building Energy Management Systems (BEMS)

BEMS provide real-time monitoring and integrated control of connected systems from lighting and HVAC to security systems and elevators. They allow modes of operation, energy use and environmental conditions to be monitored and allowing hours of operation, set points and so on to be adjusted to optimize building's performance and comfort. Some common BEMS scopes are:

- Lighting controls: daylight harvesting, occupancy based controls, wireless switching.
- HVAC controls: AHU/FCU controls, compressor operation monitoring and control, chiller monitoring and control, ventilation controlling system, temperature/pressure/humidity/CO_2 control.
- Water management: water level monitoring and control, pump automation, water meters.
- Fire alarm system: Addressable, conventional and wireless fire and smoke detection and alarm.
- CCTV system: analog cameras, IP based Cameras, web based monitoring system.
- Access control system: time based attendance system, boom barrier system, door lock management system.
- Renewable power generation: monitoring the performance of solar PV system.
- Smart plug: monitoring and control of electrical loads.
- Etc.

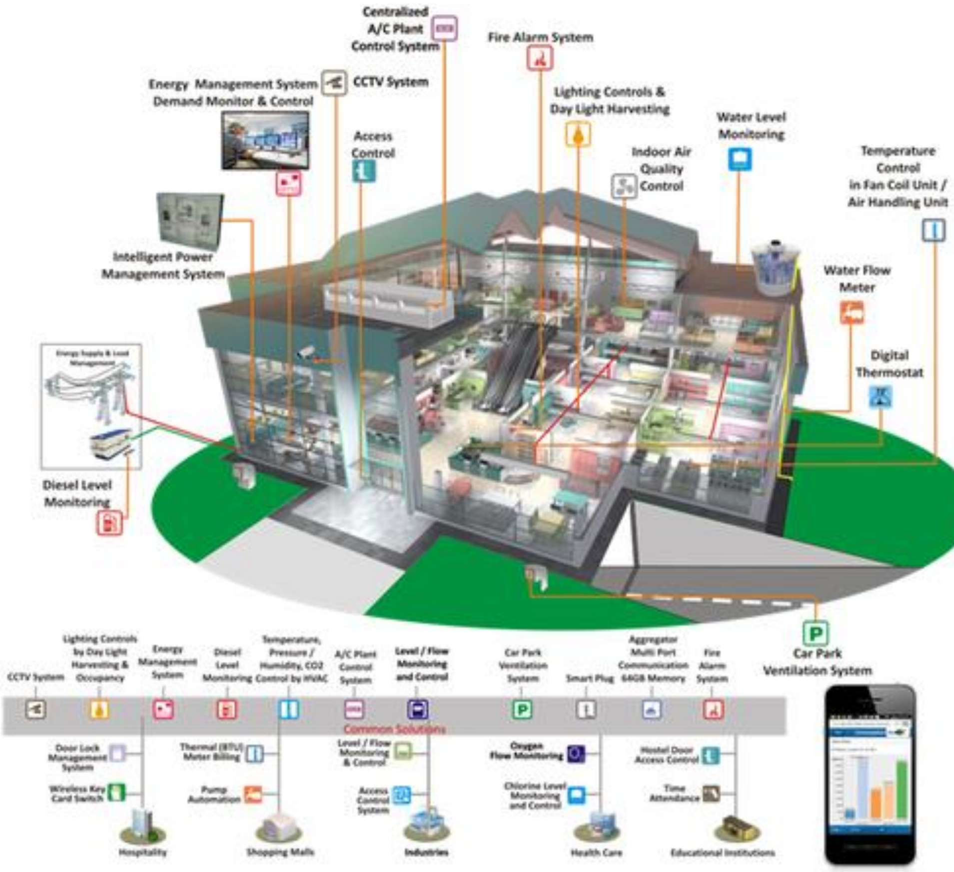

***Figure 36: Examples of BEMS components*[32]**

32 Source: Elmeasure India Private Limited

BEMS can also trigger alarms, and in some cases predicting problems and informing maintenance program. They provide historical performance records, enable benchmarking of performance against other buildings or sites and help automate reports.

Latest development of Internet of Things (IoT) sensors and platforms have enhanced the BEMS capability to include other data inputs to extrapolate anomalies, make correlations, and help end users gain knowledge to make smart operational decisions. With the right data variables, collected, correlated, and analyzed it is possible to design optimal energy management approach for cost savings. The followings list some examples of these features.

- Total energy consumption and how the connected systems and equipment contribute the overall energy use.
- Occupants' behavior including activities, behavior patterns, and comfort preferences of the occupants.
- Energy usage patterns. Knowing when and the building uses energy and attempting to reshape those patterns strategically. Shifting energy use away from high-priced time periods to generate savings.
- Cyclical or seasonal factors. Over time, your building's energy consumption may follow predictable change patterns that an IoT-based platform can analyze and propose the best operation solutions.
- Weather data. Collecting, compiling, and analyzing weather data in connection with other building information allows proactive control of HVAC energy consumption under changing environment conditions.

Implementation of BEMS with integrated control of major energy consuming systems can generally achieve energy saving of 15-20% in most commercial buildings.

3.6.2 Combined Heat and Power (CHP)

Combined heating and power (CHP) or cogeneration uses single energy source to produce electricity and thermal energy for heating and/or cooling at the same time. By capturing and using heat that would otherwise be wasted, CHP can achieve over 80% energy efficiencies compared to 50% for conventional electricity generation and independent heating generation. CHP are suitable for facilities or buildings that need both electricity and thermal energy and operate at long operating hours such as hotels, hospitals and mixed-use building compound.

The most common CHP system for buildings are fuel-gas engine generator to produce electricity and utilize the generator wasted heat to produce steam or hot water for direct use and further use of steam in absorption chiller to produce chilled water for cooling. CHP can be installed at an individual facility or a central utility plant for the district energy complex.

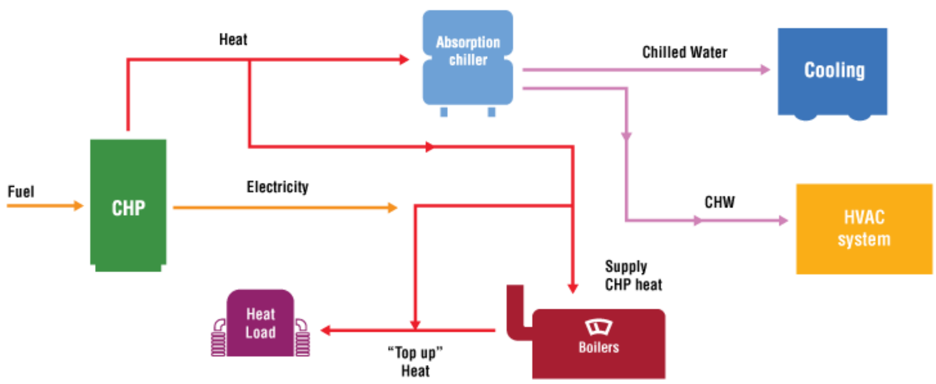

Figure 37: Combined heat and power scheme with fuel engine generator and thermal energy production[33]

[33] Source: https://unitedhvacbd.com/vapor-absorption-chiller/]