CHAPTER II

REVIEW OF RELATED LITERATURE AND THEORY

Review of Related Literature

Prasongkit, J. the architect, was granted a commendatory award, which was the best award bestowed in 1998, for the designing of this energy-efficient building from the Association of Siamese Architects. The building envelope is made of high quality non-reflexive double glass. The outer layer is coated green in order to reduce the intensity of daylight from the outside. The inner layer is clear float glass so that the properties of the light penetrating into the building would be as close as possible to the daylight. Between the two layers of the glass is 12 mm insulation, preventing the building from the outside heat and noise while retaining coolness inside. There are skylight roof-panels on the top floor to allow daylight to come in, instead of using electric light. The energy conservation standards of this building are far better than the standards stipulated by law, as shown in the following Table 1:

Table 1 The energy conservation standards of this building are far better than the standards stipulated by law.

Standard	OTTV (W/m^2)	RTTV (W/m^2)	DAYLIGHT (W/m^2)	CHILLER (kW/ton)
Standards Stipulated by Law	<45	<25	<16	<1.4
NEPO Building Specifications	39.96	10	12.8	1.17

Given all the features mentioned above, this building becomes a fine example of energy-conservation office building. The ground floor of the building serves as energy conservation technology training and demonstration center, the office of the "Divide-by-

Two" Information Center and the meeting venue of the "Divide-by-Two" Club formed by juveniles interested in activities related to dissemination of and campaign on efficient use of energy to the general public.

EASON, the secretary for planning environment and lands, he study about the building energy efficiency regulation applies should be designed and constructed to have following OTTV in Hong Kong. This Regulation imposes requirements relating to the energy efficiency of buildings. The Regulation applies to commercial buildings and hotels. The main requirement is that those buildings be constructed to a suitable overall thermal transfer value. The Regulation also requires that when plans are submitted to the Building Authority, certain information specified in the regulation and relating to the energy efficiency of the building concerned be included. The component of the energy efficiency are concerned the OTTV of the external walls of a building tower or a podium ($OTTV_w$), the OTTV of the roofs of a building tower or a podium ($OTTV_r$) and thermal transmittance of opaque construction (U).The component coefficient and parameters used in calculating the thermal transmittance of opaque construction should be assessed as follows:

(a) Thermal conductivity of building materials (k)

(b) Surface film resistance for walls and roofs (R_i, R_o)

(c) Air space resistance for walls and roofs (R_a)

(d) Absorptive (α)

(e) Equivalent temperature difference for walls (TD_{EQw})

(f) Solar factor (SF)

(g) Equivalent temperature difference for roofs (TD_{EQr})

Areree and Thosuwan, this research studies the analysis of overall thermal transfer value (OTTV) and roof thermal transfer value (RTTV) at Industrial of Teacher Building in King Mongkut's Institute of Technology North Bangkok. In 1999, the result of this study determine that OTTV =61.9 W/m^2, RTTV = 30.2 W/m^2. After use insulator, they have new OTTV = 52.6 W/m^2.

They have 3 methods to reduce OTTV

1. Change clear glass to tinted glass, OTTV=54.7 W/m^2
2. Change clear glass to solar reflective glass, OTTV=54.8 W/m^2
3. Add solar reflective film on clear glass, OTTV= 55.0 W/m^2

And have 2 methods to reduce RTTV

1. Add solar reflective insulator sheet under the roof, RTTV= 25.0 W/m^2
2. Add fibertex with single size aluminum foil under the roof, RTTV= 25.0 W/m^2

For solar reflective film use budgets 329,700 Bath, life 6 years, budgets for solar reflective glass are 390,365 Bath and 403,300 Bath for tinted glass. Budgets for solar reflective insulator sheet are 42,570 Bath, for fibertex with single size aluminum foil have cost estimate 82,500 Bath. This research not includes wind, rain and heat transfer from electric and machine.

Boonyatikarn, the architectural and researcher at Chulalongkorn University studied and developed about energy saving houses by, using the standard in Thailand. The house's name is Ban Chewatit. It save energy more than others houses 15 times. This house has 2 floors, 3 bedrooms, 3 bathrooms, area for using 200 m^2 and install air conditioner every rooms (Non except bathrooms). The roofs have insulator thickness 12 inches. The wall used EIFS (Exterior Insulator and Finish System) that has 7 materials layers as follows: first is sheathing gypsum board, second is steel stud U, third is sheathing gypsum board, fourth is fire retardant EPS insulation board 6 inches., fifth is fiberglass mash, sixth is adhesive base coat and the last one is finishing coat. The energy saving house is made of high quality glass. The glass for doors and windows are heat stop glass that has two layers and inert gas between glasses. The research and program developing about design building that can calculate value of OTTV and RTTV base on Standards Stipulated by Law. The program use to calculate and assess value of energy. The tool will help for designers, engineers, architects, etc. The research about reflector of CPAC tile with houses and building in Thailand climate are research for develop and reduce energy in housing and building. The research about glass that appropriate for housing and building in Thailand are used in technical to design energy saving houses.

These are methods to save energy in the house by reducing the intensity of daylight from the outside that have 2 ways: using double glass and install solar reflective film. For roof and wall are installed insulator for reduce thermal accumulate in the house. Therefore, in this thesis will design the house by install solar reflective film instead of double glass because is not expensive. In terms of wall will install sheathing gypsum board and EPS (Extrude Polystyrene) insulation board. And improve the roof by install fiberglass insulator which covered by aluminum foil.

Mathematical model in this thesis use for user to select and improve houses in each part that follow standard of conservation energy in Thailand and suitable prices. By use basic data from the house that is designed and developed in this thesis.

Theory

Overall Thermal Transfer Value (OTTV)

OTTV = Overall Thermal Transfer Value is a value to control heat gain through building envelope, thus reduce cooling load and energy of the building.

Basic elements of building envelope consists of:

- External walls
- Roofs
- Windows
- Door

The OTTV is a measure of the energy consumption of a building envelope. Its formulation allows authorized persons, registered structural engineers and other persons responsible for the design and construction of buildings freedom to innovate and vary important envelope components such as type of glass, window size, external shading to windows, wall color and wall. Any measure to improve energy efficiency or to save energy should be considered in planning a building and can be expressed as

$$OTTV = \frac{Q}{A} \tag{2.1}$$

where Q = Total heat transfer through envelope (W)

A = Area of building envelope (m^2)

Heat transfer has 3 heats gain components are considered

1. Heat conduction through wall, Q_w
2. Heat conduction through window glass, Q_{gc}
3. Solar radiation through window glass, Q_{gs}

The usual practice is to have two sets of OTTV equations for external walls and roofs. OTTV of an external wall is calculated by

$$OTTV = \frac{(Q_w + Q_{gc} + Q_{gs})}{A} \quad (2.2)$$

$$= \frac{[(A_w \cdot U_w \cdot TD_w) + (A_g \cdot U_g \cdot TD_g) + (A_g \cdot SC \cdot SF)]}{A} \quad (2.3)$$

where A_w = Area of wall, (m^2)

U_W = Thermal transmittance of wall, ($W/m^2\ {}^oC$)

TD_w = Equivalent temperature difference for wall, (${}^oC$)

A_g = Area of glass, (m^2)

U_g = Thermal transmittance of glass, ($W/m^2\ {}^oC$)

TD_g = Equivalent temperature difference for glass, (${}^oC$)

SC = Shading coefficient of glass

SF = Solar factor for the vertical surface, (W/m^2)

A = Area of external walls, i.e. $A_W + A_g$, (m^2)

Total OTTV of an external wall is calculated by

$$OTTV_T = \frac{A_1 \cdot OTTV_1 + A_2 \cdot OTTV_2 + ... + A_n \cdot OTTV_n}{A_1 + A_2 + ... + A_n} \quad (2.4)$$

where $OTTV_T$ = Total of overall thermal transfer value

n = Number of pieces of wall

Roof Thermal Transfer Value (RTTV)

RTTV equation for roofs is similar to wall, but external shading is not considerate for roofs. The terms and coefficients (TD_r and SF) may very different OTTV standards

$$RTTV = \frac{(A_r \cdot U_r \cdot TD_r) + (A_{tr} \cdot U_{tr} \cdot TD_{tr}) + (A_{tr} \cdot SC \cdot SF)}{A} \tag{2.5}$$

where A_r = Area of roof or ceiling, (m^2)

U_r = Thermal transmittance of roof, ($W/m^2\,^oC$)

TD_r = Equivalent temperature difference for roof, (^oC)

A_{tr} = Area of transparent roof, (m^2)

U_{tr} = Thermal transmittance of transparent roof, ($W/m^2\,^oC$)

TD_{tr} = Equivalent temperature difference for transparent roof, (^oC)

SC = Shading coefficient of roof

SF = Solar factor for the vertical surface, (W/m^2)

A = Total Area of roof, i.e. $A_r + A_{tr}$, (m^2)

Thermal Transmittance of Construction (U)

Walls and roof usually involve a composite of materials. The thermal transmittance of an opaque wall, transparent wall or roof should be derived by the following formula:

$$U = \frac{1}{R_i + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \ldots + \frac{x_n}{k_n} + R_a + R_o} \tag{2.6}$$

where U = Thermal transmittance of materials, (W/m^2 °C)

x = Thickness of building material of the wall or roof or other parts, (m)

k = Thermal conductivity of the building material (W/m °C)

R_i = Surface film resistance of internal surface of the wall or roof, (m^2 °C/W)

R_o = Surface film resistance of external surface of the wall or roof, (m^2 °C/W)

R_a = Air space resistance (m^2 °C/W)

Component Coefficients and Parameters of Thermal Transmittance

The component coefficient and parameters used in calculating the thermal transmittance of building construction should be assessed as follows:

Thermal Conductivity (k)

Thermal conductivity is a property of materials that expresses the heat flux f (W/m^2) that will flow through the material if a certain temperature gradient DT (°C/m) exists over the material. The thermal conductivity is usually expressed in W/m-°C and use abbreviation k. The usual formula is:

$$k = \frac{f}{DT}$$

It should be noted that thermal conductivity is a property that is describes the semi static situation; the temperature gradient is assumed to be constant. As soon as the temperature starts changing, other parameters enter the equation. This is far form easy because it usually requires a carefully planned laboratory experiment and a lot of time to get to equilibrium. The thermal conductivity of the building materials of walls and roofs should be obtained from Table 2.

Table 2 Thermal Conductivity (k) and Density (ρ) in Difference Materials Types (The energy conservation promotion act supports, 2535)

No.	Material	k (W/m-°C)	ρ (kg/m³)	No.	Material	k (W/m-°C)	ρ (kg/m³)
1	Cement Asbestos Plate	0.198	1860	16	Mineral Fiber Board	0.05	290
2	Cement Asbestos Insulation	0.108	720	17	Materials for Coating		
3	Asphalt	1.226	2240		a) Gypsum	0.191	880
4	Bitumen	1.298	0		b) Light Weight Cement coating	0.063	377
5	Brick				c) Medium Weight Cement coating	0.274	1104
	a) Dry and Portland Cement Coating or Mosaic Tile Cladding	0.807	1760		d) Perlite	0.115	616
	b) Moisture 6%	1.211	1872		e) Cement/Sand	0.533	1568
	c) Brick	1.154	1600		f) Vermiculite	From Manufactory	From Manufactory
6	Concrete	1.442	2400	18	Polystyrene	0.035	16
7	Light Weight Concrete			19	Polyurethane	0.024	24
	a) Density = 620 kg/m2	0.16	620	20	PVC	0.713	1360
	b) Density = 960 kg/m2	0.303	960	21	Soil (Moisture 14%)	0.375	1200
	c) Density = 1120 kg/m2	0.346	1120	22	Stone		
	d) Density = 1280 kg/m2	0.476	1280		a) Sandstone	1.298	2000
8	Cork Board	0.042	144		b) Granite	2.927	2640
9	Fiber Board	0.052	264		c) Marble	1.298	2640
10	Fiber Glass			23	Tile	0.836	1890
	a) Blanket	0.038	From Manufactory	24	Wood		
	b) Rigid Board	0.033	From Manufactory		a) Softwoods	0.125	608
	c) Rigid Pipe Sections	0.038	From Manufactory		b) Hardwoods	0.138	702
11	Plate Glass	1.053	2512		c) Plywood	0.138	528
12	Glass Fiber Mat or Quilt	0.035	32	25	Vermiculite with Sand	0.065	From Manufactory
13	Gypsum Board	0.191	880	26	Ship Board Plywood	0.144	800
14	Hardboard Plywood			27	Firewood	0.086	400
	a) Standard	0.216	1024	28	Grit	0.115	2245
	b) Medium	0.123	640	29	Concrete Roof Tile	1.050	1370
15	Metals			30	Cement	1.010	From Manufactory
	a) Aluminum Alloy Typical	211	2672	31	Concrete Block	1.730	1750
	b) Copper Commercial	385	8784	32	Air	0.024	1.225
	c) Steel, Carbon	47.6	7840				

Thermal Resistance (R)

The value of the thermal resistance of a piece of material can be thought of as the temperature difference across it required producing one unit of heat flow per unit area. A building structure is usually composed of a number of different materials which may be considered to act:

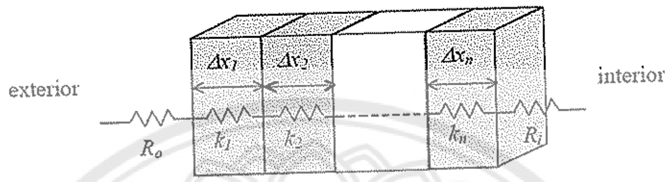

Figure 1 These picture show the layers of composite wall section and thermal resistance for wall section.

Air film resistance results from convection currents at the surface of a material. As the surface heats up or cools down, it affects the temperature of the air immediately adjacent. This then starts to rise or fall depending on whether it is hotter or colder. This has the same effect as increasing the resistance of the material to the flow of heat.

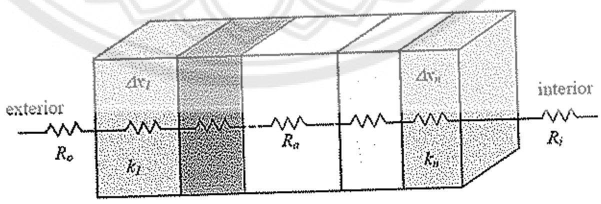

Figure 2 These picture show the layers of composite wall section and air layers (R_a) between wall and resistance for wall section.

Surface Film Resistance for Walls (R_i, R_o)

The surface film resistance for walls should be obtained from Table 3

Table 3 Surface Film Resistance for Wall (R_i, R_o)

Types of Surface	Resistance of Film (R) (m^2-°C/W)	
	Internal Surface (R_i)	External Surface (R_o)
High Radiation Surface Coefficient	0.120	0.044
Low Radiation Surface Coefficient	0.299	–

Air Film Resistance for Air Space inside Double Wall (R_a)

The air film resistance air space inside double wall should be obtained from Table 4.

Table 4 Air Film Resistance (R_a) of Air Space inside Double Wall

Air Film Resistance of Air Space Inside Double Wall (R_a) (m^2-$^oC/W$)		
Air Space (mm)	Surface Coefficient of Materials of the Wall	
	High Radiation	Low Radiation
5	**0.1100**	**0.2500**
10	0.1227	0.3593
15	0.1353	0.4686
20	**0.1480**	**0.5779**
25	0.1488	0.5797
30	0.1495	0.5814
35	0.1503	0.5832
40	0.1510	0.5849
45	0.1518	0.5867
50	0.1525	0.5884
55	0.1533	0.5902
60	0.1540	0.5919
65	0.1548	0.5937
70	0.1555	0.5954
75	0.1563	0.5972
80	0.1570	0.5989
85	0.1578	0.6007
90	0.1585	0.6024
95	0.1593	0.6042
≥100	**0.1600**	**0.6059**

Surface Film Resistance for Roofs (R_i, R_o)

The surface film resistance for roofs should be obtained from Table 5.

Table 5 Surface Air Film Resistance of Roofs (R_i, R_o)

Surface Air Film Resistance of Roofs (R) (m^2-$^oC/W$)				
Roof Slope (Degree)	Surface Coefficient of Materials of Roofs			
	High Radiation		Low Radiation	
	Internal(R_i)	External(R_o)	Internal(R_i)	External(R_o)
0	**0.1620**	**0.055**	**0.8010**	–
2.5	0.1604	0.055	0.7781	–
5	0.1589	0.055	0.7552	–
7.5	0.1573	0.055	0.7323	–
10	0.1558	0.055	0.7094	–
12.5	0.1542	0.055	0.6866	–
15	0.1527	0.055	0.6637	–
17.5	0.1511	0.055	0.6408	–
20	0.1496	0.055	0.6179	–
22.5	**0.1480**	**0.055**	**0.5950**	–
25	0.1463	0.055	0.5723	–
27.5	0.1447	0.055	0.5497	–
30	0.1430	0.055	0.5270	–
32.5	0.1413	0.055	0.5043	–
35	0.1397	0.055	0.4817	–
37.5	0.1380	0.055	0.4590	–
40	0.1363	0.055	0.4363	–
42.5	0.1347	0.055	0.4137	–
≥45	**0.1330**	**0.055**	**0.3910**	–

Air Space Resistance for Roofs (R_a)

The air space resistance for roofs should be obtained from Table 6.

Table 6 Air Film Resistance (R_a) of Air Space inside Roof

Air Space (mm)	Air Film Resistance of Air Space Inside The Roof (R_a), (m^2-°C/W)																		
	High Radiation Surface Coefficient of Materials of The Wall																		
	Roof Slope (Degrees)																		
	0.00	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50	40.00	42.50	≥45
5	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110
10	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123
15	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135
20	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148	0.148
25	0.150	0.150	0.150	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149
30	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.149	0.149	0.149
35	0.153	0.153	0.153	0.152	0.152	0.152	0.152	0.152	0.151	0.151	0.151	0.151	0.151	0.151	0.150	0.150	0.150	0.150	0.150
40	0.155	0.154	0.154	0.154	0.154	0.153	0.153	0.153	0.153	0.152	0.152	0.152	0.152	0.151	0.151	0.151	0.151	0.151	0.151
45	0.156	0.156	0.156	0.155	0.155	0.155	0.154	0.154	0.154	0.153	0.153	0.153	0.153	0.152	0.152	0.152	0.152	0.151	0.151
50	0.158	0.157	0.157	0.157	0.156	0.156	0.156	0.155	0.155	0.154	0.154	0.154	0.154	0.153	0.153	0.153	0.152	0.152	0.152
55	0.159	0.159	0.159	0.158	0.158	0.157	0.157	0.156	0.156	0.155	0.155	0.155	0.154	0.154	0.154	0.153	0.153	0.153	0.152
60	0.161	0.160	0.160	0.160	0.159	0.159	0.158	0.158	0.157	0.157	0.156	0.156	0.155	0.155	0.155	0.154	0.154	0.153	0.153
65	0.163	0.162	0.162	0.161	0.160	0.160	0.159	0.159	0.158	0.158	0.157	0.157	0.156	0.156	0.155	0.155	0.155	0.154	0.154
70	0.164	0.164	0.163	0.162	0.162	0.161	0.161	0.160	0.159	0.159	0.158	0.158	0.157	0.157	0.156	0.156	0.155	0.155	0.154
75	0.166	0.165	0.165	0.164	0.163	0.162	0.162	0.161	0.160	0.160	0.159	0.159	0.158	0.158	0.157	0.156	0.156	0.155	0.155
80	0.168	0.167	0.166	0.165	0.165	0.164	0.163	0.162	0.162	0.161	0.160	0.160	0.159	0.158	0.158	0.157	0.157	0.156	0.156
85	0.169	0.168	0.168	0.167	0.166	0.165	0.164	0.163	0.163	0.162	0.161	0.161	0.160	0.159	0.159	0.158	0.157	0.157	0.156
90	0.171	0.170	0.169	0.168	0.167	0.166	0.166	0.165	0.164	0.163	0.162	0.162	0.161	0.160	0.159	0.159	0.158	0.157	0.157
95	0.172	0.171	0.171	0.170	0.169	0.168	0.167	0.166	0.165	0.164	0.163	0.162	0.162	0.161	0.160	0.160	0.159	0.158	0.157
≥100	0.174	0.173	0.172	0.171	0.170	0.169	0.168	0.167	0.166	0.165	0.164	0.163	0.163	0.162	0.161	0.160	0.160	0.159	0.158

Table 6 (CONT.)

Air Space (mm)	Low Radiation Surface Coefficient of Materials of The Wall																		
	Roof Slope (Degrees)																		
	0.00	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	≥ 45
5	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
10	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357	0.357
15	0.465	0.465	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.464	0.463	0.463
20	0.572	0.572	0.572	0.572	0.572	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.570	0.570	0.570	0.570
25	0.625	0.623	0.620	0.618	0.616	0.613	0.611	0.608	0.606	0.604	0.602	0.599	0.597	0.595	0.593	0.590	0.588	0.586	0.584
30	0.678	0.674	0.669	0.664	0.660	0.655	0.650	0.646	0.641	0.636	0.632	0.628	0.623	0.619	0.615	0.610	0.606	0.601	0.597
35	0.731	0.725	0.718	0.711	0.704	0.697	0.690	0.683	0.676	0.669	0.663	0.656	0.650	0.643	0.637	0.630	0.624	0.617	0.611
40	0.785	0.775	0.766	0.757	0.748	0.739	0.730	0.720	0.711	0.702	0.693	0.685	0.676	0.667	0.659	0.650	0.641	0.633	0.624
45	0.838	0.826	0.815	0.803	0.792	0.781	0.769	0.758	0.746	0.735	0.724	0.713	0.702	0.692	0.681	0.670	0.659	0.648	0.638
50	0.891	0.877	0.864	0.850	0.836	0.822	0.809	0.795	0.781	0.767	0.755	0.742	0.729	0.716	0.703	0.690	0.677	0.664	0.651
55	0.944	0.928	0.912	0.896	0.880	0.864	0.848	0.832	0.816	0.800	0.785	0.770	0.755	0.740	0.725	0.710	0.695	0.680	0.665
60	0.997	0.979	0.961	0.943	0.924	0.906	0.888	0.870	0.851	0.833	0.816	0.799	0.781	0.764	0.747	0.730	0.712	0.695	0.678
65	1.051	1.030	1.010	0.989	0.968	0.948	0.927	0.907	0.886	0.866	0.846	0.827	0.808	0.788	0.769	0.750	0.730	0.711	0.692
70	1.104	1.081	1.058	1.035	1.013	0.990	0.967	0.944	0.921	0.898	0.877	0.855	0.834	0.812	0.791	0.769	0.748	0.727	0.705
75	1.157	1.132	1.107	1.082	1.057	1.032	1.006	0.981	0.956	0.931	0.908	0.884	0.860	0.837	0.813	0.789	0.766	0.742	0.719
80	1.210	1.183	1.155	1.128	1.101	1.073	1.046	1.019	0.991	0.964	0.938	0.912	0.887	0.861	0.835	0.809	0.784	0.758	0.732
85	1.263	1.234	1.204	1.174	1.145	1.115	1.086	1.056	1.026	0.997	0.969	0.941	0.913	0.885	0.857	0.829	0.801	0.773	0.745
90	1.317	1.285	1.253	1.221	1.189	1.157	1.125	1.093	1.061	1.029	0.999	0.969	0.939	0.909	0.879	0.849	0.819	0.789	0.759
95	1.370	1.336	1.301	1.267	1.233	1.199	1.165	1.131	1.096	1.062	1.030	0.998	0.966	0.933	0.901	0.869	0.837	0.805	0.772
≥ 100	1.423	1.386	1.350	1.314	1.277	1.241	1.204	1.168	1.131	1.095	1.061	1.026	0.992	0.958	0.923	0.889	0.855	0.820	0.786

Air Film Resistance for Ceilings (R)

The air film resistance for ceilings should be obtained from Table 7.

Table 7 Air Film Resistance of the Ceiling (R)

Type of Surface Ceiling	Resistance of Air Film (R) (m^2-^{o}C/W)
High Radiation Surface Coefficient	0.458
Low Radiation Surface Coefficient	1.356

Absorptivity (α)

Energy simulation studies have shown that the external surface and color of walls and roofs, and therefore their absorptivity, have a significant effect on chiller energy used. The absorptivity for wall and roof surfaces should be obtained from Table 8.

Table 8 Absorptivity for Wall and Roof Surfaces

Materials	Absorptivity (α)	Paint	Absorptivity (α)
Black glass	1.0	Optical flat black paint	0.98
Black concrete	0.91	Flat black paint	0.95
Stafford blue brick	0.89	Black lacquer	0.92
Red brick	0.88	Dark grey paint	0.91
Bituminous felt	0.88	Dark blue lacquer	0.91
Blue grey slate	0.87	Black oil paint	0.9
Roofing, green	0.86	Dark olive drab paint	0.89
Brown concrete	0.85	Azure blue or dark green	0.88
Asphalt pavement, weathered	0.82	Dark brown paint	0.88
Wood, smooth	0.78	Dark blue-grey paint	0.88
Uncolored concrete	0.65	Medium brown paint	0.84
White marble	0.58	Medium light brown paint	0.8
White mosaic tiles	0.58	Brown or green lacquer	0.79
Light buff brick	0.55	Medium rust paint	0.78
Built-up roof, white	0.5	Light grey oil paint	0.75
Bituminous felt, aluminized	0.4	Red oil paint	0.74
Gravel	0.29	Medium dull green paint	0.59
White on galvanized iron	0.26	Medium orange paint	0.58
White glazed brick	0.25	Medium yellow paint	0.57
Polished aluminum reflector sheet	0.12	Medium blue paint	0.51
Aluminized Mylar film	0.1	Medium Kelly green paint	0.51
Tinned surface	0.05	Light green paint	0.47
		Aluminum paint	0.4
		White semi-gloss paint	0.3
		White gloss paint	0.25
		Silver paint	0.25
		White lacquer	0.21
		Laboratory vapor deposited coatings	0.02

Equivalent Temperature Difference for Wall (TD_w)

Energy has indicated that thermal mass affects the total heat flow through walls sufficiently to warrants its inclusion in the formulation of an OTTV. The equivalent temperature difference for walls should take into account the wall mass and absorptivity. Heavyweight construction gives a better performance than lightweight construction because it resists the passage of heat. The equivalent temperature difference for walls should be obtained from Table 9.

Table 9 Equivalent Temperature Difference for Wall (TD_w)

Equivalent Temperature Difference for Wall (TD_w), (°C)					
Mass of Material (kg/m^2)	Absorptivity (α)				
	$0.0 \le \alpha \le 0.20$	$0.2 < \alpha \le 0.4$	$0.4 < \alpha \le 0.6$	$0.6 < \alpha \le 0.8$	$0.8 < \alpha \le 1.0$
0-125	14	15	16	17	18
126-195	11	12	13	14	15
≥196	9	10	11	12	13

Shading Coefficient of Glass (SC_1)

The shading coefficient of glass or window is the ratio of the solar heat gain through a particular type of glass under a specific set of conditions to the solar heat gain through double strength sheet clear glass under the same conditions. The shading coefficient of glass published by glass manufacturers in Thailand or overseas can be used without modification provided that the calculations have been based on a normal angle of incidence.

Shading Coefficient of External Shading (SC_2)

Shading of windows is of paramount importance in reducing solar heat gain to the building. This shading can be provided by projections over the window, at the side of the window, or a combination of both. For the purpose of simplicity in OTTV calculations this shading effect is taken into account as an external shading multiplier which should be assessed as follows:

(a) Overhang projections to windows

The external shading multiplier for overhang projections to windows should be obtained from Table 10 according to the overhang projection factor and the orientation of the window.

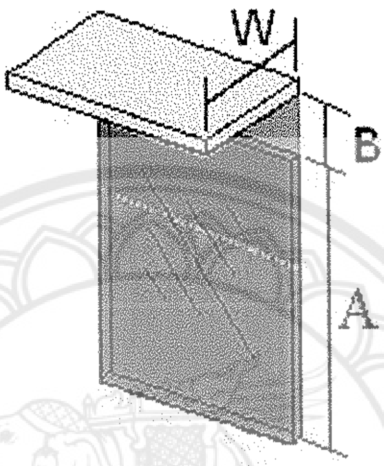

Figure 3 Window with overhang.

Table 10 External Shading Multiplier for Overhang Projections to Windows

W/A Ratio	Aspects and B/A Ratio									
	N		NE / NW		E / W		SE / SW		S	
	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.4
0.2	0.91	0.95	0.91	0.97	0.89	0.97	0.87	0.97	0.81	0.94
0.4	0.89	0.91	0.85	0.92	0.81	0.92	0.77	0.90	0.72	0.82
0.6	0.88	0.89	0.81	0.88	0.75	0.86	0.70	0.82	0.65	0.76
0.8	0.88	0.89	0.79	0.84	0.71	0.81	0.66	0.76	0.59	0.70
1.0	0.88	0.88	0.77	0.82	0.68	0.77	0.63	0.72	0.58	0.64
1.2	0.88	0.88	0.76	0.80	0.65	0.74	0.60	0.68	0.57	0.60

(b) Vertical fins or louvers projections to windows

The external shading multiplier for vertical fin projections to windows should be obtained from Table 11 according to the vertical fin projection factor and the orientation of the window.

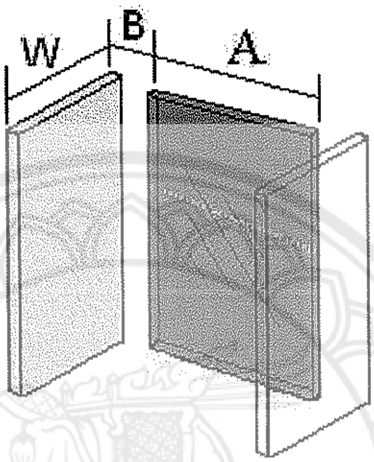

Figure 4 Vertical fins or louvers projections to windows

Table 11 External Shading Multiplier for Vertical Fin Projections to Windows

W/A Ratio	Aspects and B/A Ratio									
	N		NE / NW		E / W		SE / SW		S	
	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.4
0.2	0.95	0.99	0.92	0.98	0.95	0.99	0.9*3	0.99	0.88	0.97
0.4	0.90	0.94	0.87	0.94	0.90	0.98	0.88	0.97	0.80	0.91
0.6	0.89	0.91	0.83	0.90	0.86	0.96	0.84	0.94	0.74	0.85
0.8	0.89	0.90	0.80	0.87	0.82	0.94	0.80	0.91	0.70	0.80
1.0	0.89	0.90	0.79	0.84	0.79	0.91	0.77	0.88	0.67	0.76
1.2	0.88	0.89	0.78	0.82	0.77	0.88	0.74	0.86	0.65	0.73

The shading coefficient of glass or window is the ratio of the solar heat gain through a particular type of glass under a specific set of conditions to the solar heat gain through double strength sheet clear glass under the same conditions not includes the combination of overhang and vertical fin projections.

Solar Factor for Walls (SF)

The solar factor for vertical surfaces at various orientations and that for horizontal surfaces should be obtained from correction factor for walls because solar factor is equal correction factor is multiplied by 160 from Table 12. The solar factors have been calculated for the Thailand climate.

Correction Factor for Walls (CF)

The correction factor for wall is a factor for finding SF = CF X 160 from Table 12.

Table 12 Correction Factor for Walls (CF)

Direction / Slope	N	NE	E	SE	S	SW	W	NW
70	1.06	1.24	1.52	1.63	1.63	1.60	1.48	1.22
75	0.96	1.14	1.42	1.52	1.50	1.48	1.38	1.12
80	0.87	1.05	1.33	1.40	1.37	1.37	1.28	1.02
85	0.78	0.96	1.22	1.29	1.24	1.25	1.17	0.93
90	0.70	0.87	1.12	1.17	1.11	1.13	1.03	0.84

Equivalent Temperature Difference for Roof (TD_r)

The equivalent temperature difference for roofs should take into account the roof mass, density and orientation. Heavyweight construction gives a better performance than lightweight construction because it resists the passage of heat. The equivalent temperature difference for roofs should be obtained from Table 13.

Table 13 Equivalent Temperature Difference for Roof (TD_r)

Equivalent Temperature Difference for Roof (TD_r), (°C)				
Mass of Material (kg/m^2)	Absorptivity (α)			
	$0.0 \leq \alpha \leq 0.20$	$0.2 < \alpha \leq 0.4$	$0.4 < \alpha \leq 0.6$	$0.6 < \alpha \leq 1$
0-50	20	24	28	32
50-200	16	20	24	28
$\geq$201	12	16	20	24

Solar Factor for Roofs (SF)

The solar factor for horizontal surfaces should be obtained from correction factor for roofs because solar factor is equal correction factor are multiplied by 370 from Table 14. The solar factors have been calculated for the Thailand climate. Any slopping or angled roof can be resolved into vertical and horizontal components. The vertical components of the sloping or angled roof can be treated as a vertical surface with a solar factor at that respective orientation; whereas the horizontal component can be treaded as a horizontal surface.

Correction Factor for Roofs (CF)

The correction factor for roof is a factor for finding SF = CF X 370 from Table 14.

Table 14 Correction Factor for Roof (CF)

Slope \ Direction	N	NE	E	SE	S	SW	W	NW
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	0.98	0.99	0.99	1.01	1.01	1.01	0.99	0.99
10	0.96	0.97	0.99	1.01	1.02	1.01	0.99	0.97
15	0.93	0.95	0.98	1.01	1.02	1.01	0.98	0.95
20	0.90	0.93	0.97	1.00	1.02	1.00	0.97	0.93
25	0.87	0.90	0.95	0.99	1.01	0.99	0.95	0.90
30	0.83	0.86	0.93	0.98	0.99	0.98	0.93	0.86
35	0.78	0.83	0.90	0.96	0.97	0.96	0.90	0.83
40	0.74	0.79	0.87	0.93	0.95	0.93	0.87	0.79
45	0.69	0.75	0.84	0.90	0.92	0.90	0.84	0.75
50	0.64	0.71	0.81	0.87	0.88	0.87	0.81	0.71
55	0.59	0.66	0.77	0.83	0.84	0.83	0.77	0.66
60	0.54	0.62	0.73	0.79	0.80	0.79	0.73	0.62
65	0.50	0.58	0.69	0.75	0.75	0.75	0.69	0.58

Estimation of Solar Radiation

Solar radiation is the one of most important interesting input parameters for estimating the performance of this system. The correlation, which is widely available to estimate solar radiation, is possible to use. In this study, the monthly mean daily total radiation on horizontal surface was taken from the solar radiation map of Thailand by Silpakorn University to obtain the hourly mean radiation on a tilted surface, $\overline{I_T}$, in order to calculate the performance of this system.

Solar Time

The solar time is difference from standard time because of the difference in longitudes between the country and the specific location. The time difference was determined as 4 minutes per 1 degree of longitude or 15° within an hour. For Thailand, the location standard longitude for calculating solar time is 105 east referenced from 0 longitude at Greenwich near London, UK

Another reason why the standard local time is difference from the solar time is due to the fluctuation of the earth. The offset value in this case is called the Equation of Time, E, and it can be calculated by the equation as follows (Duffie and Beckman, 1980. p. 9):

$$E = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B) \tag{2.7}$$

$$B = \frac{360(n-81)}{365} \tag{2.8}$$

where E = Equation of Time, (minute)

n = Day number of the year; $1 \le n \le 365$

And the correlation between solar time and the local standard time can be calculated by the equation as follows:

$$t_{sol} = t_{Std} \pm 4(L_{St} - L_{Loc}) + E \tag{2.9}$$

where t_{sol} = Solar time, (Hour)

t_{Std} = Standard time, (Hour)

L_{St} = Standard meridian for the local time zone, (Degrees)

L_{Loc} = Longitude of the location in question, (Degrees)

The solar time is considered negative when the East meridian points and positive when the West meridian points

Declination Angle (δ)

Declination angle is the angle between the Sun's rays and Earth's equatorial plane. The Solar declination angle is zero during an equinox, and 23.45° during a solstice. By convention, the angle is considered negative when the North Pole points toward the Sun, positive when the South Pole points toward the Sun. The Declination angle is 23.45° during the Northern Summer Solstice and –23.45° during the Southern Summer Solstice. It is between –23.45° and 23.45° the rest of the year. The declination for a particular day can be represented by the formula:

$$\delta = 23.45 \sin(360 \frac{284+n}{365}) \tag{2.10}$$

where δ = Solar declination angle

n = Day number of the year; $1 \leq n \leq 365$

The Hour Angle (ω) and The Sunset Hour Angle (ω_s)

The Hour Angle is the angular distance that the earth has rotated in a day. It is equal to 15 degrees multiplied by the number of hours from local solar noon. This is based on the nominal time, 24 hours, required for the earth to rotate once i.e. 360 degrees. Values East of due South, morning values are positive; and values West of due South, evening values are negative. The Hour Angle can be defined by

$$\omega = 15 \times (t_{sol} - 12) \tag{2.11}$$

where ω = The hour angle, (Degrees)

t_{sol} = Solar time, (Hour)

The sunset hour angle (ω_s) is often calculated by the following equation:

$$\cos\omega_s = -\tan\phi\tan\delta \tag{2.12}$$

where ϕ = Latitude, (Degrees)

δ = Declination angle, (Degrees)

Radiation on a Horizontal Surface

Solar radiation which incident on the earth is composed of two major components.

- Direct or beam radiation ($\overline{I_b}$): radiated from sun to earth surface directly.
- Diffuse radiation ($\overline{I_d}$): reflected and/or scattered by small matter in the atmosphere such as cloud, water drops then through the earth surface.

Thus, the whole solar radiation incident at the earth surface on horizontal surface is called total radiation. Mathematical model which represents the correlation between beam, diffuse, and total radiation can be written as following:

Total radiation = Beam radiation + Diffuse radiation (2.13)

where Total, Beam, and Diffuse radiation are on a horizontal surface.

Extraterrestrial Radiation on a Horizontal Surface

Solar radiation at normal incidence received at the surface of the earth is subject to variations due to change of the extraterrestrial radiation. The calculation of the theoretical possible extraterrestrial radiation is necessary to obtain the ratio of radiation level under atmosphere.

It is often necessary for calculation of daily solar radiation to have the integrated daily extraterrestrial radiation on a horizontal surface (H_0) over the period from sunrise to sunset. The monthly mean daily extraterrestrial radiation, ($\overline{H_0}$), is a useful quantity. (Duffie and Beckman. 1991:40) For latitudes in the range of +60 to -60, it can be calculated with equation (2.14) using n and δ for the mean day of the month from Table 15

$$H_0 = \frac{24 \cdot 3600}{\pi} \cdot G_{sc} \cdot (1 + 0.033 \cdot \cos\frac{360n}{365}) \cdot (\cos\phi \cos\delta \sin\omega_s + \frac{\pi\omega_s}{180} \sin\phi \sin\delta) \quad (2.14)$$

Table 15 Recommended Average Days for Months and Values of n, (Klein, 1997)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Date	17	16	16	15	15	11	17	16	15	15	14	10
Day of Year(n)	17	47	75	105	135	162	198	228	258	288	318	344
δ	-20.9	-13.0	-2.4	9.4	18.8	23.1	21.2	13.5	2.2	-9.6	-18.9	-23.0

where G_{sc} = Solar constant (1367 W/m^2)

n = Day number of the year; $1 \leq n \leq 365$

δ = Monthly mean solar declination (Degrees)

ω_s = Sunset hour angle (Degrees)

ϕ = Latitude of location (Degrees)

H_0 = Monthly mean daily extraterrestrial radiation on horizontal surface (MJ/m^2-day)

Correlation between Monthly Mean Diffuse and Total Radiation

Correlation between monthly diffuse and total radiation introduced by (Sopin Wachirapuwadon, 1996. p. 15) the following is

$$\frac{\overline{H_d}}{H_0} = -4.6408 + 26.5495\left(\frac{\overline{H}}{H_0}\right) - 28.3422\left(\frac{\overline{H}}{H_0}\right)^2 - 31.4546\left(\frac{\overline{H}}{H_0}\right)^3 + 46.4421\left(\frac{\overline{H}}{H_0}\right)^4 \quad (2.15)$$

where $\overline{H_d}$ = Monthly mean diffuse radiation on horizontal surface, (MJ/m^2-day)

H_0 = Monthly mean daily extraterrestrial radiation on horizontal surface, (MJ/m^2-day)

$\overline{H}$ = Monthly mean daily total radiation on horizontal surface, (MJ/m^2-day)

Correlation between Hourly Total Radiation and Daily Total Radiation (Duffie and Beckman, 1991. p. 89)

After the monthly mean daily total radiation is found from the solar map, the assessment of hourly total radiation can be determined in the form of ratio of hourly radiation to daily radiation(r_t) obtained by statistical process as follows:

$$r_t = \frac{\overline{I_t}}{\overline{H}} = \frac{\pi}{24}(a + b\cos\omega)\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{\pi\omega_s}{180}\cos\omega_s} \quad (2.16)$$

where r_t = Ratio of hourly radiation to daily radiation

a = $a_1 + a_2\sin(\omega_s - 60)$

b = $b_1 + b_2\sin(\omega_s - 60)$

$\overline{I_t}$ = Hourly mean total radiation on horizontal surface, (MJ/m^2-hr)

ω = Hourly angle, (Degrees)

ω_s = Sunset hourly angle, (Degrees)

Coefficient a_1, a_2, b_1, and b_2 at four stations in Thailand KMUTT, Chiang Mai, Ubon RatchaThani and Songkhla are show in Table 16

Table 16 The coefficients of Correlation between Hourly Total Radiation and Daily Total Radiation. (Sanparwat Vitthayasai. 2000:41)

Station	a_1	a_2	b_1	b_2
KMUTT	0.792	-0.250	0.189	0.471
Chiang Mai	0.514	0.228	0.512	0.083
Ubon RatchaThani	0.760	-0.031	0.207	0.238
Songkhla	0.607	-0.124	0.417	0.007

Correlation between Hourly Diffuses Radiation and Daily Diffuse Radiation (Duffie and Beckman. 1991:91)

$$r_d = \frac{\overline{I_d}}{\overline{H_d}} = \frac{\pi}{24} \cdot \frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{\pi\omega_s}{180}\cos\omega_s} \qquad (2.17)$$

where r_d = Ratio of hourly radiation to daily radiation

$\overline{I_d}$ = Hourly mean diffuse radiation on horizontal surface (MJ/m^2-hr)

$\overline{H_d}$ = Monthly mean diffuse radiation on horizontal surface (MJ/m^2-day)

ω = Hourly angle (Degrees)

ω_s = Sunset hourly angle (Degrees)

Ratio of Beam Radiation on Tilted Surface to That on Horizontal Surface Determined by: (Duffie and Beckman. 1991:25)

$$R_b = \frac{\sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega}{\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta} \tag{2.18}$$

where R_b = Ratio of beam radiation on tilted surface to that on horizontal surface

β = Angle between the plane surface and the horizontal, (Degrees)

γ = Surface azimuth, (Degrees)

ω = Hourly angle, (Degrees)

δ = Monthly mean solar declination, (Degrees)

ϕ = Latitude of location, (Degrees)

Correlation between Hourly Total, Beam and Diffuse Radiation is:

$$\overline{I_t} = \overline{I_b} + \overline{I_d} \tag{2.19}$$

where $\overline{I_t}$ = Hourly mean total radiation on horizontal surface, (MJ/m^2-hr)

$\overline{I_b}$ = Hourly mean beam radiation on horizontal surface, (MJ/m^2-hr)

$\overline{I_d}$ = Hourly mean diffuse radiation on horizontal surface, (MJ/m^2-hr)

Radiation on a Tilted Surface and Its Estimation

Hourly radiation on a tilted surface is given by (Duffie and Beckman. 1991:95)

$$\overline{I_T} = \overline{I_b}R_b + \overline{I_d}\left(\frac{1+\cos\beta}{2}\right) + \overline{I_t}\rho_g\left(\frac{1-\cos\beta}{2}\right)$$

(2.20)

where $\overline{I_T}$ = Hourly mean diffuse radiation on tilted surface, (MJ/m^2-hr)

ρ_g = Ground albedo = 0.2 for non-snow cover

Heat Flow Rate for Conditioned Building

Two methods for estimating the heating and cooling loads of a conditioned building are explained follows:

Steady State Method

This method does not account the effect of heat capacity of building materials. The heat balance under this approach can be written as:

$$Q_m = Q_e + Q_i + Q_v + Q_{st} \tag{2.21}$$

where Q_m = Heat balance load, (W)

Q_e = External load, (W)

Q_i = Internal load, (W)

Q_v = Ventilation load, (W)

Q_{st} = Storage load, (W)

Q_e consists of load due to condition (Q_c) and load through transparent openings (Q_s) and hence can be written as:

$$Q_e = Q_c + Q_s \tag{2.22}$$

The equation of Q_m gives a positive value for heat gain and negative one for heat loss. The objective of the equation is to find out the rate of heat flow required to heat or cool the building by mechanical means. Since the cost of installing and running mechanical equipment is high, the value of Q_m should be minimized by reducing the contribution of each factor through appropriate design changes.

Conduction (Q_c)

The heat flow rate through a building component (e.g. wall, roof, glass, etc.) is given by the following equation:

$$Q_c = A \cdot U \cdot \Delta T \tag{2.23}$$

where A = Surface area (m^2)

U= Thermal transmittance coefficient ($W/m^2\,^{o}C$)

ΔT= Equivalent temperature difference (^{o}C)

The above equation is solved for each of the elements enclosing the whole building i.e., each wall, window, door and roof and the result are summed up. The heat flow rate through the building envelope is the sum of the area and the U-value products of all the elements of the building multiplied by the temperature difference:

$$Q_c = \sum_{i=1}^{n}(A_{wi} \cdot U_{wi}) \cdot TD_w + \sum_{i=1}^{n}(A_{gi} \cdot U_{gi}) \cdot TD_g + \sum_{i=1}^{n}(A_{ci} \cdot U_{pi}) \cdot \Delta T \tag{2.24}$$

where A_w = Area of opaque wall, (m^2)

U_w = Thermal transmittance of opaque wall, ($W/m^2\,^{o}C$)

TD_w = Equivalent temperature difference for wall, (^{o}C)

A_g = Area of windows and doors, (m^2)

U_g = Thermal transmittance coefficient of glass, ($W/m^2\,^{o}C$)

TD_g = Equivalent temperature difference for glass, (°C)

A_c = Area of ceiling, (m^2)

U_c = Thermal transmittance of ceiling, ($W/m^2\ ^oC$)

ΔT = Equivalent temperature difference (T_o-T_i), (°C)

T_o = Daily average temperature outdoor, (°C)

T_i = Indoor set temperature, (°C)

i = Types of materials

n = Number of components

Radiation through Transparent Elements (Q_s)

The solar gain through transparent elements can be written as following:

$$Q_s = \sum_{i=1}^{n} (A_{gi} \cdot \overline{I_{Ti}} \cdot SC_{1i} \cdot SC_{2i}) \qquad (2.25)$$

where A_g = Surface area of glass, (m^2)

$\overline{I_T}$ = Hourly mean diffuse radiation on tilted surface, (MJ/m^2-hr)

SC_1 = Shading coefficient of glass

SC_2 = Shading coefficient of external shading

i = Types of materials

n = Number of components

Storage Heat Load of a Room Intermittently Air Conditions (Q_{st})

$$Q_{st} = (Q_c + Q_s) \cdot SHF$$

(2.26)

where SHF = Storage heat load (20%)

Internal Heat Gain (Q_i)

The internal heat gain of a house is estimated as follows:

$$Q_i = (No.\ People \times Heat\ Rate) + Q_p \qquad (2.27)$$

where Q_p = Transmission heat gain through partition, (W)

The heat generated by occupants (people) is a heat gain for the house and its magnitude depends on the level of activity of a person. Table 17 shows the heat output rate of human bodies for various activities.

Table 17 Heat Production rate in A Human Body

Activity	Rate of Heat Production	
	W	W/m^2
Sleeping	60	35
Resting	80	45
Sitting, Normal office work	100	55
Typing	150	85
Slow walking (3 km/hr)	200	110
Fast walking (6 km/hr)	250	140
Hard work	More than 300	More than 170

Calculation of sensible heat load in interior zone is transmission heat load of partition and ceiling and sensible heat load due to internal heat sources.

- Transmission heat load of partition

$$Q_p = \sum_{i=1}^{n}(A_{pi} \cdot U_{pi}) \cdot \Delta T \tag{2.28}$$

where Q_p = Transmission heat gain through partition, (W)

A_p = Area of partition, (m^2)

U_p = Thermal transmittance of partition, ($W/m^2\ ^oC$)

ΔT = Temperature difference (T_o-T_i), (^oC)

T_o = Daily average temperature outdoor (^oC)

T_i = Indoor set temperature (^oC)

Ventilation (Q_v)

The heat flow rate due to ventilation of air between the interior of a building and the outside depends on the rate of air exchange. It is given by:

$$Q_v = \rho \cdot V_r \cdot C \cdot \Delta T \tag{2.29}$$

where ρ = Density of air, (kg/m^3)

V_r = Ventilation rate, (m^3/s)

C = Specific heat of air, (J/kg-^oC)

ΔT = Temperature difference, (T_o-T_i), (^oC)

T_o = Daily average temperature outdoor, (^oC)

T_i = Indoor set temperature, (^oC)

If the number of air changes is known, then

$$V_r = \frac{N \cdot V}{3600} \tag{2.30}$$

where N = Number of air change per hour

V = Volume of the room or space, (m^3)

The minimum standards for ventilation in terms of air changes per hour (N) are presented in Table 18

Table 18 Recommended air change rates

Space to be Ventilation	Air Changes Per Hour
Assembly hall / Auditorium (smoking)	3-6
Bedrooms / Living rooms (smoking)	3-6
Bathrooms / Toilets	6-12
Space to be Ventilation	Air Changes Per Hour
Cafes / Restaurants (smoking)	12-15
Cinemas / Theatres (non-smoking)	6-9
Classrooms	3-6
Factories (medium metal work)(smoking)	3-6
Garages (smoking)	12-15
Hospital wards (smoking)	3-6
Kitchens (common)(smoking)	6-9
Kitchens (domestic)(smoking)	3-6
Laboratories	3-6
Offices (smoking)	3-6

Economic Analysis

The economic analysis for this study is Pay Back Period method. The calculation of Pay Back Period is determined by:

$$n = \frac{Investment\ Cost}{Cost\ of\ Energy\ Saving} \tag{2.31}$$

where n = Pay back period, (years/months/days)

And the calculation of percentage of energy saving is determined by:

$$Energy\ Saving = \frac{Q_m - Q_{m1}}{Q_m} \times 100\,\% \tag{2.32}$$

where Q_m = Heat balance load before install insulation, (W)

Q_{m1} = Heat balance load after install insulation, (W)