CHAPTER III

METHODOLOGY

The methods are as following:

1. Literature review of research topic.
2. Study on located solar radiation, solar collector, storage tank, auxiliary heat in solar cooling system and heat gain & cooling load.
3. Study structure and material of the building.
4. Collect data from SACS at TESTING Building SERT, NU
5. Separate data from SACS follow solar intensity (Diffuse fraction).
6. Analyze LPG consumption, the efficiency of collector
7. Conclusion and writing thesis

Description

1. Solar cooling system at SERT

Solar cooling system install on TESTING Building SERT, NU that is compose two terms that are Energy supply term as energy source for Absorption chiller, and the air condition term in table 4

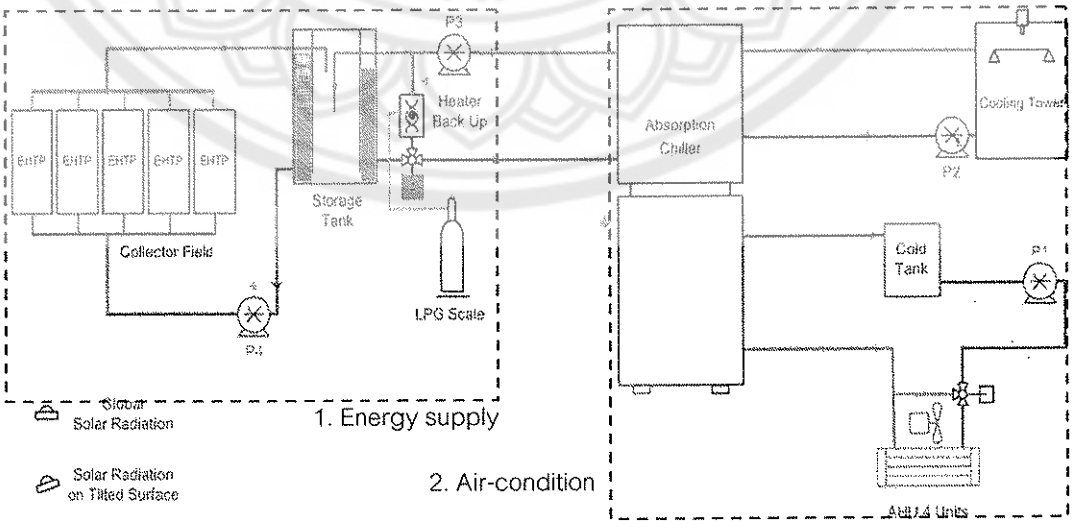

Figure 17 Components of the solar cooling system at SERT

Table 4 Components of the solar cooling system at SERT

Energy supply		
	Detail	Remark
1. Solar collector	Apricus model AP-30 (30 module) Absorber area 2.4 m^2/module Aperture area 2.82 m^2/module	From effect shading, total area 69.9m^2 (See specification in Figure C-1 and C-2)
2. Heat backup (Auxiliary heat)	Gas Water heater -Rinnai model Heavy Duty32 LPG 2 tank (48 kg/Tank)	
3. Hot water storage tank	Insulation tank capacity 400 liter	
The air condition term		
	Detail	Remark
4. Absorption Chiller	Yazaki model WFC-S Series: 10 Cooling capacity 10 tons of refrigeration (35 kW)	(See specification in Figure C-3)
5. Cooling tower	BKC-40 RT	
6. Fan coil unit	Aircon model WQW-32V Capacity 32,000 Btu	

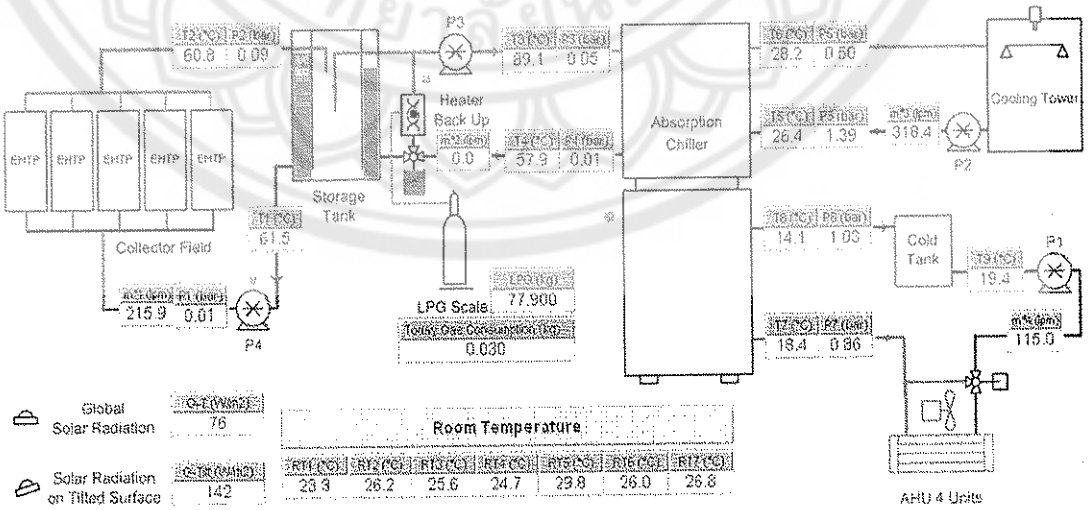

Figure 18 Measurement points of the solar cooling system at SERT

T_1 = Return water temperature to collectors, (^{o}C) (RTD PT100 Sensor)

T_2 = Heated water temperature from collectors, (^{o}C) (RTD PT100 Sensor)

T_3 = Supplying hot water inlet temperature to chiller, (^{o}C) (RTD PT100 Sensor)

T_4 = Supplying hot water outlet temperature from chiller, (^{o}C) (RTD PT100 Sensor)

T_5 = Cooling water inlet temperature to chiller, (^{o}C) (RTD PT100 Sensor)

T_6 = Cooling water outlet temperature from chiller, (^{o}C) (RTD PT100 Sensor)

T_7 = Refrigerated water inlet temperature to chiller, (^{o}C) (RTD PT100 Sensor)

T_8 = Refrigerated water outlet temperature from chiller, (^{o}C) (RTD PT100 Sensor)

T_9 = Refrigerated water outlet temperature from cold tank, (^{o}C) (RTD PT100 Sensor)

RT_1 = Room temperature at the wall beside fan coil no.1, (^{o}C) (RTD PT100 Sensor)

RT_2 = Room temperature at the wall beside fan coil no.2, (^{o}C) (RTD PT100 Sensor)

RT_3 = Room temperature at the wall beside fan coil no.3, (^{o}C) (RTD PT100 Sensor)

RT_4 = Room temperature under roof, (^{o}C) (RTD PT100 Sensor)

RT_5 = Room temperature at the window below fan coil no.2, (^{o}C) (RTD PT100 Sensor)

RT_6 = Ambient temperature or outside temperature, (^{o}C) (RTD PT100 Sensor)

$\dot{m}_1$ = Water flow rate via collectors, (kg/s)

$\dot{m}_2$ = Supplying hot water flow rate, (kg/s)

$\dot{m}_3$ = Cooling water flow rate, (kg/s)

$\dot{m}_4$ = Refrigerated water flow rate, (kg/s)

G_t = Solar radiation on tilted surface, (W/m^2)

G_h = Total or global radiation on a horizontal surface, (W/m^2)

M = LPG consumption, (kg)

For specific data of designed SACS; total radiation on collector tilt, energy from solar collector, energy from auxiliary heat (LPG) are shown in tables bellow

Table 5 Total cooling load for design sizing SACS at SERT (Nipon Ketjoy, May 1st 2005.)

The average cooling load of the room - with out recovery (kW)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7:00 - 8:00	14.118	14.903	15.630	16.919	17.078	16.983	16.051	15.854	16.184	16.080	14.722	14.101
8:00 - 9:00	15.263	16.868	17.790	19.355	19.514	19.436	18.282	18.194	18.488	18.235	16.788	15.697
9:00 - 10:00	16.599	18.422	19.467	20.979	21.300	21.096	19.895	19.847	20.030	19.629	18.216	17.128
10:00 - 11:00	16.955	19.145	20.341	22.077	22.445	22.252	21.073	21.022	21.016	20.333	18.575	17.434
11:00 - 12:00	16.044	18.860	19.751	21.324	21.626	21.515	20.485	20.367	20.174	19.327	17.527	16.531
12:00 - 13:00	15.093	17.790	18.971	20.223	20.456	20.385	19.433	19.187	18.884	17.994	16.261	15.485
13:00 - 14:00	13.995	16.105	16.975	18.137	18.303	18.442	17.627	17.256	16.734	15.856	14.247	14.100
14:00 - 15:00	13.143	14.429	14.999	16.134	16.153	16.228	15.627	15.091	14.437	13.476	12.238	12.667
15:00 - 16:00	12.023	12.298	12.785	13.935	13.614	13.652	13.117	12.470	11.793	10.868	9.455	11.000
16:00 - 17:00	12.453	13.452	13.937	15.152	14.780	14.607	13.769	13.438	13.764	13.656	12.490	12.405
Total	145.686	162.272	170.646	184.235	185.269	184.596	175.359	172.726	171.504	165.454	150.519	146.548

Table 6 Total radiation for design sizing SACS at SERT (Nipon Ketjoy, May 1st 2005.)

Total radiation on roof of the Testing building (W/m^2)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7:00 - 8:00	221.000	238.000	298.000	351.000	346.000	315.000	286.000	267.000	284.000	280.000	266.000	254.000
8:00 - 9:00	430.000	449.000	511.000	550.000	517.000	469.000	436.000	418.000	449.000	448.000	443.000	452.000
9:00 - 10:00	628.000	649.000	708.000	727.000	666.000	602.000	570.000	554.000	594.000	593.000	597.000	631.000
10:00 - 11:00	779.000	804.000	857.000	854.000	771.000	697.000	669.000	653.000	697.000	690.000	701.000	756.000
11:00 - 12:00	855.000	885.000	931.000	910.000	812.000	738.000	715.000	698.000	739.000	721.000	734.000	806.000
12:00 - 13:00	841.000	878.000	916.000	884.000	785.000	718.000	702.000	684.000	711.000	682.000	690.000	768.000
13:00 - 14:00	740.000	784.000	817.000	782.000	695.000	639.000	631.000	610.000	621.000	579.000	579.000	652.000
14:00 - 15:00	570.000	621.000	650.000	620.000	554.000	516.000	514.000	491.000	482.000	430.000	420.000	480.000
15:00 - 16:00	366.000	418.000	444.000	427.000	386.000	367.000	370.000	346.000	319.000	262.000	243.000	282.000
16:00 - 17:00	160.000	208.000	233.000	229.000	216.000	213.000	220.000	195.000	157.000	102.000	76.000	93.000
Total	5590.000	5934.000	6365.000	6334.000	5748.000	5274.000	5113.000	4916.000	5053.000	4787.000	4749.000	5174.000

Table 7 Energy from Solar collector for design sizing SACS at SERT (Nipon Ketjoy, May 1st 2005.)

Energy supply from solar collector field (W/m^2)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7:00 - 8:00	99.229	122.332	165.390	203.580	199.988	177.660	156.728	143.112	155.348	152.712	142.576	133.858
8:00 - 9:00	211.130	224.500	269.297	297.000	273.493	239.190	215.384	202.312	224.500	224.000	220.171	226.904
9:00 - 10:00	352.936	367.983	410.640	423.841	380.286	334.110	311.220	299.714	316.602	327.929	330.738	355.253
10:00 - 11:00	461.168	479.184	517.628	514.962	455.661	402.169	382.668	370.904	402.169	397.440	405.178	444.528
11:00 - 12:00	515.565	537.195	570.703	555.100	484.764	431.730	415.415	403.444	432.315	419.622	429.390	480.376
12:00 - 13:00	505.441	532.068	559.676	536.588	465.505	417.876	405.756	393.300	412.380	391.468	397.440	453.120
13:00 - 14:00	433.640	464.912	488.566	463.726	401.015	361.035	355.253	340.380	347.760	317.871	317.871	370.336
14:00 - 15:00	311.220	347.760	368.550	347.200	299.714	272.964	271.392	254.829	248.230	211.130	203.700	246.720
15:00 - 16:00	165.066	202.312	221.112	208.803	179.490	165.884	167.980	150.856	131.428	90.652	77.031	104.904
16:00 - 17:00	17.440	51.792	69.900	66.868	57.672	55.380	60.500	42.510	15.386	0.000	0.000	0.000
Total	3072.835	3330.038	3641.462	3617.668	3197.588	2857.998	2742.296	2601.361	2686.118	2532.824	2524.095	2815.999

Table 8 Energy from auxiliary heat (LPG) for design sizing SACS at SERT (Nipon Ketjoy, May 1st 2005.)

	Energy supply from auxiliary heat (Wh)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7:00 - 8:00	-12232.011	-12475.760	-10416.891	-9522.320	-10007.943	-11472.069	-11638.240	-12337.451	-11931.200	-11989.269	-10772.149	-10504.206
8:00 - 9:00	-6607.966	-7920.183	-6036.206	-6258.800	-8189.463	-10556.274	-10611.223	-11414.309	-10234.469	-9924.160	-8115.497	-6092.526
9:00 - 10:00	1705.303	184.617	1738.080	558.720	-3049.131	-6061.783	-5997.749	-6755.017	-4951.486	-4430.469	-2205.257	1104.389
10:00 - 11:00	8991.451	7153.840	8181.269	5546.469	736.034	-2808.571	-2570.046	-3323.029	-1042.857	-428.583	2650.926	7119.886
11:00 - 12:00	14216.880	11742.743	12844.446	9512.983	4022.114	361.086	645.234	-63.874	2327.920	2609.120	5851.589	10991.086
12:00 - 13:00	14852.571	12909.874	13184.011	9743.760	4300.343	942.891	1476.331	898.960	2725.737	2499.566	5388.560	10524.091
13:00 - 14:00	11206.903	10464.217	10924.880	7457.680	2729.897	-360.194	391.531	-162.789	1151.006	236.651	2535.223	6513.703
14:00 - 15:00	3647.966	4443.863	5126.457	1956.309	-1477.874	-3547.017	-2791.406	-3212.971	-2743.806	-4055.109	-2802.777	-318.194
15:00 - 16:00	-5283.474	-2991.451	-2345.086	-4865.623	-6523.851	-7558.777	-6639.691	-6954.526	-7381.303	-9002.514	-7964.583	-8158.606
16:00 - 17:00	-16532.160	-15481.063	-14883.680	-16826.034	-16965.646	-16873.303	-15314.720	-16132.103	-18559.817	-19508.571	-17842.857	-17721.429
Total	-40655.611	-38868.457	-33681.863	-37472.777	-46213.909	-59237.989	-55563.074	-60356.069	-56844.937	-59338.674	-49703.120	-42794.960

2. Testing building

Testing Building locate latitude (Ø) 16.78°, longitude (L_{loc}) 100.28° and above sea level 800 m. Conditioning room of SACS is showed in figure 19 (gray shade), area 220.19 m^2.

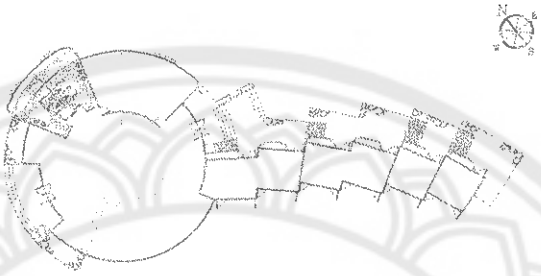

Figure 19 TESTING Building of SERT,NU

Detail of the material for conditioning room in Testing Building is showed in Table 9 For a brick wall between mortars. It is thick 10 cm including mortar thick 1 cm for each side. From energy department, science technology and environment office, it has U-value 8.07 $W/m^2\,^oC$.

For windows are a single glazing thick 6 mm and wood frame. From specific data of Thai Asahi Glass Company and energy department, science technology and environment office, it has U-value 5.83 $W/m^2\,^oC$, shading coefficient (SC) = 0.96, transmittance (α) = 0.13, absorbtance (τ) = 0.80 and relative heat gain (RGH) = 650 W/m^2 hr.

Table 9 Material of room condition

Type	Detail	U-value ($W/m^2\,^oC$, $Btu/h\,ft^2\,^oF$)	Remark
Door (D)	D1 - Double wood door and glass 6 mm. - 1.80x2.05 m. D3 - Wood door - 0.80x2.05 m.		

Table 9 (Cont.)

Type	Detail	U-value ($W/m^2\ ^oC$, $Btu/h\ ft^2\ ^oF$)	Remark
Roof (R)	- Metal sheet white color - Sandwich Glass wool 3 in.		Slope 20^o
Slab (S)	- Concrete 15 cm. on ground - Cover, terrazzo	-	Slab on ground is not calculate in cooling load
Wall (WL)	WL1 - Brick between mortar 10 cm - white color WL2 - EIFS with gypsum board - Glass wool 3 in.	8.07[1]	
Window (W)	W1 - Fix glass 6 mm. wood frame - 1.20x1.85 m. W2 - Fix glass 6 mm. wood frame - 1.20x1.55 m. W6 - glass 6 mm. wood frame - 0.9x1.25 m. W7 - Fix glass 3 mm. wood frame - 0.60x1.50 m.	5.83 $(1.03)^2$ 5.83 $(1.03)^2$ 5.83 $(1.03)^2$ 5.84 $(1.03)^2$	Glass 6 mm.[2] SC = 0.96, α = 0.13 τ = 0.80 RGH = 650 W/m^2 hr Glass 3 mm.[2] SC = 1.00, α = 0.06 τ = 0.86 RGH = 680 W/m^2 hr

The wall in chosen part composes the window W2 and the wall WL1 as area shown in table 10 For the heat sources inside the conditioned space, people 9 persons and table 12 show Electric lights, Equipment and appliances.

Table 10 Total shell area of the Testing building at SERT

Direction	Degree	Side area (m^2)				Roof area (m^2)			
								Dome	
		Materials	Door	Window	Wall	Materials	Roof	Side	Top
S	337.5-2.23	W2,WL1	-	6.82	13.42	W6,WL2,R	57.5		2.01
	2.23-9.77	WL1	-	-	6.164				
	9.77-22.5	W2,WL1	-	3.5185	6.9235				
		Total	0	10.339	26.508	36.846	57.5	0	2.01
SE	22.5-30	WL1	-	-	5.106	W6,WL2,R	75.8		2.01
	30*	WL1	-	-	8.092				
	30-53.93	W7,WL1	-	1.0744	15.327				
	53.93-57.14	WL1	-	-	2.2176				
	57.14-65.57	W1,WL1	-	2.3125	3.4625				
	65.57-67.5	WL1	-	-	1.3398				
		Total	0	3.3869	35.545	38.9314	75.8	0	2.01
E	67.5-69.26	WL1	-	-	1.2012	W6,WL2,R	75.8		2.01
	69.26-80.74	D1,WL1	3.485	-	4.369				
	80.74-84.43	WL1	-	-	2.541				
	84.43-90	W1,WL1	-	1.5355	2.2991				
	90-92.86	W1,WL1	-	0.777	1.1634				
	92.86-96.83	WL1	-	-	2.7258				
	97.52*	D2,WL1	1.845	-	11.755				
	96.35-112.50	WL1	-	-	5.76				
		Total	5.33	2.3125	31.815	39.457	75.8	0	2.01
NE	112.50-157.5	WL1	-	-	16.04	W6,WL2,R	81.2		2.01
		Total	0	0	16.04	16.04	81.2	0	2.01
N	157.5-165	WL1	-	-	2.68	W6,WL2,R	81.7		2.01
	165*	D2,WL1	1.845	-	2.955				
	165-176.98	WL1	-	-	5.28				
	187.5*	D3,WL1	1.845	-	1.835				
	97.5*	WL1	-	-	9.2				
	187.5*	D3,WL1	1.845	-	1.835				
	198.02-202.5	WL1	-	-	1.96				
		Total	5.535	0	25.745	31.28	81.7	0	2.01

*A line wall

Table 10 (Cont.)

Direction	Degree	Side area (m^2)				Roof area (m^2)			
								Dome	
		Materials	Door	Window	Wall	Materials	Roof	Side	Top
NW	202.5-209.09	WL1	-	-	3.096	WL2,R	64.9	2.43	2.43
	210*	WL1	-	-	15.6				
	209.44-213.2	WL1	-	-	2.958				
	213.2-227.19	W2,WL1	-	3.8595	6.8475				
	227.19-233.16	WL1	-	-	4.902				
	232.5*	WL1	-	-	7.1145				
	234-237.25	WL1	-	-	1.9776				
	237.25-245.32	W1,WL1	-	2.331	2.8602				
	245.32-247.5	WL1	-	-	1.1536				
		Total	0	6.1905	46.509	52.6999	64.9	2.43	2.43
W	247.5-248.99	WL1	-	-	1.0712	WL2,R	64.8	4.64	2.73
	248.99-261.01	D1,WL1	3.485	-	3.519				
	261.01-264.13	WL1	-	-	2.2248				
	264.13-273.29	W1,WL1	-	2.331	2.8602				
	273.29-275.45	WL1	-	-	1.9776				
	277.5*	WL1	-	-	7.412				
	276.66-282.48	WL1	-	-	5.244				
	282.48-292.5	W2,WL1	-	2.6815	4.7575				
		Total	3.485	5.0125	29.066	37.5638	64.8	4.64	69.39
SW	292.5-316.94	W2,WL1	-	6.82	12.991	WL2,R	47.1		2.05
	316.94-328.06	WL1	-	-	8.648				
	328.06-337.5	W2,WL1	-	2.6815	5.2765				
		Total	0	9.5015	26.916	36.417	47.1	0	2.05

*A line wall

Table 11 External wall area of the Testing building at SERT on direction

Direction	Degree	Material	Side Area (m^2)		
			Door	Window	Wall
NW	209.44-213.2	WL1	-	-	2.958
	213.2-227.19	W2,WL1	-	3.8595	6.8475
	227.19-233.16	WL1	-	-	4.902
	232.5*	WL1	-	-	7.1145
	234-237.25	WL1	-	-	1.9776
	237.25-245.32	W1,WL1	-	2.331	2.8602
	245.32-247.5	WL1	-	-	1.1536
W	247.5-248.99	WL1	-	-	1.0712
	248.99-261.01	D1,WL1	3.485	-	3.519
	261.01-264.13	WL1	-	-	2.2248
	264.13-273.29	W1,WL1	-	2.331	2.8602
	273.29-275.45	WL1	-	-	1.9776
	277.5*	WL1	-	-	7.412
	276.66-282.48	WL1	-	-	5.244
	282.48-292.5	W2,WL1	-	2.6815	4.7575
SW	292.5-316.94	W2,WL1	-	6.82	12.991
	316.94-328.06	WL1	-	-	8.648
	328.06-337.5	W2,WL1	-	2.6815	5.2765
S	337.5-2.23	W2,WL1	-	6.82	13.42
	2.23-9.77	WL1	-	-	6.164
	9.77-22.5	W2,WL1	-	3.5185	6.9235
SE	22.5-30	WL1	-	-	5.106
	57.14-65.57	W1,WL1	-	2.3125	3.4625
	65.57-67.5	WL1	-	-	1.3398
E	67.5-69.26	WL1	-	-	1.2012
	69.26-80.74	D1,WL1	3.485	-	4.369
	80.74-84.43	WL1	-	-	2.541
	84.43-90	W1,WL1	-	1.5355	2.2991
	90-92.86	W1,WL1	-	0.777	1.1634
	92.86-96.83	WL1	-	-	2.7258

*A line wall

Table 12 Sources contribute internal cooling loads, when 6 officer

Type	Power (kW)	Unit	Total Power (W)	Work Time (hr/day)
Computer Case 330 W	0.33	8.00	2.64	8.00
Monitor LCD 75 W	0.08	8.00	0.60	6.00
Computer Case 300 W	0.30	1.00	0.30	5.00
Monitor 150 W	0.15	1.00	0.15	5.00
Data Recorder			0.00	9.00
Fluorescent 46 W	0.05	32.00	1.47	0.00
Halogen 60 W	0.06	8.00	0.48	0.00
Printer HP 1000	0.44	1.00	0.44	4.00
Printer HP 1200	0.44	1.00	0.44	9.00
Printer HP 1210	0.22	1.00	0.22	4.00
Printer HP 2420	0.88	1.00	0.88	9.00
Water Boiling	0.70	76.00	53.20	1.50
Freezer	0.67	1.00	0.67	9.00

Experiments

Turn on the SACS between 9.00am – 17.00pm and collect data.

1. Solar radiation
   - 1.1 Solar radiation on horizontal surface, G_h (W/m^2)
   - 1.2 Solar radiation on tilted surface, G_t (W/m^2)
2. Water temperature and flow rate (inlet and outlet at collector field)
   - 2.1 Return water temperature to collectors, T_1 (^oC)
   - 2.2 Heated water temperature from collectors, T_2 (^oC)
   - 2.3 Water flow rate via collectors, $\dot{m}_1$ (kg/s)
3. LPG consumption
   - 3.1 LPG consumption, M (kg)
4. Inside and outside of room temperature, RT_1 – RT_6 (^oC)

Calculate of Diffuse fraction

The a daily clearness index K_T and The diffuse fraction, H/H_d calculate from equation (2.24) to (2.28) when

$$H = G_{h\text{-}avg} \times 8 \text{ hr} \times 3.6 / 1000 \quad (3.1)$$

Where

$G_{h\text{-}avg}$ = Average solar radiation on horizontal surface, (W/m^2)

Calculate of the efficiency of collector

The efficiency of collector is given by:

$$\eta_C = \frac{\dot{m}_l (T_2 - T_1)}{G_t A_C} \quad (3.2)$$

Where

$\dot{m}_l$ = Water flow rate via collectors, (kg/s)

T_1 = Return water temperature to collectors, (^oC)

T_2 = Heated water temperature from collectors, (^oC)

G_t = Solar radiation on tilted surface, (W/m^2)

A_C = Aperture area of collector field, (m^2)

The energy from collector (E_c) is given by:

$$E_c = \eta_c \times G_t \quad (3.3)$$

Where

E_c = Energy from collector, W/m^2

E_{cd} = Designed data energy from collector (Table 3.4), W/m^2

Calculate of Auxiliary heat

For calculation, the high heating value of LPG 25.7 MJ per liter and 1 liter of LPG is 0.53 kg (Nipon Ketjoy, May 1st 2005.)

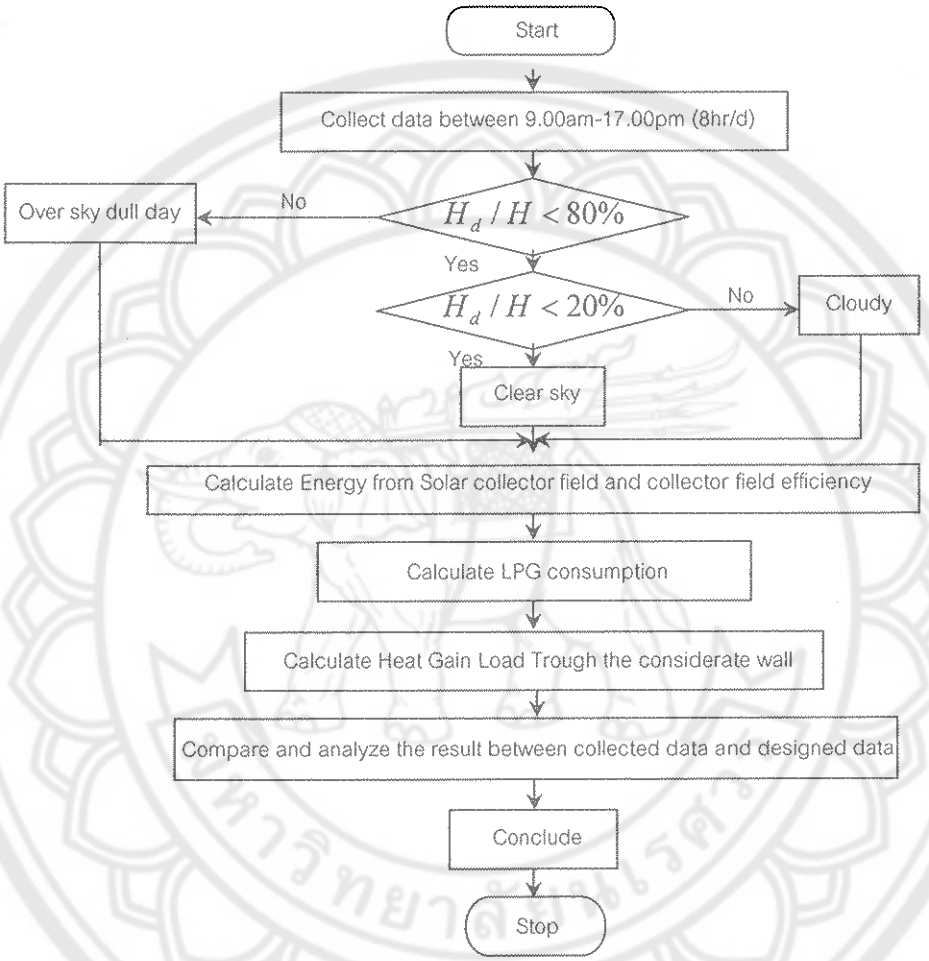

Figure 20 Flow diagram for finding the optimize and auxiliary heat demand of the SACS at SERT