CHAPTER IV

RESULTS AND DISCUSSION

The experimental results are divided into 3 parts; 1) the effect of different chemical ingredient in paint formulation by keeping white grey color shade constant, which compares the solar reflectivity and absorbance 2) the different of heat performance and energy consumption of two building, which are coated with conventional paints (colors), and coated with high solar reflective paint (Beger Cool UV Shield). These cases are used the two shades of colors namely white and white grey color, the effect of building location on envelop surface and of room temperature (Based case), and 3) the results show a numerical method calculation that comparing between Beger and conventional color and then comparison of surface temperature between numerical and experimental results. These results are as follows:

The result shows different solar reflective value according to 6 different chemical parameters of paint formulation for both primer and top coat.

1. From 4 experiments of different color (white, black, aluminum or metallic effect and material) in primer, the result of Beger Cool white primer 9000 shows the highest reflectance.

Table 2 for primer - color: white, black, aluminum or metallic effect

Primer color	name	film appearance	Max.%reflectance	Absorbance
White	Beger Cool primer 9000	white	95.09	1.0004
Black	Beger Delight E-8900	black	3.81	1.475
Metallic	Solarflair 9880	metallic white	94.02	0.997
Aluminium	Shinedecor 5000	silver	74.9	1.0731

2. From 5 experiments of different dosage of microsphere ceramic in primer, the result of microsphere ceramic Type A at 5% dosage shows the highest reflectance.

Table 3 for primer - dosage of microsphere ceramic: high and low dosage

Dosage of MS Ceramic	name	Film appearance	Max.% reflectance	Absorbance
non MS Ceramic	-	white	95.09	1.0504
Dosage 2%	MS ceramic Type A	white	95.18	1.0004
Dosage 5%	MS ceramic Type A	white	95.51	1.0386
Dosage 7%	MS ceramic Type A	white	94.98	1.0246
Dosage 2%	MS ceramic Type B	white	95.18	1.0106

3. From 3 experiments of different dosage of IR pigment and normal pigment in top coat, the result of white primer with IR pigment shows the highest reflectance.

Table 4 for topcoat - dosage of IR pigment and normal pigment

Primer	Top coated (grey)	Film appearance	Max.%reflectance	Absorbance
White	IR-pigment	grey	52.31	1.0472
White	normal pigment	grey	48.51	1.0467
Black	normal pigment	grey	47.58	1.0443

4. From 3 experiments of different dosage of insulate microsphere ceramic in top coat, the result of white primer with 7% microsphere ceramic shows the highest reflectance.

Table 5 for topcoat - dosage of insulate microsphere ceramic

Primer	Top coated (grey)	Film appearance	Max.%reflectance	Absorbance
White	White	grey	51.62	1.0499
White	White+MS ceramic 5%	grey	52.51	1.0486
White	White+MS ceramic 7%	grey	53.39	1.0565

5. From 6 experiments of different dosage of contamination with 0.5% of carbon black in top coat, the result shows the lowest reflectance.

Table 6 for primer - contamination such as carbon black

Primer	Top coated (grey)	Film appearance	Max.%reflectance	Absorbance
White	Carbon black dosage 0.1%	grey	59.93	1.0255
White	Carbon black dosage 0.3%	grey	42.38	1.0762
White	Carbon black dosage 0.5%	grey	33.1	1.082
White	Black oxide dosage 0.1%	grey	83.59	1.0246
White	Black oxide dosage 0.3%	grey	68.18	1.0506
White	Black oxide dosage 0.5%	grey	68.2	1.0278

6. From 4 experiments of different opacity at low and high hiding power in top coat, the result of white primer with high opacity shows the highest reflectance.

Table 7 for topcoat - opacity: low and high hiding power

Primer	Top coated	Opacity	Max.%reflectance	Absorbance
White	High opacity-grey	99.89	52.55	1.0445
Black	High opacity-grey	99.81	52.12	1.0436
White	Low opacity-grey	84.55	59.63	1.0457
Black	Low opacity-grey	85.13	54.32	1.0443

All of the laboratory test result point out that the paint with optimum solar reflective property need to take into account all important parameter of ingredient. Apparently, the white primer with microsphere ceramic will give the best solar reflective. If the white grey topcoat is formulated with optimum dosage of IR pigment, microsphere ceramic, and black oxide pigment, it will also show higher solar reflective compare to normal paint in white grey shade.

It is well known that the Brewster's angle is incidence angle making reflected ray as polarization which will completely reflects solar ray and heat energy from the substrate. As The Brewster's angle increases by the shape of pigment ingredient in paint film, the ability of reflection increases and cause higher solar reflectivity.

Titanium dioxide molecule also show high Brewster's angle up to 69.067^{o} compare to normal paint ingredient like calcium carbonate which has refractive index only at 1.65846 and Brewster's angle of 58.911^{o}. These figures explain why Beger

Cool UV Shield result in better solar reflection of almost every angle of incident rays throughout the day. Therefore, as the overall solar energy was reflected away, the heat coming into the house is then significantly reduced because there are some residues refracted rays coming through the coating into the house wall. Comparing to the conventional coated and non-coated, in which their film possess lower refraction index, and lower Brewster's angle, less of reflectivity performance are achieved hence more of solar energy can penetrate through the building surface to inside. In addition, the critical angle indicating all reflected rays with the high refraction index can be referred in this research. It is found that the Beger Cool UV Shield coating can reflect almost complete angle of incident solar ray due to spherical shape particle of microsphere ceramic, high refractive index of titanium dioxide, and infrared reflective pigment cause reflective ray angles higher than critical angle. Only small amount of residue solar energy can pass through Beger Cool UV Shield paint film in form of transmission, which causes significant reduction of surface temperature and cooling energy consumed by air conditioner. Therefore, it can be concluded that the effect of solar ray reflection are the key to achieve lower building surface temperature and consequently higher energy saving are obtained.

Table 8 The chemical ingredient of the Beger Cool UV Shield

No.	Category	Chemical	%
1	Binder	Special acrylic latex	35-45
2	Additive	Silicone, UV absorber, biocide	2-4
3	Pigment	Titanium dioxide	18-22
4	Pigment	IR pigment	1-5
5	Pigment	Microsphere ceramic	1-5
6	Filler	Extender	5-10
7	Solvent	Water	15-25

Beger Cool UV Shield has mainly the optimized composition of reflectivity and refractivity pigment such as: titanium dioxide, IR reflective and microsphere ceramic, table 8. Thus, at building scale, the use of cool colored coatings with increased solar reflectance and refractive can improve building comfort and reduce cooling energy use, and at city city-scale it can contribute to the reduction of the air temperature due to the heat-transfer phenomena and therefore improve outdoor thermal comfort and reduce the heat-island effect.

The result of heat gain reduction, the energy consumption and energy saving from three small buildings.

The result of thermal conductivity is obtained by hot disk thermal constant analyzer method from thermal analysis laboratory at MTEC, see appendices. It's found that of the thermal conductivity of Beger Cool UV Shield is lower than any other painting approximately 18% (this result). This parameter indicates that the Beger Cool has insulated capability which can protect heat from the outside. Moreover, the Beger has reflectivity more than other painting, about 5%, which can productively reflect the ray from heat corresponding to the experiment and mathematical simulation.

1. The effect of building location on envelop surface and of room temperature (Based case)

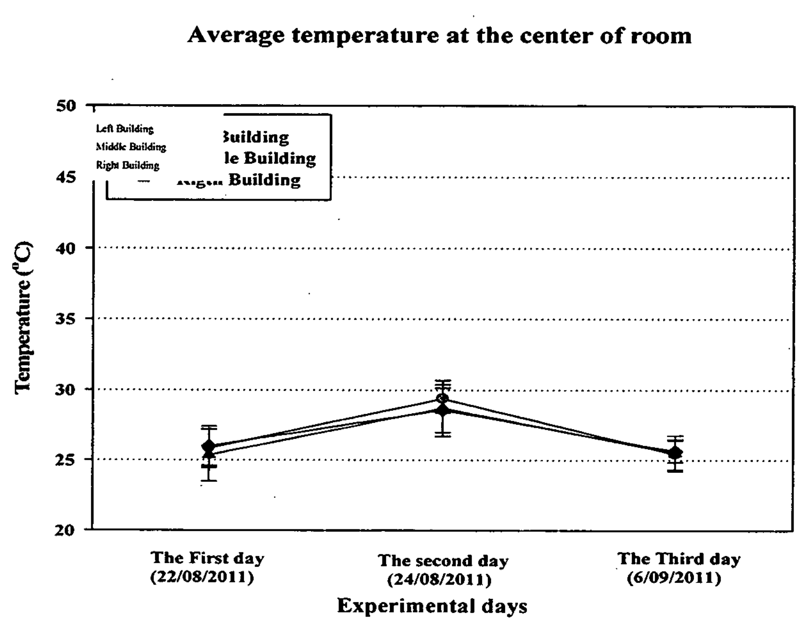

Figure 30 (a) The effect of building location on envelop surface and of room temperature (Based case) at center of the room

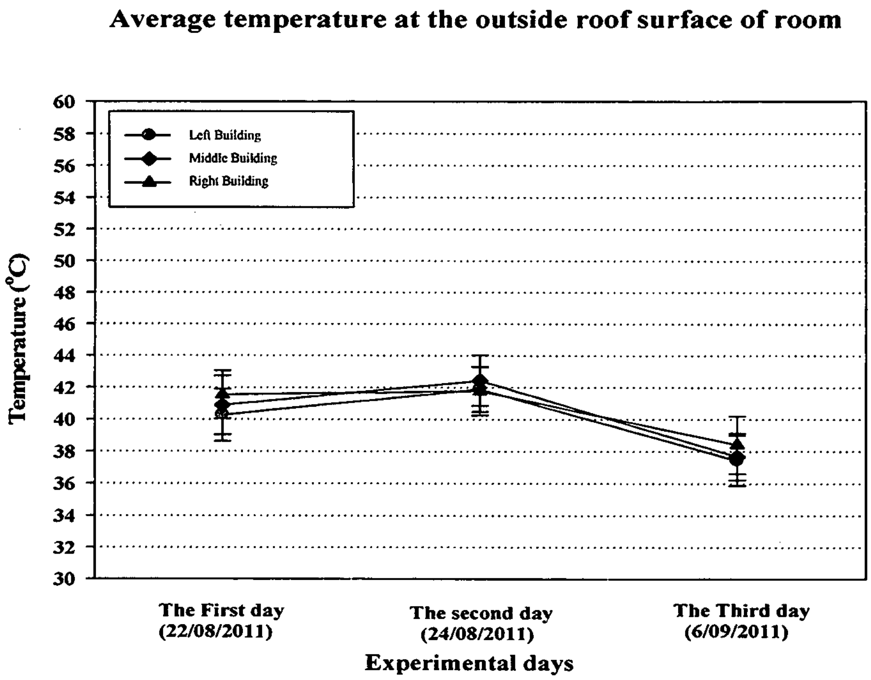

Figure 31 (b) The effect of building location on envelop surface and of room temperature (Based case) at the outside roof surface of room

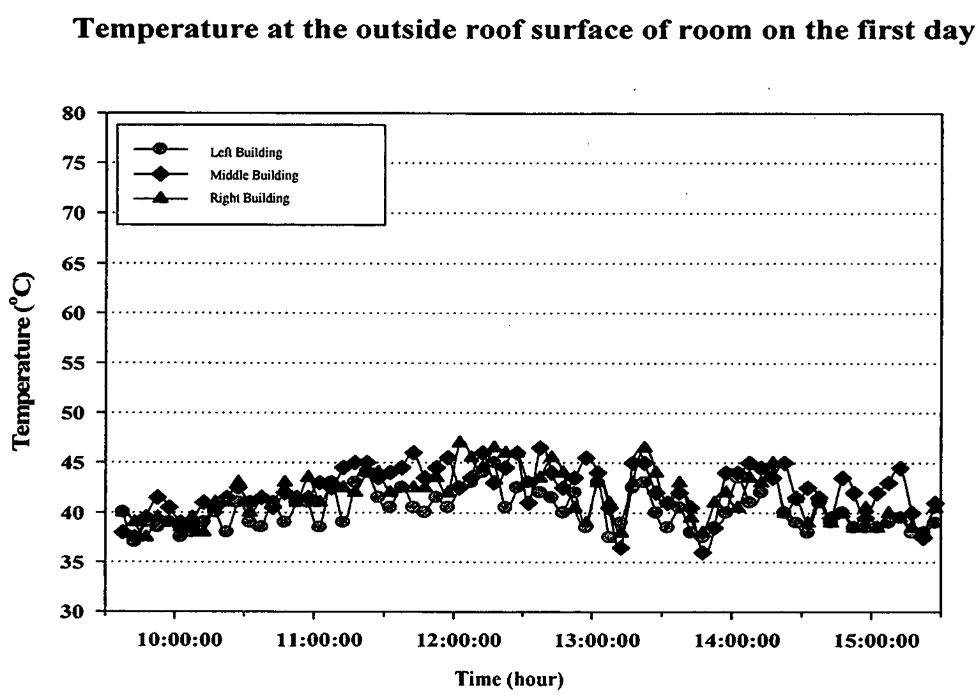

Figure 32 (c) The effect of building location on envelop surface and of room temperature (Based case) at the outside roof surface on the first day

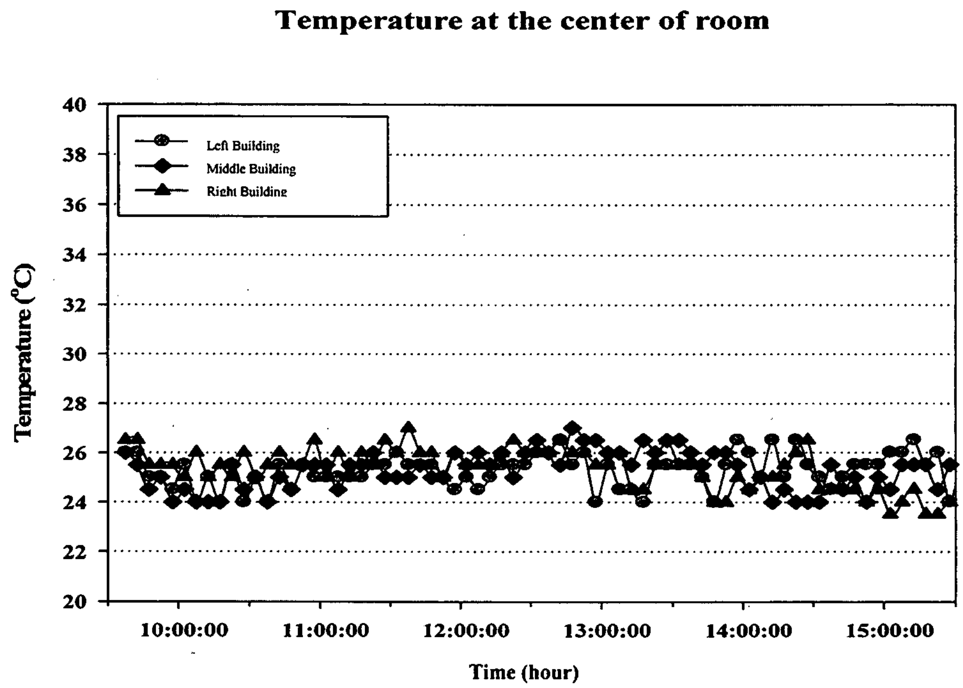

Figure 33 (d) The effect of building location on envelop surface and of room temperature (Based case) at the center of room

Although the three small buildings are built in same area but the physical environment such as solar direction and convection velocity are not the same. Therefore, it is important to make sure that the physical values of each building location of three small buildings are not significant to experimental result. In experiment, the three small buildings are not coated color on envelop surface of small building. The results of the temperature are presented in figure 30. It shows that the building location is not effect on the envelop surface (roof and walls) and room temperature of small buildings. The temperature of all surfaces is nearly equal in every experimental day. These show that three small buildings have got a nearby thermal load and convection velocity transfer.

2. Envelop surface (roof and wall) and room temperature of small building coated with high solar reflective paint, conventional color and uncoated

White color paint

At the outside roof surface temperature of room

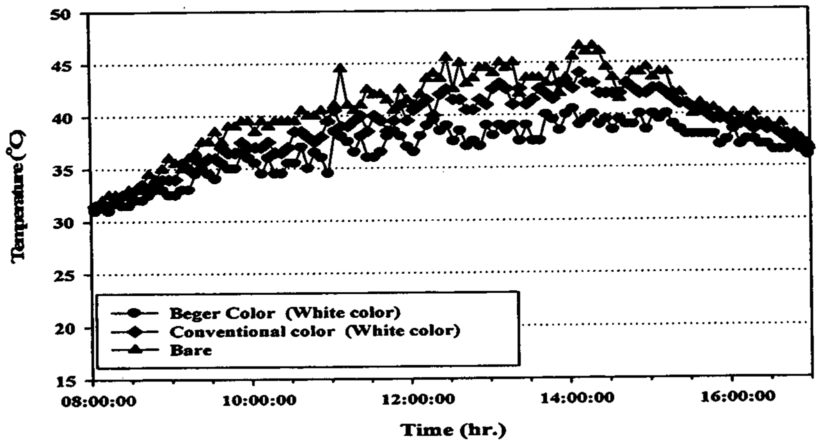

Figure 34 (a) Comparing envelop at the outside roof surface show room temperature of small building coated with high solar reflective paint, conventional color and uncoated

At the inside roof surface temperature of room

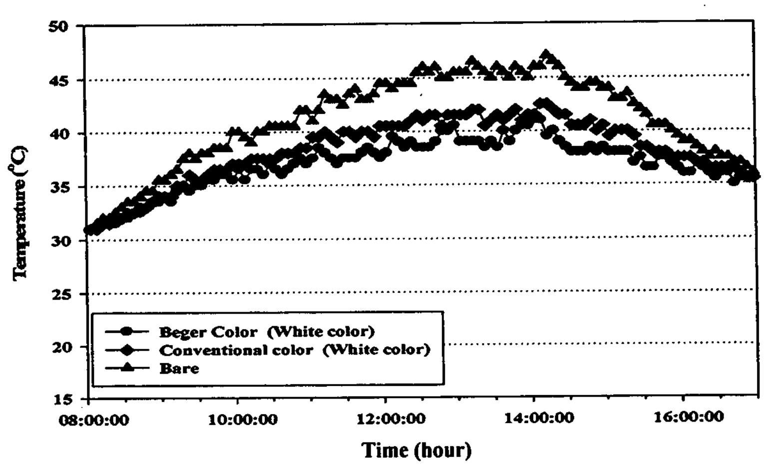

Figure 35 (b) Comparing envelop at the inside roof show surface room temperature of small building coated with high solar reflective paint, conventional color and uncoated

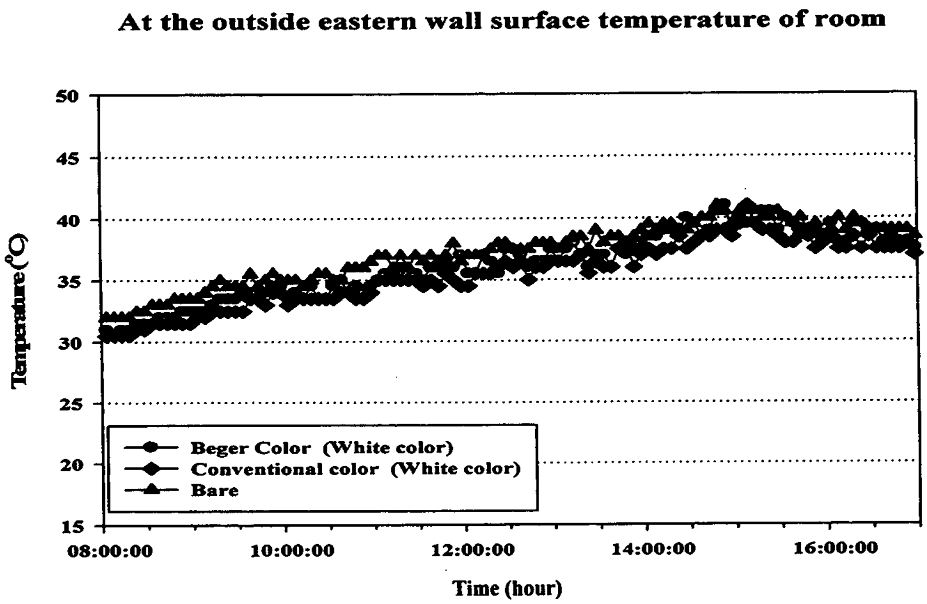

Figure 36 (c) Comparing envelop at the outside eastern wall surface show room temperature of small building coated with high solar reflective paint, conventional color and uncoated

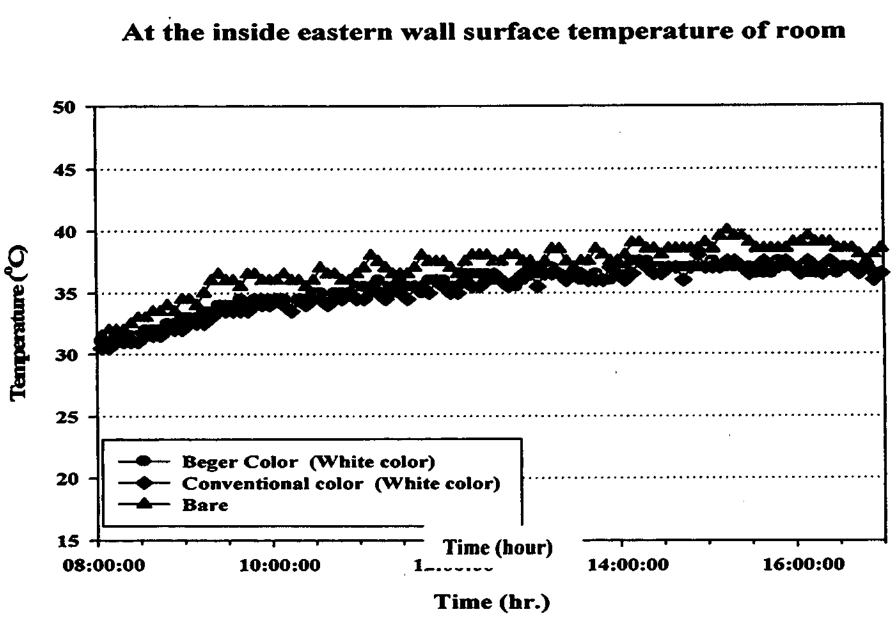

Figure 37 (d) Comparing envelop at the inside eastern wall surface show room temperature of small building coated with high solar reflective paint, conventional color and uncoated

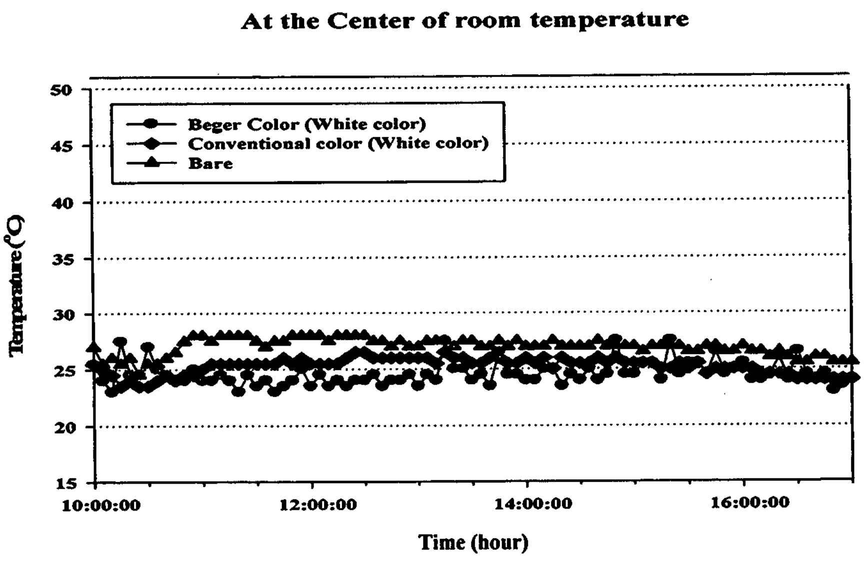

Figure 38 (e) Comparing envelop at the center of room show room temperature of small building coated with high solar reflective paint, conventional color and uncoated

White grey color paint

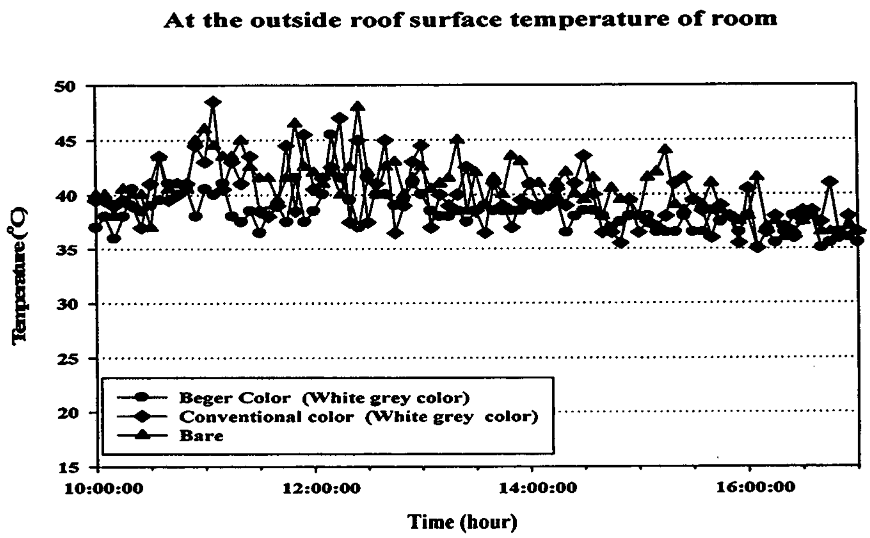

Figure 39 (f) Comparing envelop at the outside roof surface show room temperature of small building coated with high solar reflective paint, conventional color and uncoated

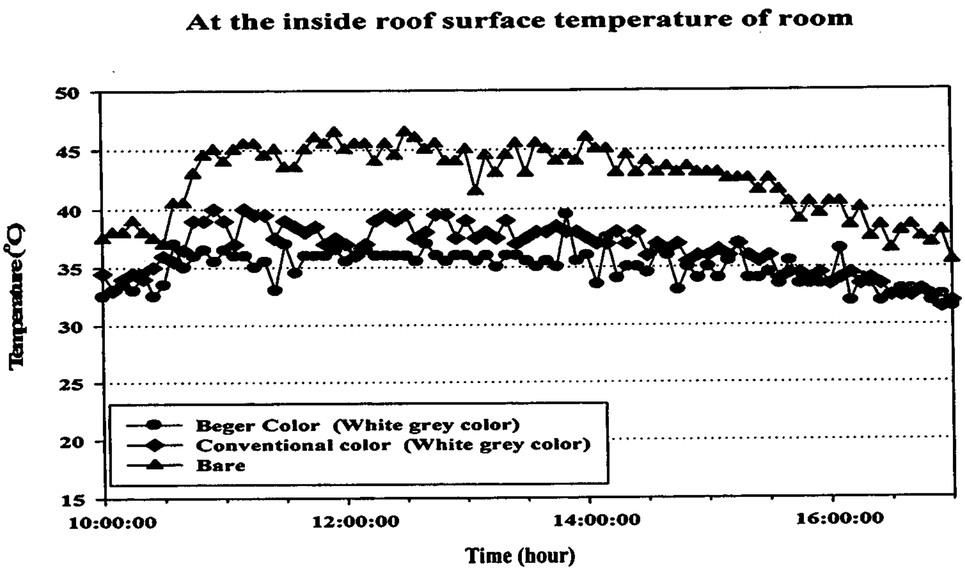

Figure 40 (g) Comparing envelop at the inside roof surface show room temperature of small building coated with high solar reflective paint, conventional color and uncoated

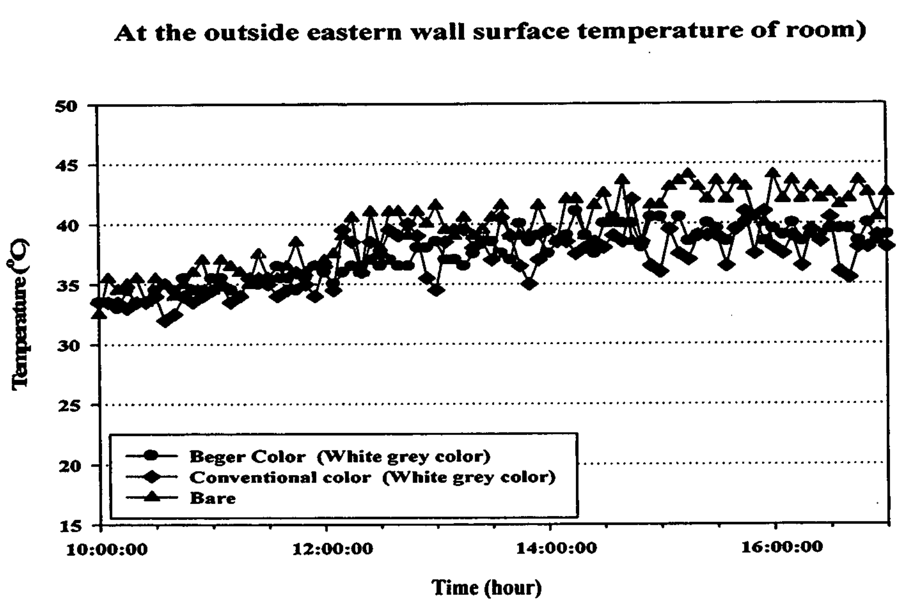

Figure 41 (h) Comparing envelop at the outside eastern wall surface show room temperature of small building coated with high solar reflective paint, conventional color and uncoated

At the inside eastern wall surface temperature of room

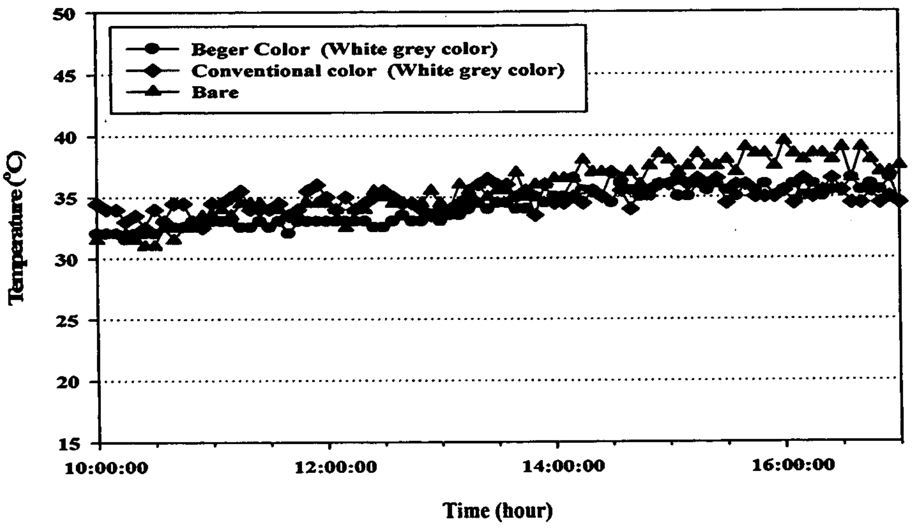

Figure 42 (i) Comparing envelop at the inside eastern wall surface show room temperature of small building coated with high solar reflective paint, conventional color and uncoated

At the Center of room temperature

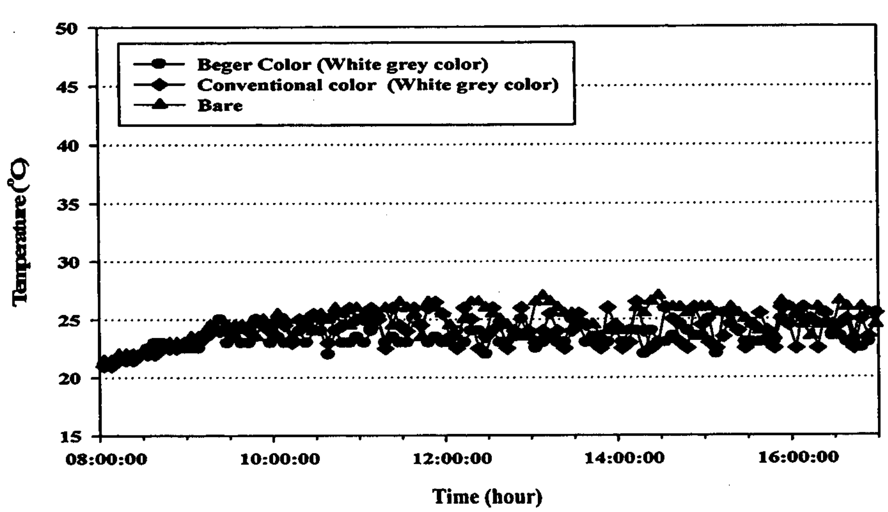

Figure 43 (j) Comparing envelop at the of the room show room temperature of small building coated with high solar reflective paint, conventional color and uncoated

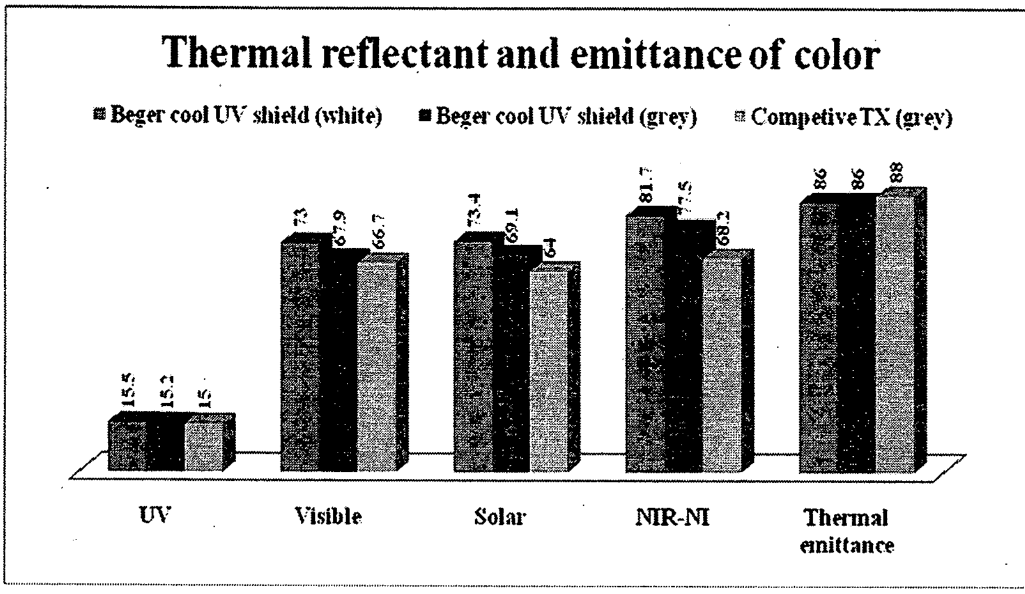

Figure 44 The percentile of thermal reflectance and emittance of different type of paint

The envelop surface and room temperature, as shown in figure 18, are compared only the maximum of saving energy percentile of each color shade (white and white grey color) because it observes obviously in surface temperature different. When considering the room temperature comparison of buildings which the high solar reflective paint, conventional paint coating and uncoated, as shown in figure 38 - 39, found that the room temperature of the coated building, both white and white grey color case, is less than another. The average temperature of the heat solar reflective paint coated building is 24.8 °C, while the conventional paint coated building temperature is 25.9 °C. Moreover, when compare with the uncoated building found that the uncoated building has the highest temperature, 26.8 °C.

Figures 30-43 are surface temperature comparison of each wall of the buildings with the high solar reflective paint, conventional paint coating and uncoated. The high solar reflective paint coated building is a little less wall surface temperature than the conventional paint coated building. Especially, the roof surface temperature of the high solar reflective paint coating building is less than the conventional paint coating building 2-4 °C. When compare with the uncoated building, the wall surface temperature of the uncoated is higher than the high solar reflective paint coating building. The highest temperatures of the roof during 11 am to 2 pm are about 45-47 °C, more than the temperature of high solar reflective coating building about 5-7 °C. At the eastern wall of building, the highest temperatures are 42-43 °C in the morning, more than the temperature of high solar reflective coating building about 10 °C.

This result is caused by the uncoated building has low sunlight reflective performance, so most of heat energy from the sunlight can pass through the inside of the building. The coating with the higher values of solar reflectance demonstrated significantly lower surface temperature. Therefore, it can be concluded that the main factor affecting the thermal performance of samples during the day is their solar reflectance. The high solar reflective paint coated building can reflect almost 100% of sunlight energy, as shows in figure 32, when it incidents into the building, as well emit the heat. With these reasons, the average room and roof surface temperatures, both inside and outside, of the coated building is less than the conventional paint coated and uncoated.

3. The percentile of saving energy of small building coated with white and white grey color

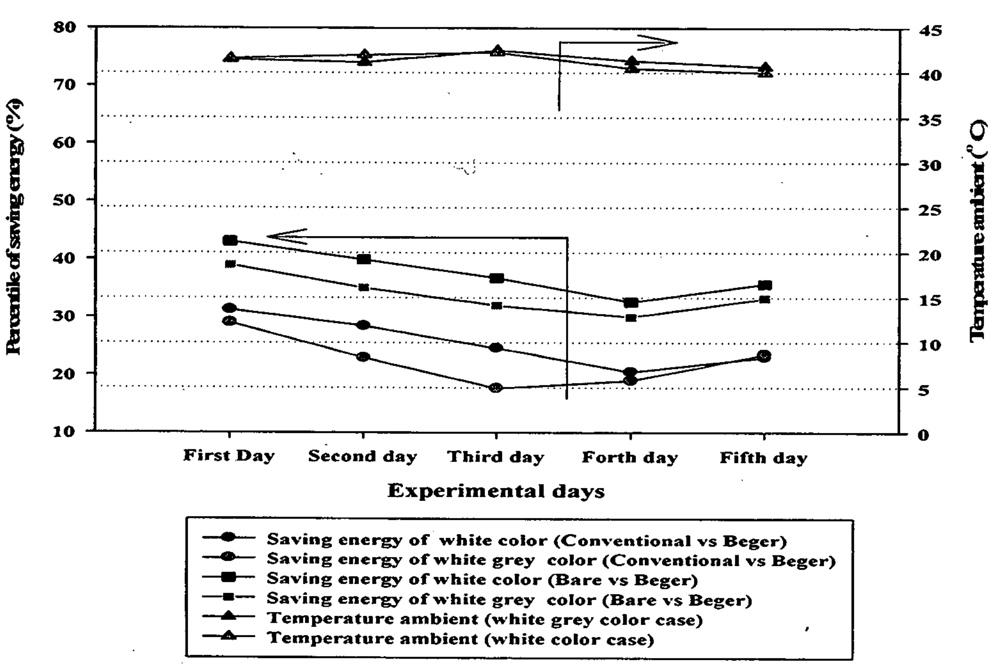

Figure 45 The comparing percentile of saving energy of small building coated with white and white grey color

From Figure 33, The electric energy consumptions of building with the high solar reflective paint are compared with the conventional paint coated (white and white grey color shade) and uncoated building. These results are compared from experimental day that have a same temperature ambient from all operating condition. The high solar reflective paint coating building obviously uses the electric energy less than the conventional coated and uncoated building. The electric consumption is lower than another coated building because of high sunlight reflecting performance. The lower heat energy that transfers to the building causes the lower load of the air conditioner. When comparing the saving energy during small building coated with white and white grey color found that the percentile of saving energy of small building which coated with white color has a higher value than white grey color in all condition cases because of high efficiency in reflect the solar ray. High solar reflective paint coated building can save the electric energy range 25-30% of the conventional paint coated building consumption and range 35-40% of the uncoated building consumption. For the white grey, the high solar reflective paint coated building can save the electric energy range 19-30% of the conventional paint coated building consumption and range 30-38% of the uncoated building consumption.

Therefore, from the experiment, we can conclude that the small building that coated with high solar reflective paint (Beger Cool UV Shield) has less electric energy consumption due to it can reflect the sun light or infrared ray very well. It can help reducing the transfer of heat into the building and can reduce the energy loss in cooling the building. Those cause surface temperature of envelop (roof and wall) and room temperature to lower about 3-4°C when comparing with conventional color coated.

4. Overall Heat Transfer into the building (Heat gain) and the comparison with experimental information.

Table 9 Heat Gain comparison of 3 buildings

Heat Transfer	Beger Cool UV Shield	Conventional Color	No Color
OTTV (W/sq.m.)	65	82	89
RTTV (W/sq.m.)	150	161	169
Heat Gain x 100 (W)	33	40	42
Heat Transfer (MJ)	94	113	121

Heat transfer different between Beger Cool UV Shield coated building and Conventional color coated building is 17%. And Heat transfer different between Beger Cool UV Shield coated building and building with no color is 22%. These two percentage different figures comply with the different in solar reflective value of 14% higher and the different in conductivity value of 18% lower of Beger Cool UV Shield.

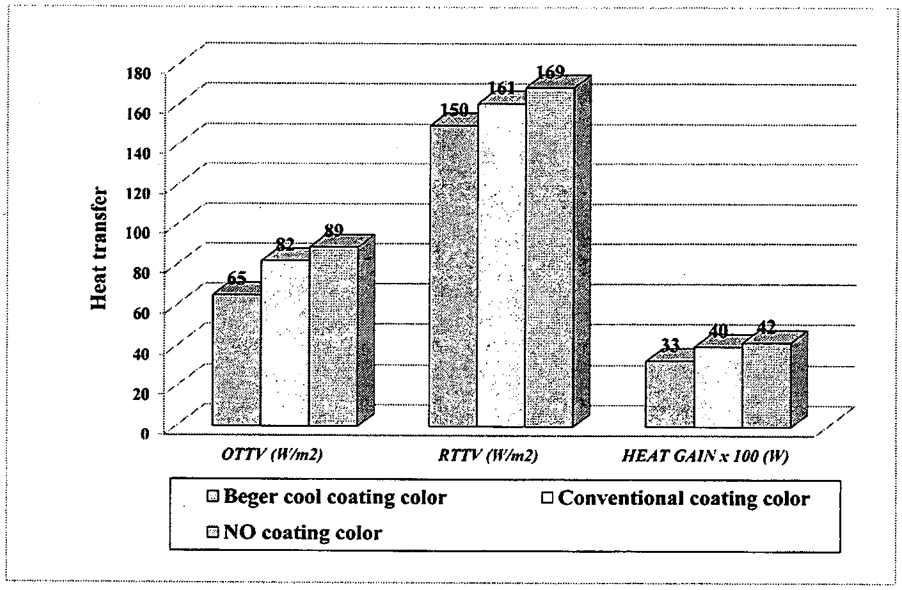

Figure 46 Representations a comparison between overall heat transfers in to the building painted with Beger Cool, conventional paint, and no coating

Figure 46 illustrate of overall heat transfer into the building each case from experiment. First case was painted Beger Cool UV Shield. Second case was painted conventional color; third case was not painted color. And then determine OTTV and RTTV which this research is calculated without results of heat internal the building. From figure 46 is represented the result of the building was painted Beger Cool UV Shield has overall heat transfer into that one less than another case from all case experiment, which related with internal wall surface temperature and ceiling of the building was acquired data all day. The reason that explain why building painted with Beger Cool UV Shield has less heat transferred into the building is because it has a special property of low thermal conductivity (0.23 W/mK), and high thermal reflectivity when comparison with conventional colors and no color building.

From the experiment, the energy consumption of the air condition per 8 hour can be concluded in the below table

Table 10 Average Energy Consumption comparison of 3 buildings

	Beger Cool UV Shield building	Conventional Color building	No color building
Average energy consumption	10.22 kWh	12.55 kWh	14.06 kWh

The percentage different of average energy consumption between Beger Cool UV Shield coated building and Conventional color coated building is 19%. And, the percentage different of average energy consumption between Beger Cool UV Shield coated building and no color building is 27%. From the experiment, the average electrical cost of the air condition consumed per 8 hours operation can be concluded in the below table.

Table 11 Average Electrical cost comparison of 3 buildings

	Beger Cool UV Shield building	Conventional Color building	No color building
Average energy consumption kWh	10.22	12.55	14.06
Energy Consumption kWh /year	3,723	4,580	5,132
Energy Saving (compare Beger Cool) kWh /year	-	858	1,409
Electrical cost 3.5 Bath/ day	35.70	43.93	49.21
Electrical Expense Baht/year	13,030.50	16,033.63	17,962.65
Electrical Saving (compare Beger Cool) Baht/year	-	3,002	4,931

The percentage different of electrical expense between Beger Cool UV Shield coated building (13,030 Baht/year) and Conventional color coated building (16,033 Baht/year) is 19%. And the percentage different of electrical expense between Beger Cool UV Shield coated building (13,030 Baht/year) and building with no color (17,962 Baht/year) is 4,931 Baht/year or 27% lower.

So, the building painted with solar reflective paint can reduce heat transfer into the building, and reduce load of air-conditioning inside. Therefore the energy saving is very well achieved.

The outer and inner wall temperature under reflection of solar radiation are presented in this thesis in order to compare surface temperature of coating colors i.e. Beger Cool UV shield (White and white grey) and conventional color (white and white grey). The four kinds of color have different properties such as thermal reflectivity and thermal conductivity. The calculation was set up in period 8.00 am. to

5.00 pm. by applying Transient heat conduction in plane wall in one-dimension and Explicit finite differential method. To identify the boundary conditions, outer wall is affected by solar heat radiation (W/m^2), convection heat transfer coefficient (W/m^2 K) and ambient temperature under time varying, including without heat generated in wall plane. And inner wall is affected by convection heat transfer coefficient (W/m^2 K) and constant ambient temperature at 25 °C. From numerical method, it is found that the Beger white coating has lower temperature than conventional white coating. Besides, the white color of Beger and conventional has lower temperature than white grey because it has a black carbon which can absorb solar heat radiation.

The compared surface temperature from numerical and experimental is shown in figure 47-50 When consider the outer surface both white and white grey color, it is found that the results from experiment and numerical have same tendency only in period of time 8.00 - 12.00 am but quite differ in period 1.00 - 5.00 pm. Experimental result has higher temperature as if it has the heat generated in wall. But in numerical method, we can't identify this accumulated heat for the same period. Besides, it is found that the inner surface temperatures both white and white grey also have same tendency but when consider the level of temperature, experimental results have higher for all time period approximately 2-3 °C. The result shows this trend because of the heat flux values that utilized in numerical method are the average values from among of literatures, not from experiment. Thus, it might be better for using heat flux values as same as the experiment conditions.

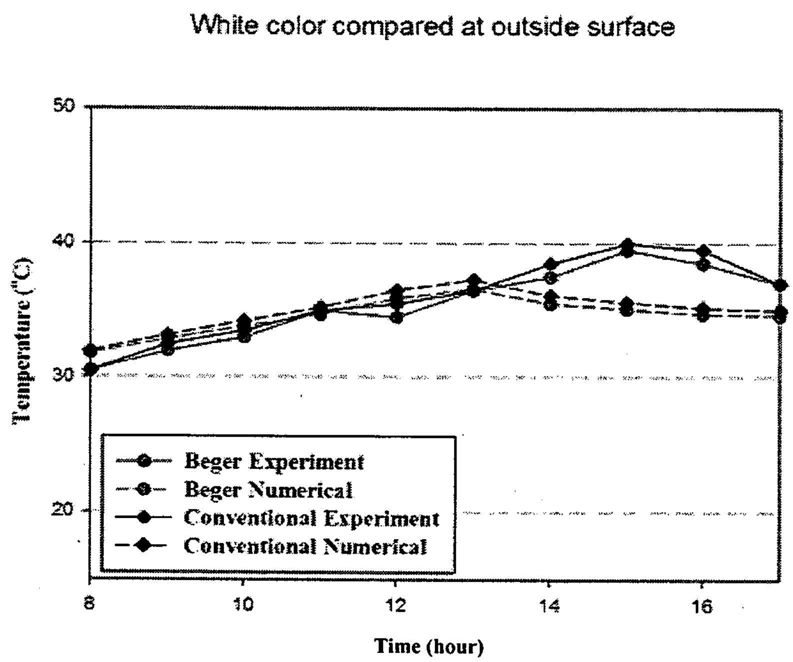

Figure 47 (a) Comparing outside wall temperature surface of numerical and experimental result

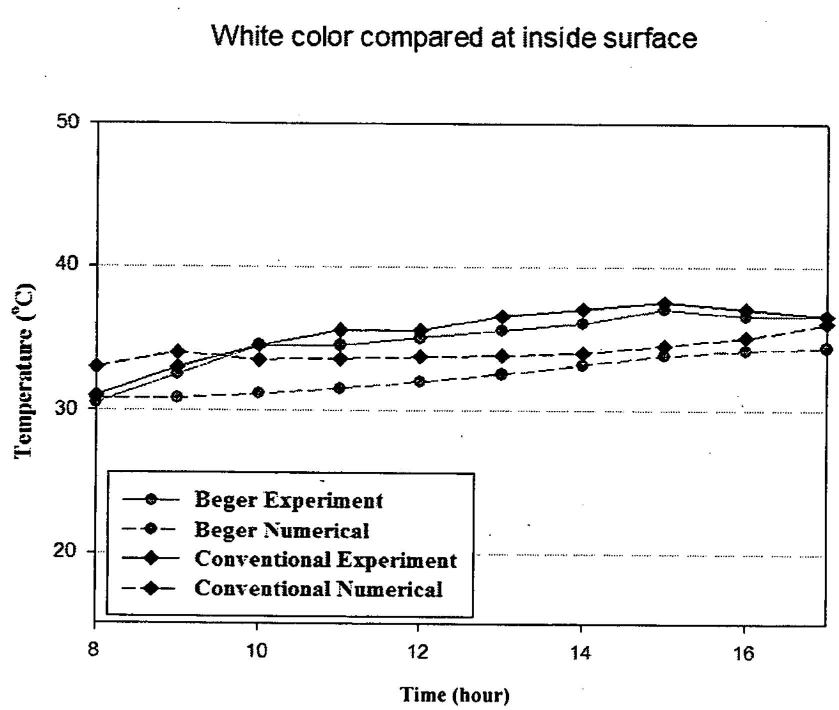

Figure 48 (b) Comparing inside wall temperature surface of numerical and experimental result

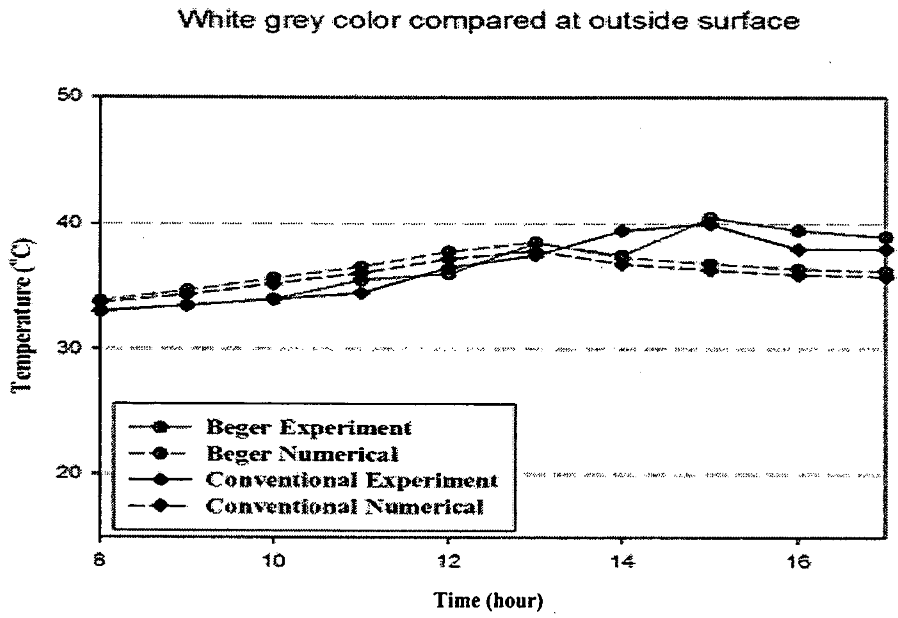

Figure 49 (c) Comparing outside wall temperature surface of numerical and experimental result

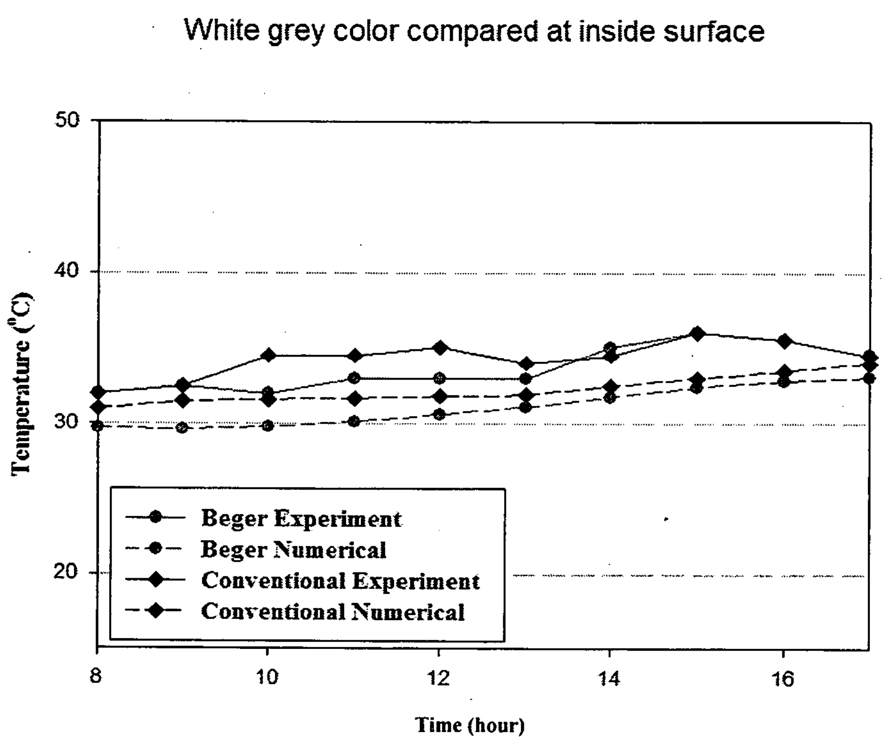

Figure 50 (d) Comparing inside wall temperature surface of numerical and experimental result