CHAPTER III

RESEARCH METHODOLOGY

This chapter describes the methodology and procedure of the research. The study was separated three parts of procedure. First, in order to reduce heat gain distributing through building roof and wall, paint systems has to be tested and maximized reflective value. Some variables that can affect a coating's reflectivity are individual pigment selection, milling, dispersing, opacity, primer type, contamination, size of filler particles. These factors will be evaluated by many test methods. Second, the heat performance testing of small building was studied and coated with the high solar reflective paint (Beger Cool UV Shield). Finally, the numerical simulations of the heat transfer into building with high solar reflective paint were studied to include in the energy consumption in building testing that had information as follow:

Formulating the high solar reflective coating that optimize energy saving

1. Identify chemical parameter that effect solar reflective value

In order to achieve higher solar reflective index, there are several parameters of coating ingredients to be tested in laboratory before coming up with the Optimized infrared reflective paint. In order to achieve the optimum Heat Management Formulation, 3 keys parameters must be equally improved, which are the greater infrared reflectivity, high emissivity, and the least thermal conductivity. A thoroughly study about functional effect and composition of the coating composite material, along with the suitable pigment selection will result in the enormous improvement in total solar reflectance, and lower heat build-up, while keeping similar to original shade. The result of the optimized formula will show the guideline to predict the correlation between the heat gain coming through the surface of building and the coating formulation.

One of the key important factors of reflectivity property largely depends on the property of the pigment. When the electromagnetic radiation in the light wave energy region penetrates into the paint film, it will scattered due to the difference of

the refractive index between pigment and the atmospheric air. Some parts of the scattered light reflect from paint film at the higher than Brewster's Angle, while the rest absorb and results in the generation of heat, free radical species and free electrons. This effect will eventually cause the increasing of molecular vibration and heat build-up inside the paint film. Formulating the paint with pigment particle size more than 200 nanometers like titanium dioxide which has refractive index of around 2.80, will become the most efficiently scatter incident light with a wavelength of 529 nanometers. Using the infrared reflecting pigment that give higher Brewster's Angle will significantly improve the reflectivity of the paint film at many incident light angle. On the other hand, low quantity of carbon black pigment (<0.01%) blending will significantly change the solar reflective characteristic of the paint substrate to absorb more radiation energy.

Six different test-methods will be used to collect data in this research. The study will first explore the combination of chemical ingredients in primer and in topcoat. However, all of the top coat color will be controlled to only one color shade value or the same L-a-b value.

1. For Primer - Color: white, black, aluminum or metallic effect
2. For Primer - Dosage of microsphere ceramic: high and low dosage
3. For Topcoat - Dosage of IR pigment and normal pigment
4. For Topcoat - Dosage of insulate microsphere ceramic
5. For Topcoat - Contamination such as carbon black
6. For Topcoat - Opacity: low and high hiding power

All sample panels will be prepared from paint laboratory sample and tested under several test methods. A carbon black based controlled panel will be used to establish the laboratory benchmark, and will be used to calculate the theoretical maximum heat build. These test method's results will proved that the use of solar reflective coatings is effective in reducing heat gain.
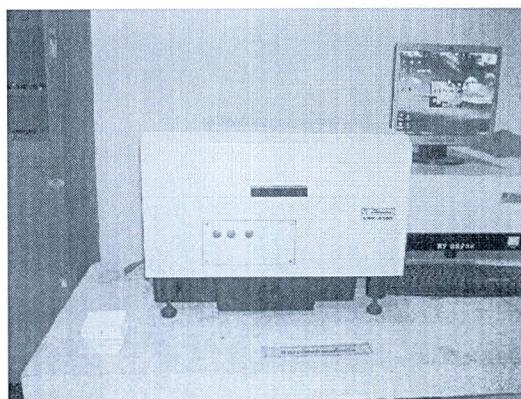
2. Apparatus and testing

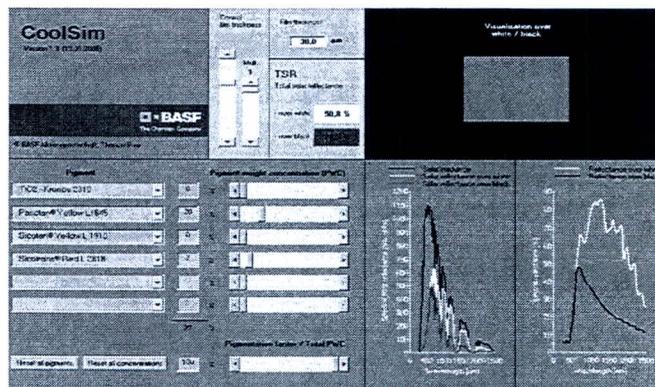Reflective index in visible range: test methodology – Spectrophotometer
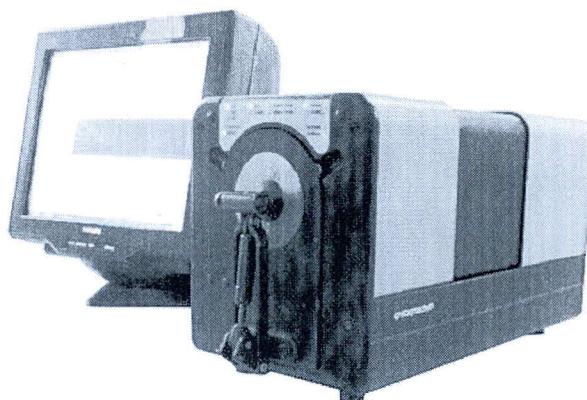
Figure 13 Spectrophotometer

Reflective Index in UV, visible, and near infrared range: Test methodology – UV-VIS-NIR Spectrophotometer, Shimadzu UV 3100

Figure 14 Shimadzu UV 3100

Figure 15 Solar reflective simulation programs (Cool Sim)

Emissivity Methodology test – Emissometer

Figure 16 Emissometer

Temperature difference on substrate under 2 different light sources:

1. visible light: test methodology – visible light bulb heat simulator

2. Temperature difference on substrate under infrared light: test methodology infrared light bulb heat simulator

3. Temperature difference on substrate under visible light and infrared light: test methodology – visible and infrared light bulb heat simulator

These three test methods start by placing the object to be tested above a thermocouple in an insulated box, and exposing the object to a 250 watt heat lamp or/and infrared light bulb until thermal equilibrium is established. The resulting

temperature delta above ambient is used to calculate a predicted heat build correlating to the temperature of an actual exposed exterior surface. The vertical heat build maximum is defined as 41 °C, and the horizontal heat build maximum is defined as 50 °C.
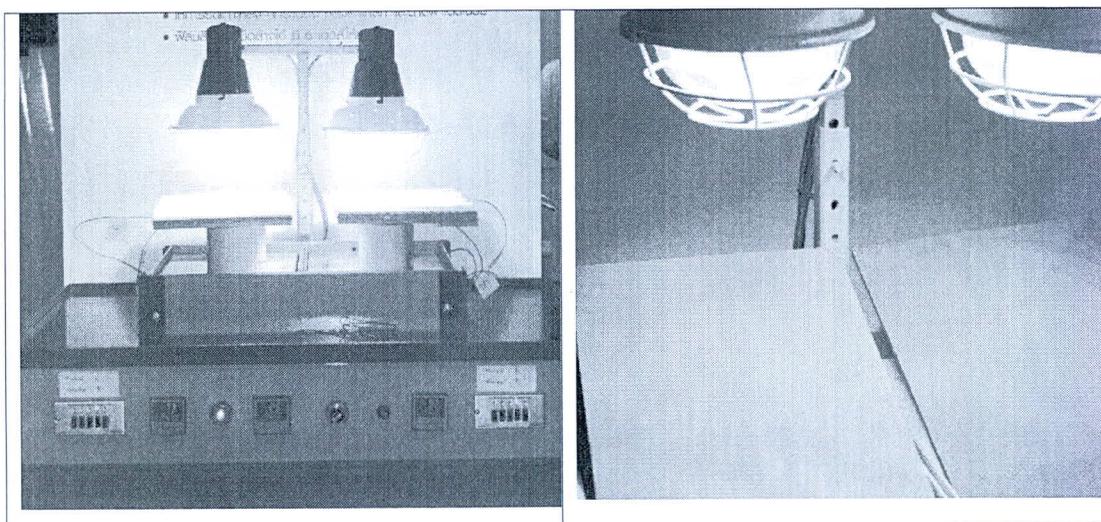
Figure 17 Two different light sources test

The heat performance testing of small building was coated with the high solar reflective paint (Beger Cool UV Shield)

The condition testing is tested the heat performance of small building that is compared with three cases testing. The first case is not coated paint anything on each wall of small building. The second case is coated on each wall with conventional color coating. The third case is coated on each wall with high solar reflective paint (Beger Cool UV Shield). Those cases are used the two shades of colors such as white and white grey color as follow.

1. The identification parameter of experiment

The parameter that is used to test the heat performance testing of the small building with the heat insulated paint is considered the effect of air conditioner that is set up outside the building. It depends on heat load outside the building which receives solar radiation through the wall and roof. (This research is not considered heat load inside the building). When the wall and roof receive solar radiation, the differences of temperatures between inside and outside of building are produced the heat transfers

through the inside building. This result is the cause that can be made load of the air conditioner. Thus, the important parameter of this research is the temperature both inside and outside building in order to determine the heat transfers loading through the inside building while are testing. Moreover, other factors of this experiment are ambient temperature, relative humidity, air velocity and electrical consumption of air conditioner.

2. The apparatus and testing

The apparatuses of the experimental testing are composed as follow: - The small building has size 4 m. x 4 m. x 2 m. It is the simulation of general building that was built from gypsum shown in figure 18.
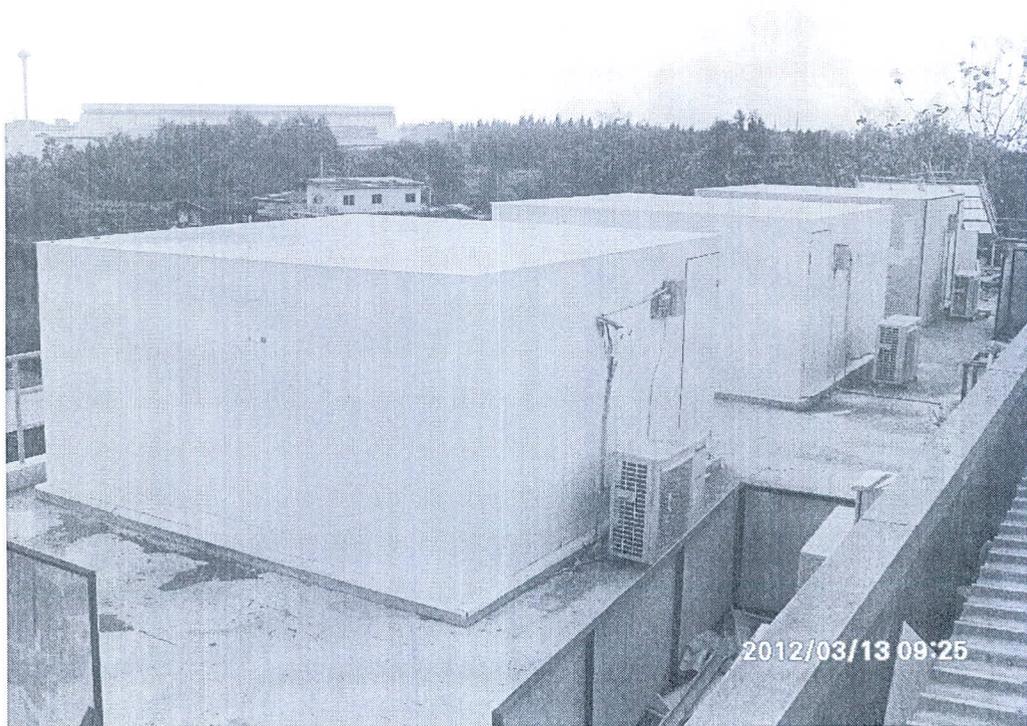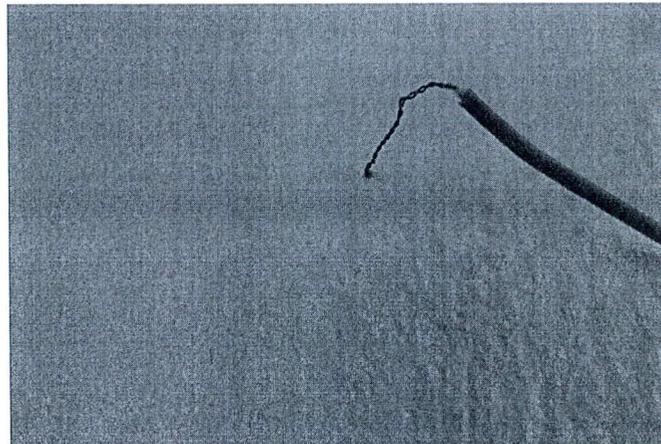

Figure 18 Two small buildings coated with different paint system and one uncoated building

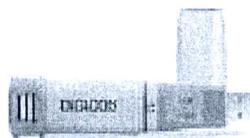1. An air conditioner has size 22000 BTU shown in figure 19.
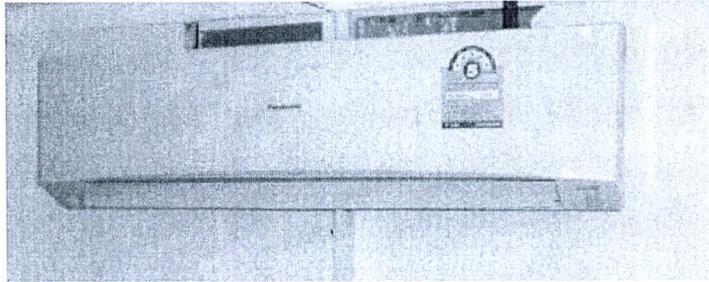
Figure 19 An air conditioner (22000 BTU)

2. The thermocouple (K type) shown in figure 20.

Figure 20 Cable of thermocouple (K type)

3. Data logger (Digical brands) is used for data acquisition shown in figure 21.

Figure 21 Data logger

4. The electrical meter is used to record the electric consumption rate shown in figure 22.

Figure 22 Electrical Meter

5. The high solar reflective paint (Beger Cool UV Shield) shown in figure 23.

Figure 23 High solar reflective paint (Beger Cool UV Shield)

6. The cup anemometer is used to measure air velocity shown in figure 24.

Figure 24 Cup anemometer

3. The positional measurement

The testing will be used the time 9 days in each shading color, total 18 days, to test all day time about 9 hours per day approximately (08.00 -17.00 local time). Thus, it will be acquired the temperature every side of the building at the same time. For data acquisition, the temperature of small building will be acquired at seven positions consisted of inside temperature, both inside and outside surface temperature in the North and East direction, and the ceiling surface temperature of inside and outside together. So, figure 25 and 26 represent a difference of temperature. As the aforementioned is the parameter to identify the heat transfers through building and it can be used to reflect and scatter the solar heat energy.
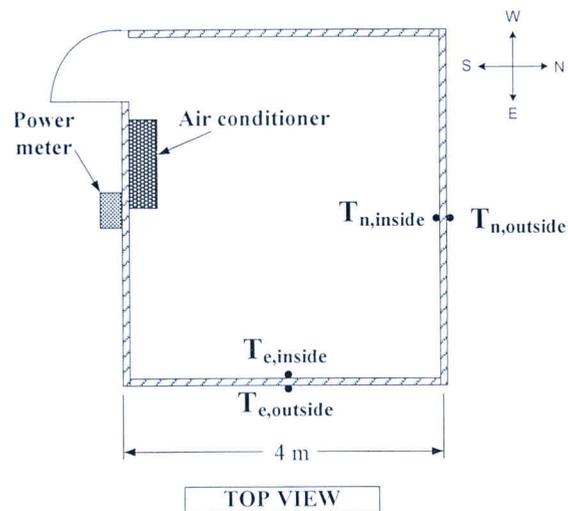
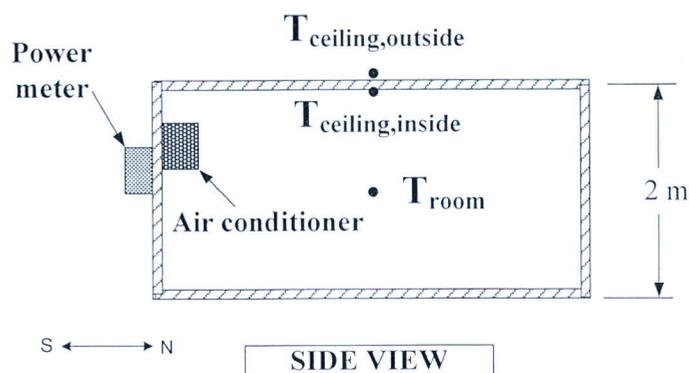**Figure 25 The position of top view to measure**

Figure 26 The position of side view to measure

4. The monitoring parameters:

4.1 The temperature of each wall both inside and outside of the building and the room temperature of the building (total seven positions) shown in figure 25 and 26.

4.2 The ambient temperature and ambient relative humidity.

4.3 The electrical rate (kWh) from the electrical meter rate both before and after testing.

4.4 The weather property or characteristic of the testing's day

4.5 The air velocity.

Step of experiment

The procedure of the heat performance testing as follow:

1. To set up the thermocouple at the middle wall on each side both inside and outside of the building, inside room, shown in figure 25 and 26.

2. To connect the thermocouple cable with Data logger before testing

3. To record the parameter of building all of cease such as the electrical consumption (kWh), weather at the moment, ambient temperature and ambient humidity.

4. To reset the temperature of air conditioner all of case at 25 $^{\circ}$C, to begin recording.

The recording will be recorded all day to start 8.00 am – 17.00 pm local time (9 hours per day) that will be increase the interval time approximately 1 minute.

5. Finally, to record all of the parameter (in step 3) again after finishing. Then, the data was lead to analysis and diagnostic for application respectively.

Energy saving of small building calculation

Energy saving calculation for all building is determined from the energy consumption (kWh), obtained from the electric meter, of air conditioners. The energy consumptions of air conditioners are define as

$$Energy_{Consume} = Energy_{After} - Energy_{Before} \qquad (3.1)$$

Then, compare the energy consumption of the high solar reflective paint (Beger Cool UV Shield) coated building with another by

Comparison the energy consumption between the high solar reflective paint (Beger Cool UV Shield) coated and uncoated building is define as

$$Energy_{consume\_no-coating} - Energy_{consume\_begercool} \qquad (3.2)$$

or measured in the percentage as

$$\frac{Energy_{consume\_no-coating} - Energy_{consume\_begercool}}{Energy_{consume\_no-coating}} \times 100 \; ; \% \qquad (3.3)$$

Comparison the energy consumption between the high solar reflective paint (Beger Cool UV Shield) coated and conventional paint coated building is define as

$$Energy_{consume\_Conventional} - Energy_{consume\_begercool} \qquad (3.4)$$

or measured in the percentage as

$$\frac{Energy_{consume\_Conventional} - Energy_{consume\_begercool}}{Energy_{consume\_conventional}} \times 100 \; ; \% \qquad (3.5)$$

where $Energy_{consume\_begercool}$ is energy consumption of the high solar reflective paint (Beger Cool UV Shield) coated building, kWh,

$Energy_{consume\_conventional}$ is energy consumption of the conventional paint coated building, kWh,

$Energy_{consume\_no-coating}$ is energy consumption of the uncoated building, kWh,

$Energy_{Before}$ is energy consumption, kWh, obtained from the electric meter of all building before testing, and

$Energy_{After}$ is energy consumption, kWh, obtained from the electric meter of all building after testing.

Determination of a conductivity and OTTV value [29]

The experiment has been compared a thermal conductivity between the first building was painted color insulation and the second case was painted conventional colors and the third case was not painted color. And then calculations determine a thermal conductivity from this equation.

$$q_x'' = -k\frac{\partial T}{\partial x}$$

(3.6)

Whereas q_x'' is heat flux means the rate of heat transfer in direction X per area unit; W/m^2

k is Thermal conductivity; W/mK

And then calculation to determine OTTV and RTTV value, for comparison safe energy between the buildings was painted color insulation, painted conventional colors and not painted color. For all case can calculation from these equations.

Overall heat transfer of outside a wall building each side (OTTV$_i$)

OTTV$_i$ = (U$_w$)(1-WWR)(TD$_{eq}$)+ (U$_f$)(WWR)(ΔT)+ (WWR)(SHGC)(SC)(ESR) (3.7)

Where

OTTV$_i$	is heat transfer of a wall is considered side W/m^2
U$_w$	is over all heat transfer coefficient of opaque wall
WWR	is window-to-wall ratio per all area that one is considered
TD$_{eq}$	is equivalent temperature difference (^{o}C)
U$_f$	is U-values of wall and window W/m^2-^{o}C
ΔT	is temperature different equivalent between external and internal building
SHGC	is the fraction of incident solar radiation admitted through a window, both admitted through a window
SC	is shading coefficients
ESR	is a solar quality

Overall Thermal Transfer Value (OTTV) is a average weight value of summation a heat transfer over all of a wall each side (OTTV$_i$) from this equation

$$OTTV = \frac{(A_{w1})(OTTV_1) + (A_{w2})(OTTV_2) + ... + (A_{wi})(OTTV_i)}{A_{w1} + A_{w2} + ... + A_{wi}} \qquad (3.8)$$

When A_{wi} is the area of side wall that is considered include wall and windows

OTTV$_i$ is Overall Thermal Transfer Value (OTTV) of wall each side which determine from equation (3.7)

Roof Thermal Transfer Values of building each parts (RTTV$_{ni}$) calculation from this equation

$$RTTV_{ni} = (U_r)(1-SRR)(TD_{eq}) + (U_s)(SRR)(\Delta T) + (SRR)(SHGC)(SC)(ESR) \quad (3.9)$$

RTTV$_{ni}$ is Roof Thermal Transfer Values   W/m^2

U$_r$ is overall heat transfer coefficient of roof W/m^2-^{o}C

SRR   is area ratio of roof per total of area roof

TD$_{eq}$ is equivalent temperature difference (^{o}C)

U$_s$ is overall heat transfer coefficient of glass roof   W/m^2-^{o}C

ΔT is different temperature between internal and external building ^{o}C

SHGC   is the fraction of incident solar radiation admitted through a roof, both admitted through a roof

SC   is shading coefficients

ESR   is a solar quality

Roof Thermal Transfer Value (RTTV) is an average weight value of summation a heat transfer over all of a roof each side (RTTV$_i$) from this equation

$$RTTV_n = \frac{(A_{w1})(RTTV_{n1}) + (A_{w2})(RTTV_{n2}) + ... + (A_{wi})(RTTV_{ni})}{A_{w1} + A_{w2} + ... + A_{wi}} \qquad (3.10)$$

Where A_{wi} is roof area (m^2)

RTTV$_n$ is Roof Thermal Transfer Value (RTTV) of roof each part on the building which determine from equation (3.9)

So, Overall heat transfer into the building

$$Q \quad = OTTV + RTTV + Q_{floor} + Q_{other} \qquad (3.11)$$

Achievements

This research is study the performance of the high solar reflective paint (Beger Cool UV Shield) coated building which had compared with conventional paint coated and uncoated building. The obtained results reach as follows:

1. Conclusion of some properties involved high solar reflective paint (reflection and distribution of the solar heat energy).

2. The possibility of energy saving using the high solar reflective paint.

3. The results of the energy saving using the high solar reflective paint that compare with conventional paint coated and uncoated building.

The numerical calculation for coated with high solar reflective paint for surface temperature through a wall

The numerical calculation using explicit finite difference is used to determine the surface temperature at outside and inside of wall. The experimental results are compared with the numerical result and then the other parameters are varied such as solar reflection, solar emissivity, heat transmission, heat absorptance and thermal conductivity respectively. In order to predict the surface temperature at outside and inside of wall with heat insulated paint and energy consumption rate respectively.

1. Apparatus determination
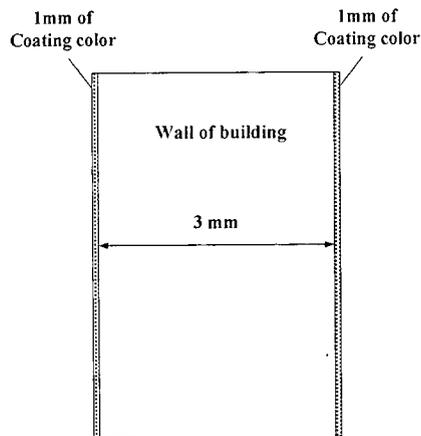
Figure 27 Simulation wall has size 3 mm. thickness that is used to analyze, coated with 1 mm of paint on both outside and inside building surface

    1.1 The boundary condition for numerical calculation method is defined following below table which shows the arrangement in figure 28. Under assumptions that we simplify scope of mathematical model by analyzing temperature distribution in one dimensional calculation, neglecting the temperature between outside coating and the wall as well as temperature between inside coating and the wall, because the experiment cannot measure these 2 temperature data precisely.
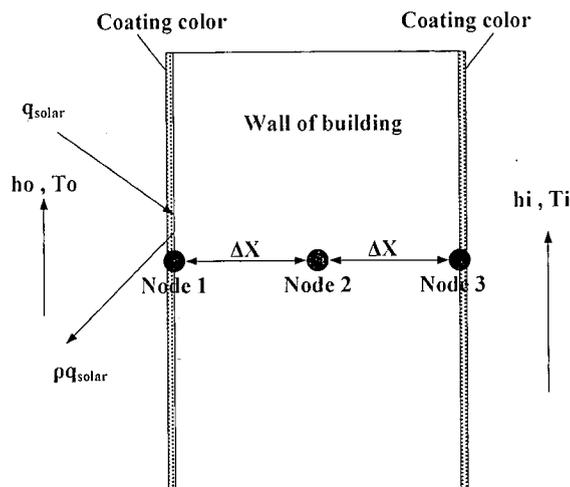
Figure 28 The arrangement of wall and defined boundary condition

Table 1 Parameter to be collected for energy balance

Parameter	Result
Solar radiation , q_{solar} (W/m^2) in every hour	To defined value following a literature [20] which vary with time.
Outside ambient temperature, T_o ($^\circ$C)	To defined value following an experimental result which vary with time
Inside ambient temperature, T_i ($^\circ$C)	25
Outside convection heat transfer coefficient, h_o (W/m^{2}K)	10 [14]
Inside convection heat transfer coefficient, h_i (W/m^{2}K)	5 [14]

1.2 Considering the energy balance of wall in one dimension, when the solar incident can derive the mathematical model of transient conduction heat transfer which are discretized on the three node of wall to find the surface temperature at outside (T_1) and inside (T_3) at any time. The scope will be considered under the assumption of temperature at outside coating surface is more than outside ambient temperature, so we consider the convection heat transfer on outside wall.

Energy balance equation [14]:

[Energy transfer into a system]-[Energy transfer exit a system]=[Energy change of system depending on time]

$$\frac{\Delta E}{\Delta t} = \frac{E_{in} - E_{out}}{\Delta t} = \rho c v \frac{dT}{dt} = \frac{\rho c v \left(T_i^{P+1} - T_i\right)}{\Delta t}$$

(3.12)

Node 1: Coating film at outside wall

[Solar energy]-[Convection heat transfer from ambient on node 1]-[Conduction heat transfer from node 1 to node 2] = [Energy change of system depending on time]

$$q_s\Delta y - \rho_r q_s\Delta y - h_0\Delta y\left(T_1 - T_{\infty,0}\right) - k\frac{\Delta y}{\Delta x}\left(T_1 - T_2\right) = \rho c\Delta y\frac{\Delta x}{2\Delta t}\left(T_1^{p+1} - T_1^0\right)$$

$$q_s(1 - \rho_r) - h_0\left(T_1^0 - T_{\infty,0}\right) - \frac{k}{\Delta x}\left(T_1^0 - T_2^0\right) = \rho c\frac{\Delta x}{2\Delta t}\left(T_1^1 - T_2^0\right)$$

$$\boxed{T_1^1 = \frac{[q_s(1 - \rho_r) - h_0\left(T_1^0 - T_{\infty,0}\right) - \frac{k}{\Delta x}\left(T_1^0 - T_2^0\right)]}{\rho c\frac{\Delta x}{2\Delta t}} + T_1^0}$$

Node 2: In the middle of fiber-cement wall

[Conduction heat transfer from node 1 to node 2]- [Conduction heat transfer from node 2 to node 3] = [Energy change of system depending on time]

$$\frac{k\Delta y}{\Delta x}\left(T_1^0 - T_2^0\right) - k\frac{\Delta y}{\Delta x}\left(T_2^0 - T_3^0\right) = \frac{\rho c\Delta x\Delta y\left(T_2^1 - T_2^0\right)}{\Delta t}$$

$$k\left(T_1^0 - 2T_2^0 + T_3^0\right) = \rho c\frac{\Delta x^2}{\Delta t}\left(T_2^1 - T_2^0\right)$$

$$T_2^1 = \left[\frac{k}{\rho c}\frac{\Delta t}{\Delta x^2}\left(T_1^0 - 2T_2^0 + T_3^0\right)\right] + T_2^0$$

$$\frac{k}{\rho c} = \propto$$

$$\boxed{T_2^1 = \left[\propto\frac{\Delta t}{\Delta x^2}\left(T_1^0 - 2T_2^0 + T_3^0\right)\right] + T_2^0}$$

Node 3: Coating film at inside wall

[Conduction heat transfer from node 2 to node 3]- [Convection heat transfer from node 3 to inside ambient] = [Energy change of system depending on time]

$$k\frac{\Delta y}{\Delta x}\left(T_2^0 - T_3^0\right) - h_i\Delta y\left(T_3^0 - T_{\infty,i}\right) = \rho c\frac{\Delta x}{2\Delta t}\Delta y\left(T_3^1 - T_3^0\right)$$

$$k\left(T_2^0 - T_3^0\right) - h_i\Delta y\left(T_3^0 - T_{\infty,i}\right) = \rho c\frac{\Delta x^2}{2\Delta t}\left(T_3^1 - T_3^0\right)$$

$$T_3^1 = \left[\frac{2\Delta t k}{\Delta x^2\rho c}\left(T_2^0 - T_3^0\right) - \frac{2\Delta t h_i\Delta y}{\rho c\Delta x^2}\left(T_3^0 - T_{\infty,i}\right)\right] + T_3^0$$

$$= \left[\frac{2 \propto \Delta t}{\Delta x^2} (T_2^0 - T_3^0) - \frac{2 \Delta t h_i}{\rho c \Delta x} (T_3^0 - T_{\infty,i}) \right] + T_3^0$$

$$\boxed{T_3^1 = \frac{2 \Delta t}{\Delta x} \left[\frac{\propto}{\Delta x} (T_2^0 - T_3^0) - \frac{h_i}{\rho c} (T_3^0 - T_{\infty,i}) \right] + T_3^0}$$

See mathematical model equation of Temperature in 3 Nodes below:

$$T_1^1 = \frac{\left[q_3 (1-\rho) - h_o (T_1^0 - T_{\infty,o}) - \frac{k}{\Delta x} (T_1^0 - T_2^0) \right]}{\rho c \frac{\Delta x}{2 \Delta t}} + T_1^0$$

$$T_2^1 = \left[\alpha \frac{\Delta t}{\Delta x^2} (T_1^0 - 2T_2^0 + T_3^0) \right] + T_2^0$$

$$T_3^1 = 2 \frac{\Delta t}{\Delta x} \left[\frac{\alpha}{\Delta x} (T_2^0 - T_3^0) - \frac{h_i}{\rho c} (T_3^0 - T_{\infty,i}) \right] + T_3^0$$

Which, ρ is a thermal reflectivity of color, k is a thermal conductivity of color and α is a thermal diffusivity.

2. Analysis Procedure

2.1 Improve and edit the simulation model in order to achieve better prediction accuracy, and become the standard simulation model of the building that is used for Base Case.

2.2 Change other parameters such as solar reflection, solar emissivity, heat transmission, heat absorptance and thermal conductivity respectively. In order to, the heat transfer can be predicted through small building coated with heat insulated paint including with energy consumption.

2.3 Compare the surface temperature of wall between before and after is change parameters
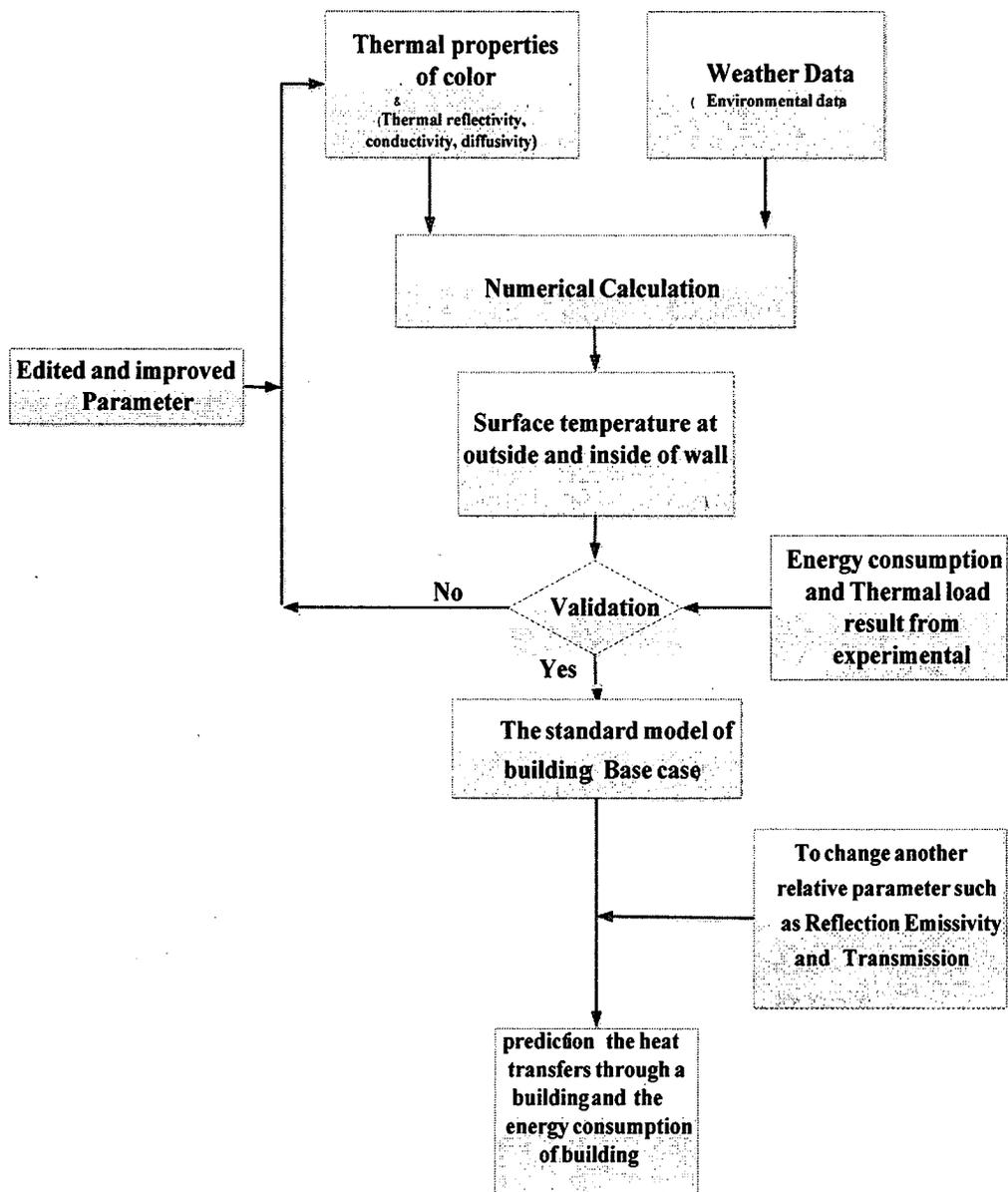
2.4 Record the testing resultant and raw data so far, the summarization shown in figure 29.

Figure 29 Flow Chart of Methodology