CHAPTER II

LITERATURE REVIEW

The literature review described in this chapter is about the four-way hot box of the previous study conducted by Karno (2008). In addition, some information and interrelated theories relating to this research study are also included in this description.

2.1. Review of Four-Way Hot Box Designed by Karno (2008)

The four-way hot box was a testing tool which was built and used to approximate thermal resistance of insulation properties based on comparison approach in a previous research experiment by Karno (2008). The tool was invented based on three major criterions: 1) low cost expense, 2) easy to construct, and 3) providing a reliable result.

2.1.1. <u>The Four-Way Hot Box Design</u>

The four-way hot box was designed for the purpose of conducting his research experiments. The objective of his experiment was to find thermal resistance (*R*-value) of different wall specimens composed of disposed packaging EPS foam installed in between traditional wall systems of building envelopes. The thermal resistance of each specimen was approximated by using the comparison approach, which thermal resistivity performance of the tested specimens were tested along with the reference materials of pre-known thermal conductance.

Generally, hot boxes are classified in two types of tools as the guarded hot box (an absolute method), and the calibrated hot box (a secondary method by requiring calibration using insulation properties of known thermal conductance). Both types of hot box used ambient temperatures to measure the thermal performance of building envelope components, such as walls, roofs and windows in a measurement standard, (Shah and Curcija, 2000). Most researchers used hot boxes to conduct experiment by using solar energy to compensate for passive heat losses or gains in building envelopes or other enclosures, (showed in Figure 2.1 and 2.2). The specimens and test-cells of those hot boxes were designed in different sizes and shapes. For example, the research of Kosney et al (1999), and Kosney and Childs (2000) used wall specimens with a dimension of 2.4 m x 2.4 m to process their experiment. Cheng and Givoni (2004) conducted experiments by using the test cells of 1.5 m long, 1.5 m wide and 1.5 m high for a large size test and 1 m long, 1 m wide, and 1 m high for a small size test in their study. Van Dessel et al. (2004), Ahmad et al. (2005) and Abela (2006) established their test cells of 1 m x 1 m x 1 m for conducting experiments. However, to obtain a sufficiency size as to reduce uncertainty in the calculation, the reference test specimen shall not have a dimension less than 0.5 m x 0.5 m (or 20“ x 20”) of visible area for installing in the surrounded panel (NFRC, 2001). The use of large size of test specimens could provide more accurate results.

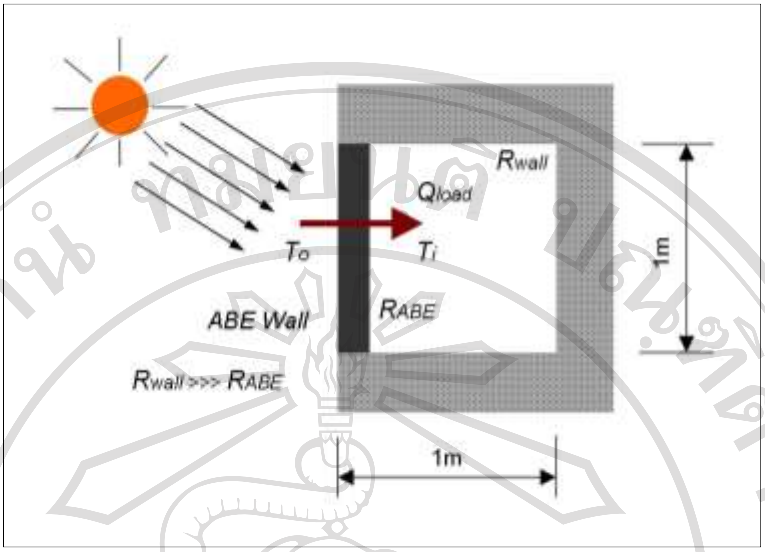

Figure 2.1 Schematic of a Generic Enclosure with Single ABE Wall System,

(Van Dessel et al., 2004)

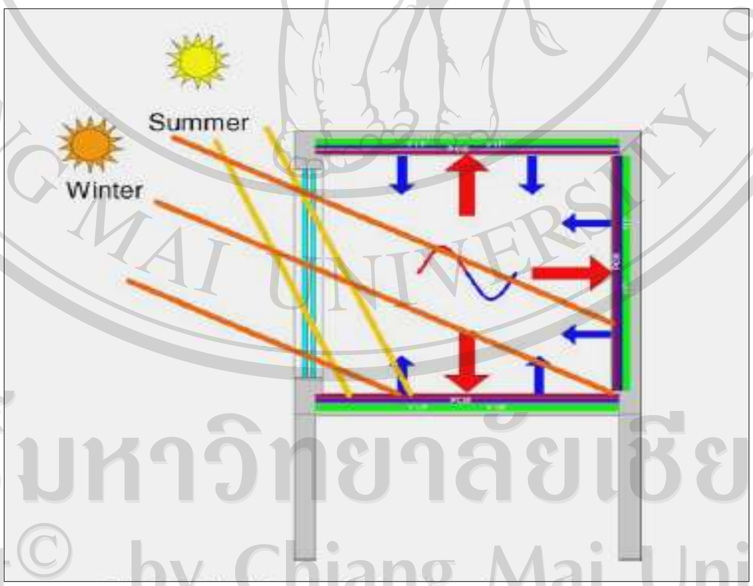

Figure 2.2 Principles Solar Heat Test-Cell System along summer and winter

periods, (Ahmad et al., 2005)

After reviewing and evaluating some theories, testing methods and devices, the four well-insulated boxes were designed with dimensions of 1 m x 1m x 0.6 m or 0.6 m^3, and they were installed as a cross symbol surrounding a heating cell. The exterior wall of the four-way hot box tool were EPS panels of 10 cm thick that the standard of EPS foam classified as the stronger one in the list of high thermal resistance (*R*-value) materials of building constructions, (Wikipedia, 2010). Moreover, EPS was also a popular insulating material which can be supplied by many factories in the developed countries including Thailand. Figure 2.3 and 2.4 are the four-way hot box test designed for this research employing the concept of comparison.

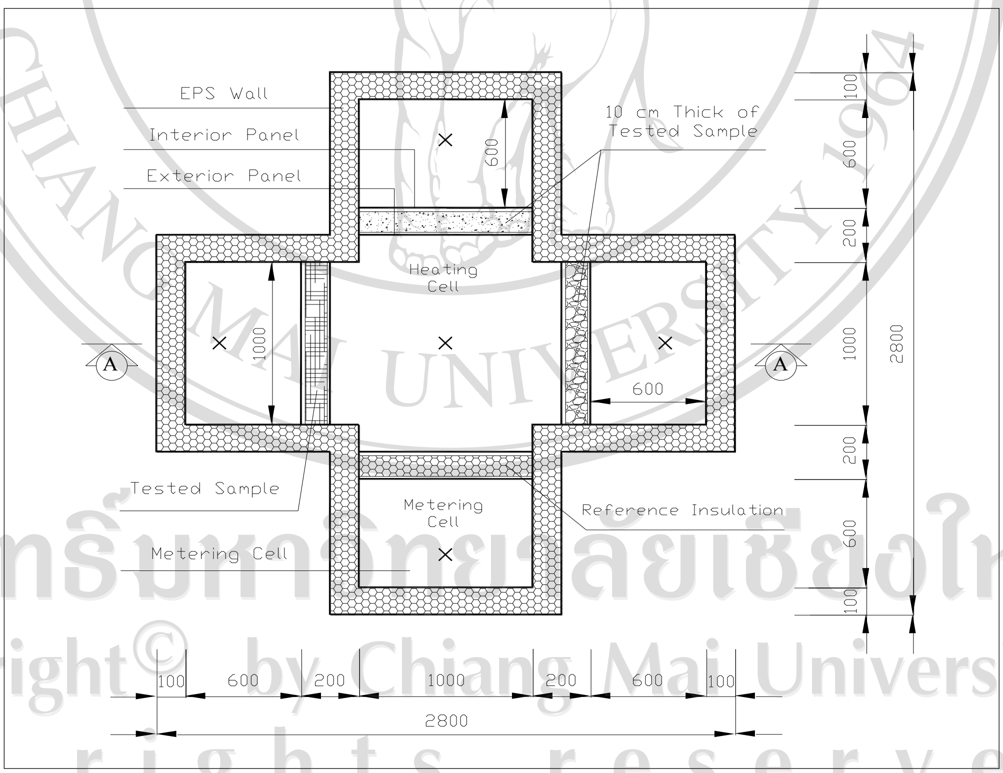

Figure 2.3 Top view outline of all heating and metering cells prepared for testing (X: thermometer positions) (Karno, 2008)

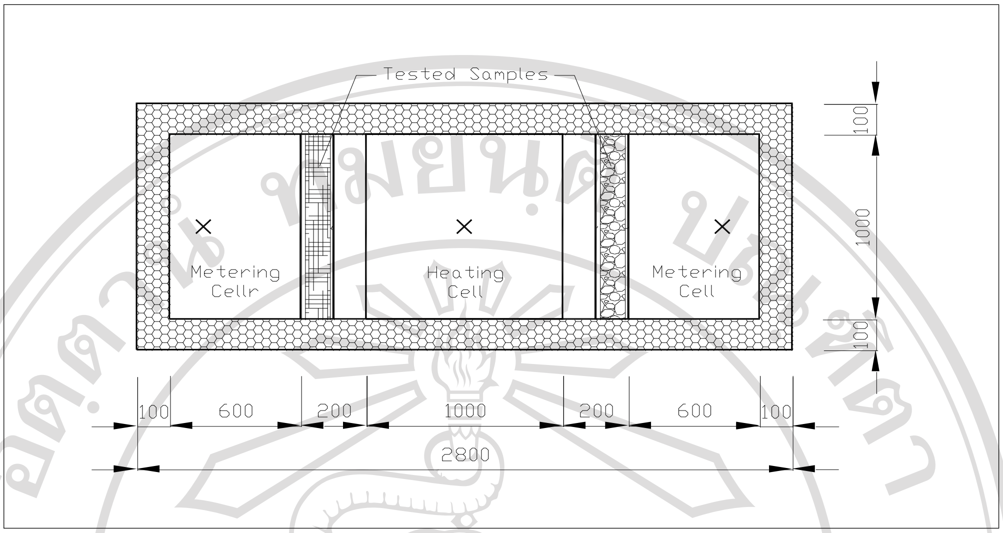

Figure 2.4 Section view (A-A) of heating and metering cells and test specimens (X: thermometer positions) (Karno, 2008)

2.1.2. The Four-Way Hot Box Construction

The four-way hot box was constructed with the exterior walls of 10 cm EPS foam material (supplied by a factory in Lamphun Province, Thailand) which had thermal resistance or *R*-value of 2.82 ºC•m^2/W (16 °F.ft^2.h/Btu). Each test-box or metering cell was made and assembled together by the flat-pieces of standard EPS panels in a cubic form. All metering cells were concerned about the issues of direct heat leaking out from the metering cells to the surrounding environment. Refer to this reason, some kind of glues and thermal properties were used, such as silicone, latex-glue and aluminum foil to stick at the connecting faces of all test cells in order to protect leakage of the internal air. Otherwise, the leakage may cause wrong results if the inside air temperatures of four-way hot box tool decrease or increase due to the air moving between the outside environmental spaces.

For a testing series, the four-way hot box can test four different specimens or samples simultaneously. All of those four specimens were to be installed between heating cell and metering cells and tested with the same of heating temperature. As a requirement of the comparison concept, one of the test samples should be a reference material and should be tested simultaneously with other samples. The following Figure 2.5 shows assembly of the four-way hot box construction.

Figure 2.5 The Hot box assembly

At the centre of the heating cell, a 200-W light bulb, which represented a heat-source of heating temperature, was installed to run the experiments. The light bulb was controlled and adjusted by a dimmer switch to increase or decrease the temperature inside the heating cell. Figure 2.6 shows the 200-W light bulb and the dimmer switch controller used in the four-way hot box.

Figure 2.6 A 200-W light bulb and a dimmer-switch controller

2.1.3. <u>The Four-Way Hot Box Operation</u>

Referring to Karno (2008), the operation of the four-way hot box was under three temperature parameters throughout the process of experiment. Three of them were established as ambient temperature, starting ambient temperature, and heating temperature. First, "starting ambient temperature" meant the temperature of the environments inside and outside the four-way hot box at the beginning of the test. This temperature level was set at 26.5 ºC for all of series of the experiments to prevent errors. Second, "ambient or room temperature" meant the temperature of room environment or temperature outside the box, and it was also kept as constant at 27 ºC to protect any errors by contacting heat leakage in between metering cells and room space. Third, "heating temperature" meant the temperature inside the heating cell to run in a series of experiment at the levels of 50 ºC, 55 ºC and 60 ºC, which represented an absorbed temperature of concrete wall during the hottest climate around 40 ºC, (Koch-Nielson, 2002).

The process of the experiment was in the following steps. First, the operation was begun with installing four of the testing specimens between the heating-cell and metering cells. After that, the test was started by turning on the 200-W light-bulb heat source in the heating cell, and turning on an air-conditioner, which would be on during the whole period of the test. The temperatures inside the heating cell and the metering cells were recorded simultaneously at a given time interval by using thermometer sensors. Each testing series was conducted during a period of four hours and all collected data were done in every 5 minutes along the test. A thermo-gun was also used to check the temperature on the surface of exterior wall of four-way hot box to observe any effect of heat gain or loss during the experiment. Figure 2.7 shows the thermometer-sensors and the thermo-gun tools.

Figure 2.7 Thermometer-Sensors and Thermo-Gun

2.1.4. <u>The Four-Way Hot Box Result</u>

After finishing the experiments, graphic results including reference charts were plotted to investigate the thermal performance of testing samples. The reference chart was an important tool to approximate the thermal resistance (*R*-value) of the tested materials based on the comparative concept. Data collected during the last 30 minutes of tests were used in the comparative analysis for the most reliable result (Karno, 2008). All the testing conditions must conformed the controlled parameters of the ambient temperatures such as the starting ambient temperature of 26.5 $^{\circ}$C, the room temperature in steady of 27 $^{\circ}$C and the heating temperatures of 50 $^{\circ}$C, 55 $^{\circ}$C, and 60 $^{\circ}$C. Figure 2.8, 2.9 and 2.10 demonstrated a reference data set of those heating temperatures using EPS panels of 5 cm, 7.5 cm, 10 cm, and 12.5 cm as reference materials**.** With this graph, an *R*-value of a specimen can be approximated by plotting the temperature recorded in its metering cell.

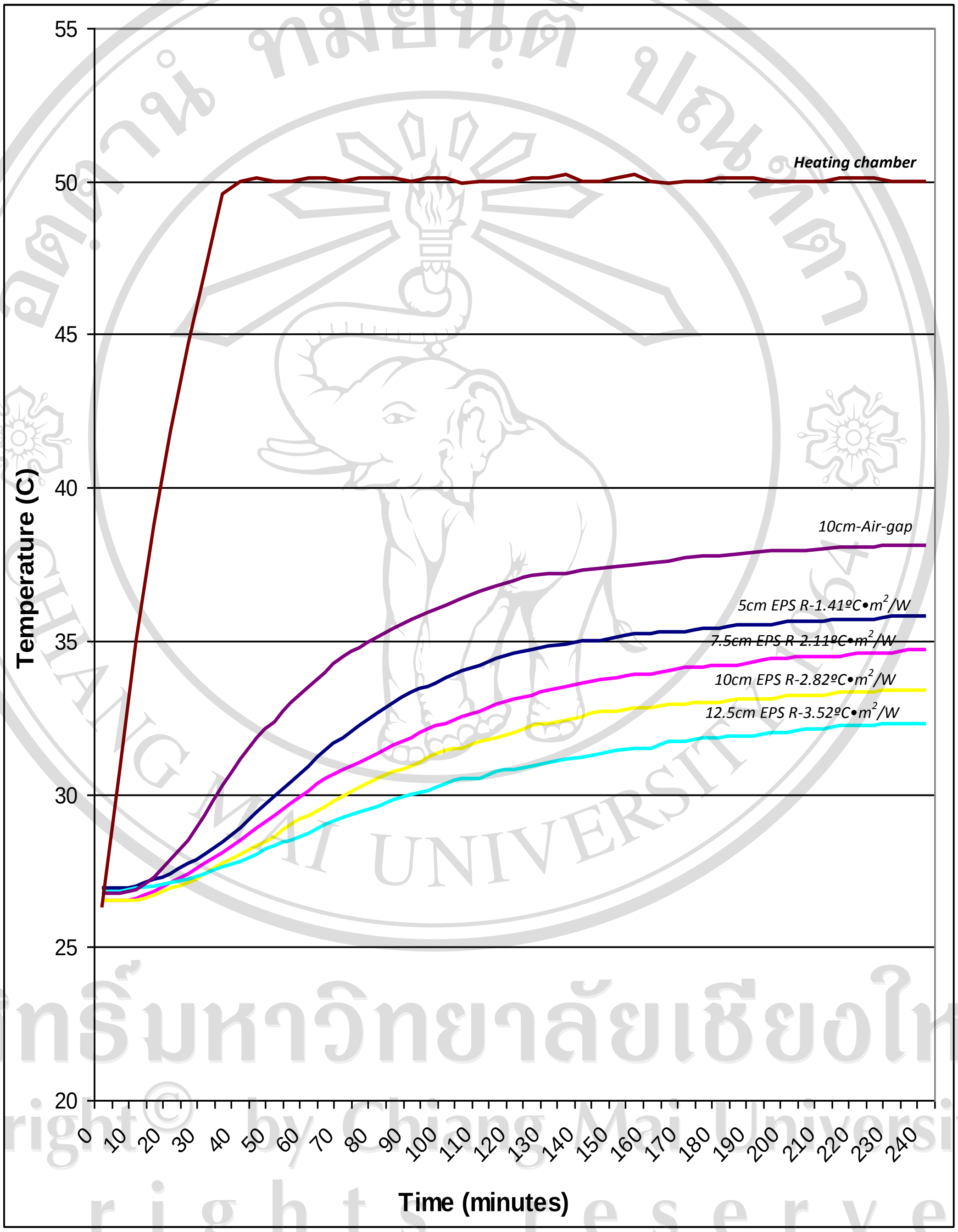

Figure 2.8 Air temperatures in metering cells when heating cell was heated up to 50°C

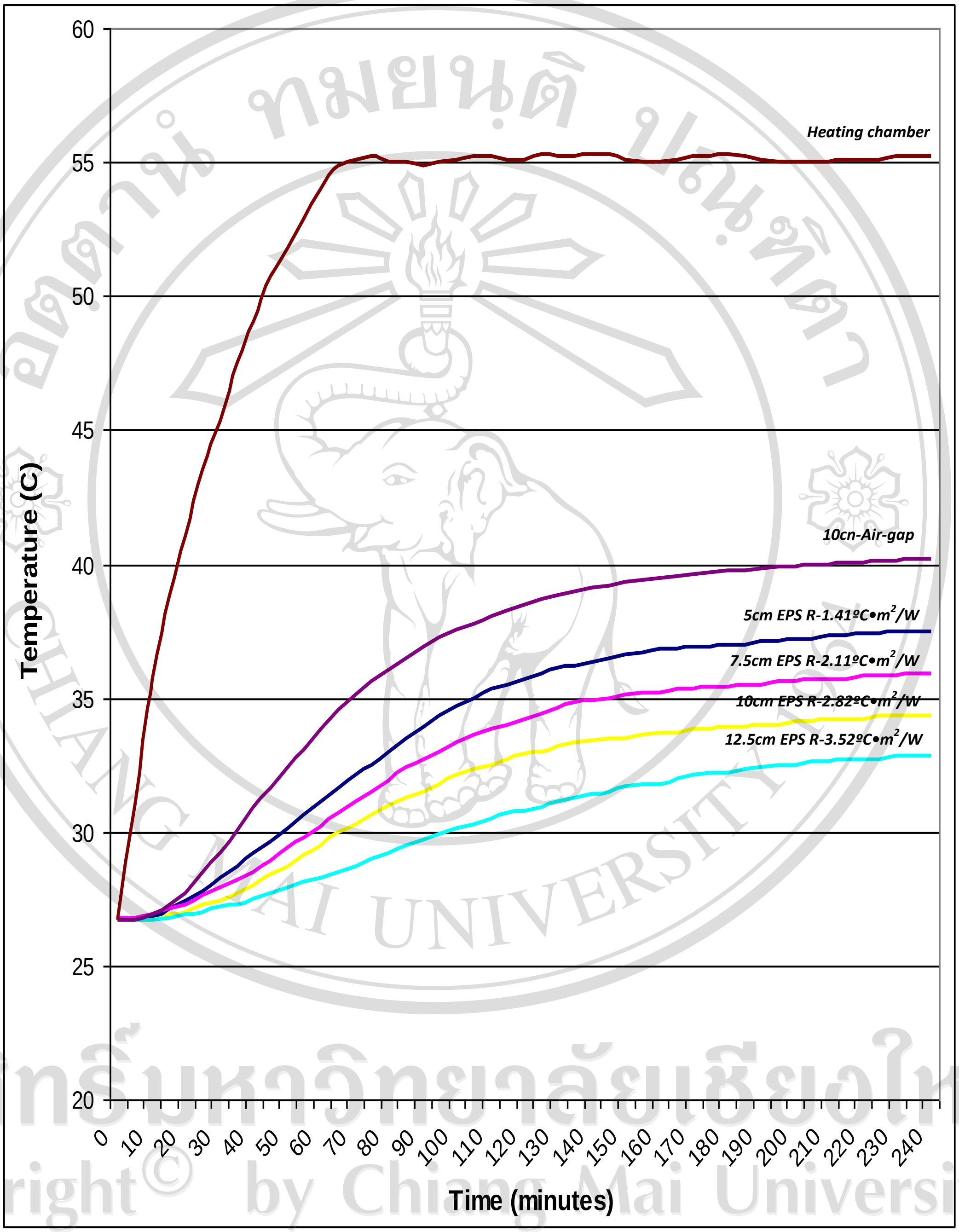

Figure 2.9 Air temperatures in metering cells when heating cell was heated up to 55°C

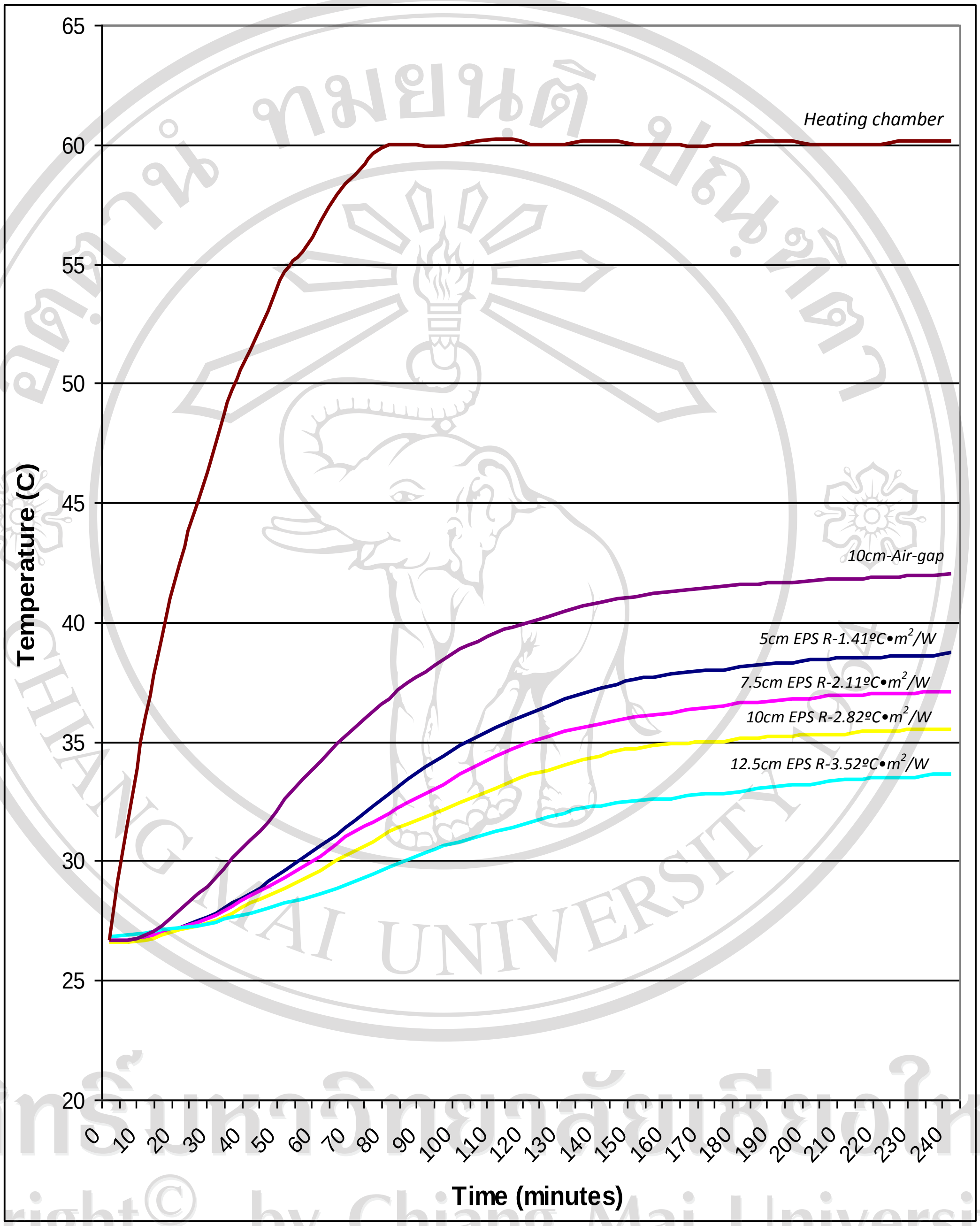

Figure 2.10 Air temperatures in metering cells when heating cell was heated up to 60°C

2.2. Criticize of the Four-Way Hot Box Test

2.2.1. Criticize of the Design

In the prior research projects conducted by Van Dessel et al. (2004), Cheng and Givoni (2004) and Ahmad et al. (2005), their test boxes were designed and operated using the solar energy by underneath the sun in a period of winter or summer to approximate the results, (showed in Figure 2.1 and 2.2). Thus, solar heat can vary when the wind-velocity, humidity, shading...etc, were changeable. Because of the four-way hot box design concept was developed from the previous researches study, an advantage was showed in Karno's research process at least three points. First of all, it was possible to conduct an experiment by running more than one sample in one testing series, simultaneously. Second, it allowed controlling the ambient temperatures factor such as the starting ambient temperature and the heating temperature of a heat-source in the process of experiment. Third, it allowed conducting the test at any places and any time without requiring the solar energy.

2.2.2. Criticize of the Construction

In refer to a reviewing of the four-way hot box construction made by Karno (2008), some issues were on considered. First of all, was the construction work good enough to process the experiment? Next, was the four inches EPS foam thickness of its exterior walls strong or weak to protect heat loses from the test? Finally, How to expect an approximate in amount of heat exchanged in the metering cells?

Generally, EPS is a soft and a fragile material that it is easy to break or warp by hard things. In this case, the EPS foam panels should be covered by a hard material on the exterior part to prevent any damages. Moreover, the installing works to put the specimens inside the metering cells of the four-way hot box tool should be a main concern for the researchers. An amount of directed contact of heats leakage can happen along the test if the specimen panel was not good enough to close-off the space between heating cell and metering cell in completeness works. This situation will lead the researcher to get the incorrect result from the experiments.

The result in Figure 2.10 showed that there was around 9 °C heat gains in metering cell with 4 inches thick of the samples in four hours of the experiment, (Karno, 2008). Moreover, based on the heat flow theory, the metering cell could reach the temperature up to 60°C slower or faster within a period of time (depend on *R*-value of it property) if heating temperature was constant 60°C. Thus, if the temperature inside the measuring cells increases, it was possible that the heat could be leaking out to the surrounding environment outside the four-way hot box during the test.

Formula of Heat Conduction

Normally, heat conduction is a heat transfer through a solid object when one part of an object is heated. It will push the molecules which begin to move faster and more vigorously. These molecules will hit other molecules within the object, which conducts heat throughout the object (Incropera and De Witt., 1990).

According to Rolle (2000), the expectation of the amount of heat loss or gain (Qx) though an object can be calculated as the formula as:

$$Qx = -KA\,\Delta T / \Delta x \qquad (1)$$

$$or \quad Qx = -A.\,\Delta T / R.\,\Delta x \qquad (2)$$

K can be finding as:

$$K = -\,Qx\,\Delta x / A\,\Delta T \qquad (3)$$

Thermal resistance (*R*-value) can be revised that:

$$R = -\,A\,\Delta T / Qx\,\Delta x \qquad (4)$$

- Qx is an amount of heat transfer quantity, (Watt or W).
- ΔT is a different temperature between an object, (ºC).
- Δx is a thickness of the object, (m).
- A is an area of the object, (m^2).
- K is thermal conductivity, (W / ºC•m^2 or Btu/°F.ft^2.h).
- R is thermal resistance (*R*-value), (ºC•m^2/W or °F.ft^2.h/Btu).

<u>*Calculation of Heat Exchanged*</u>

Based on the result in figure 2.10, an amount of heat exchanged in all metering cells of all specimens could be calculated as the formula bellow:

$$Qx = A.\,\Delta T / R.\,\Delta x \qquad (2)$$

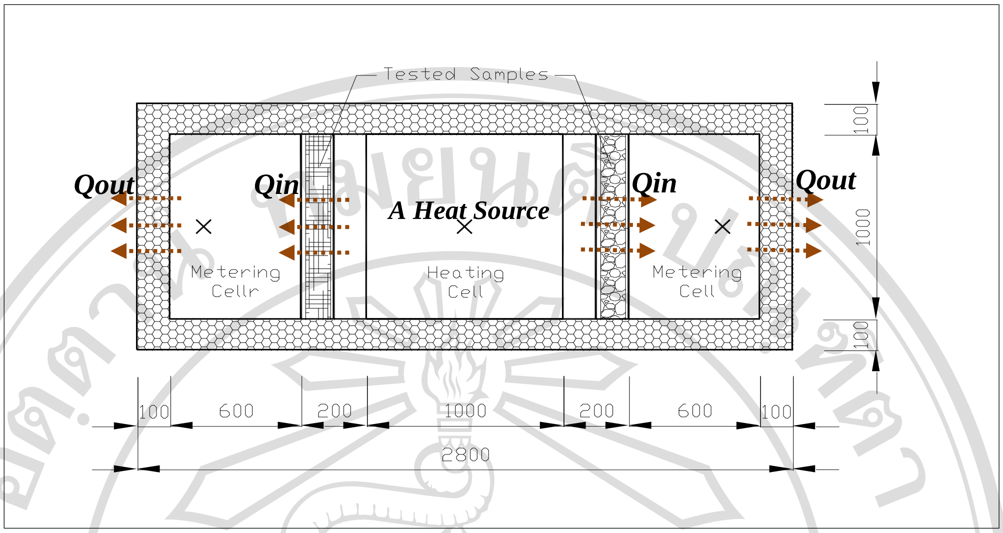

Figure 2.11 Direction of heat exchanged (Qin and Qout) of the four-way hot box on section view (A-A) of heating and metering cells between the test specimens.

1) 10 cm Air-gap: (*R-value of 0.48 ºC.m*^{2}*/W*)

- $Q\ (in) = A1.\ \Delta t1\ /\ R1.\ \Delta x = 1 \times 18\ /\ 0.48 \times 0.1 = 375$ *Watt.*
- $Q\ (out) = A^1.\ \Delta t^1/R^1.\Delta x = 3.4 \times 15\ /\ 2.82 \times 0.1 = 180.9$ *Watt.*

  ⇨ $Q\ (in) = 0.5\ Q\ (out)$

2) 2" EPS foam: (*R-value of 1.41 ºC.m*^{2}*/W*)

- $Q\ (in) = A.\Delta t\ /\ R.\Delta x = 1 \times 21.5\ /\ 1.41 \times 0.05 = 305$ *Watt.*
- $Q\ (out) = A^1.\ \Delta t^1/R^1.\Delta x^1 = 3.4 \times 11.5\ /\ 2.82 \times 0.1 = 138.6$ *Watt.*

  ⇨ $Q\ (in) = 2Q\ (out)$

3) 3" EPS foam: (*R-value of 2.11 ºC.m*^{2}*/W*)

- $Q\ (in) = A.\Delta t\ /\ R.\Delta x = 1 \times 23\ /\ 2.11 \times 0.075 = 145.3$ *Watt.*
- $Q\ (out) = A^1.\ \Delta t^1/R^1.\Delta x^1 = 3.4 \times 10\ /\ 2.82 \times 0.1 = 120.6$ *Watt.*

➪ *Q (in) = 1.2 Q (out)*

4) 4” EPS foam: (*R-value of 2.82 ºC.m²/W)*

- *Q (in) = A.Δt / R.Δx = 1 x 24.5 / 2.82 x 0.1 = 87 Watt.*
- *Q (out) = A1. Δt1/R1.Δx¹ = 3.4 x 8.5 / 2.82 x 0.1 = 102.5 Watt.*

➪ *Q (in) = 0.85 Q (out)*

5) 5” EPS foam*: (R-value of 3.52 ºC.m2/W)*

- *Q (in) = A.Δt / R.Δx = 1 x 26 / 3.52 x 0.125 = 59.1 Watt.*
- *Q (out) = A1. Δt1/R1.Δx1 = 3.4 x 7 / 2.82 x 0.1 = 84.4 Watt.*

➪ *Q (in) = 0.7 Q (out)*

▫ *Q (in)* represents amount of heat loss from the heating cell to the metering cells through the testing samples, (Figure 2.11).

▫ *Q (out)* represents amount of heat loss out-offs the metering cells to the room environment through exterior of 4-way hot box, (Figure 2.11).

According to the expected results by formula of heat conduction, it showed that exterior wall, which constructed by four inches thick of EPS foam, could not prevent the amount of heat loss from the metering chamber in four hours period of the test. Huge amount of heat loss was found leaking out from the metering cells of the testing specimens, and quantities of heat loss from all metering chambers were released in different amount of heats depending on the thermal resistance (*R*-value) of each test specimen. Therefore, two conditions between opening and closing the air-conditioner were on considering issue whether it could affect to the tests or not.

2.2.3. Criticize of the Operation Work

The experimental operation work by Karno's research was completely done along a period of four hours to finish each series of the tests. However, the tests left some issues. Following from the top reviews in section 2.1.3, at least two problems of the operating process were pointed-out. First, the researcher was unclear to estimate a shorter period of the experiment which could be saving time and reach enough a reliable result. Second, the experiment was conducted by using an 18000-BTU air conditioner capacity to run on a set of experiment in period of four hours. The 18000-BTU air conditioner consumes an amount of electrical quantity about 5275-W or 5.275-KW, (Wikipedia, 2010). Thus, to finish a series of the test, the electrical energy used up about 21100-W or 21.1-KW that this value caused researchers to spend a lot of money for each test.

2.2.4. Criticize of the Results

As describe in section 2.1.4, the test's outcomes on approximating thermal resistance of tested specimens by Karno (2008) were found many reference charts from all series of the test. However, the charts left a difficult issue for other researchers to use it to read their tests results when the starting ambient temperature, the room temperature and the heating temperature were set at temperature level different from Karno's research. To avoid this problem, other researchers must prepare and follow all Karno's experimental rules to run the tests to avoid different results.

2.3. Reliability of a Research Tool

One concern of every research tool is whether or not the tool can yield the same results or with minimum differences or errors between all testing series, known as reliability problem. After carefully considering threats to its reliability, there are two possible major threats to this issue.

1) Can the light bulb give the same temperature all the times? What should we do if the starting temperatures are different?
2) Can the room temperature affect the chamber temperature? If that can happen what should we do?

Luckily, the first threat indicated above did not happen in Karno's research because the light bulb was new. However, since the light was controlled by a dimmer switch and it was unnecessarily turned on to the maximum power all the times. Therefore, there are question that several sets of reference curves should be prepared or not because Karno (2008) provided only three heating temperatures of 50 ^{o}C, 55 ^{o}C, and 60 ^{o}C and there is an effect or not if the light bulb quality changed when it is prolonged to use in a long period of time.

For the second threat, the research project prevented this problem by turning on the air conditioner to control the room temperature throughout the experiment. However, since all experiments take four hours it means there was some extra cost to be paid for air conditioning.

2.4. Summary of the Previous Four-Way Hot Box Test Arguments

In summary, according to Karno (2008) research experiment by the four-way hot box left many suspicion issues that should be considered and improved such as:

1). The test took a long period to reach the stage that the temperature inside the measuring cell is steady or slowly increased. This case made the researcher wasting times and extra money to run his research experiment.

2). The test was done by keeping the same condition of constant room temperature for all series of the tests that the room was set constantly 27 °C in purpose to protect any error result from the test. In this case, Karno needed to turn on the air conditioner at least 4 to 5 hours to process the experiment that wasted a big amount of electricity used.

3). In refer to heat transfer theory, Incropera and De Witt (1990) and Kossecka (1992) mentioned that the heat exchange through walls panel of the boxes or cells can be released so fast when there are too much different temperatures between two spaces inside and outside the boxes or cells. Thus, this situation can provide incorrect data collected from each measurement process along the test.

4). Base on Koch-Nielson (2002), temperature in and around buildings will be affected by the nature of the surrounding surfaces. In a hot climate when air temperature was about 40 °C, surfaces temperatures of concrete can increase up to 52 °C and 62 °C depending on its color. For this reason; Karno (2008) decided to design three heating temperatures of 50°C, 55°C, and 60°C to process the experiment for possible air temperature in Thailand which could reach up to 40°C. In this case, the heating temperature was prepared in a similar condition of heating inside heating cell for all series of tests by using a 200-W light bulb heat source turning on to the maximum power of its capacity. However, researcher still did not know that three designs of heating temperature were necessary or not for the four-way hot box experiment. Moreover, a problem of variable heat source can happen when the light bulb is prolonged to use in a long period of time. Thus, a speed to reach up temperature by the light bulb should be focused or not.

5). All reference chart results of the testing specimens were built with the same starting ambient temperature of 26.5 ºC for all series of the tests, (Karno, 2008). This situation made other researchers is difficult to read their testing result from the charts when the starting temperature is different from 26.5 ºC. Thus, the correcting factor to solve this problem should be study in next research.

6). The size and shape of the four-way hot box design is not studied yet in a detail to find out that the design reach enough a standard quality to obtain valid result from the test and save cost expense for the construction work. Moreover, because of the EPS foam material is soft and easy to deform from the original form, any works to build the four-way hot box is still having some disadvantages for installation. Therefore, a safety work to develop the four-way hot box construction should be found to avoid any errors by heat leak out from the boxes or cells during conducting the experiment.

2.5. Limitation of Thesis Research

As reviewing along Karno (2008) thesis, many issues were found and on considering. However, this master thesis research was only focusing on the way to develop the four-way hot box method which can provide shortest time and saving some extra money spending for electric energy by running on the air conditioner in the whole period of the test. Moreover, because of this research thesis is done in the Faculty of Architecture at Chiang Mai University, Thailand, thus, all research experiments must be follow the average temperature of Thailand as study parameters.

2.6. Temperature in Thailand

The Kingdom of Thailand is located in both southwest and northeast monsoon areas with a high humidity and intensities of solar radiation. The temperatures are fairly uniform across the central region with an annual average of about 28 – 30°C and the average sunlight period per day is about 9 hours in winter and 8 hours in summer.

According to reports of the Thai Meteorological Department (2010), weather in Thailand is warm all year round, and annual mean minimum temperatures in the region are around 20 – 24°C (Figure 2.12) and mean maximum temperatures around 31 – 34°C (Figure 2.13). According to the reported document by TMD in last ten years (2000 – 2010), the hottest temperature in summer (March to May) can reach 40°C in daylight (Tak, 25 Apr 2007) and the coldest temperature in winter (November to January) can go down to 4.2°C in morning (Nakhon Panom, 11 Jan 2009).

However, the variance between the highest and the lowest temperature does not happen the same all years. It rarely happens, once in every five or ten years round in some regions of Thailand. Thus, this research study will focus on the average mean temperature between winter and summer season in rank between 20°C to 34°C.

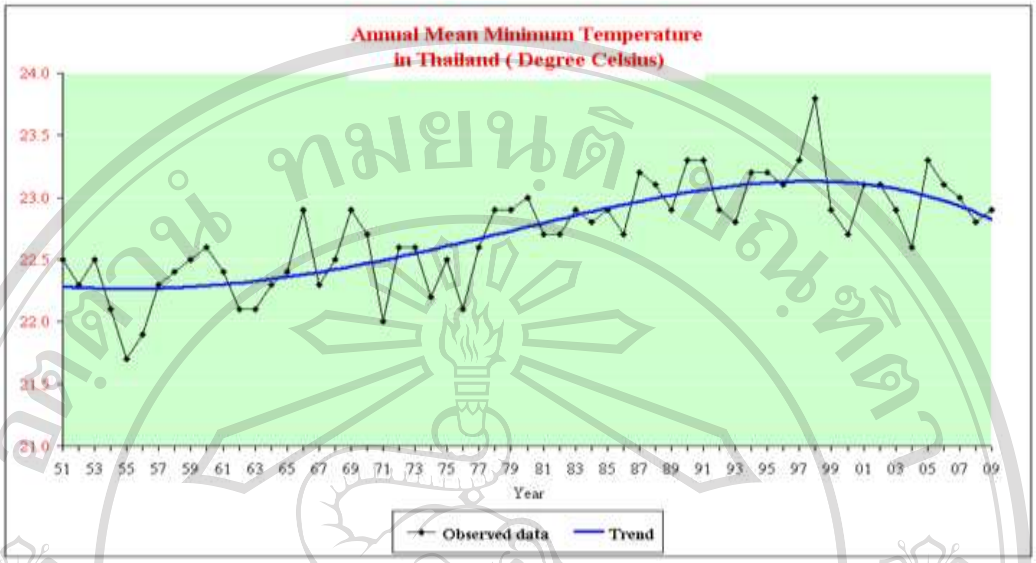

Figure 2.12 Annual mean minimum temperatures in Thailand (1951 – 2009), source from TMD, (2010).

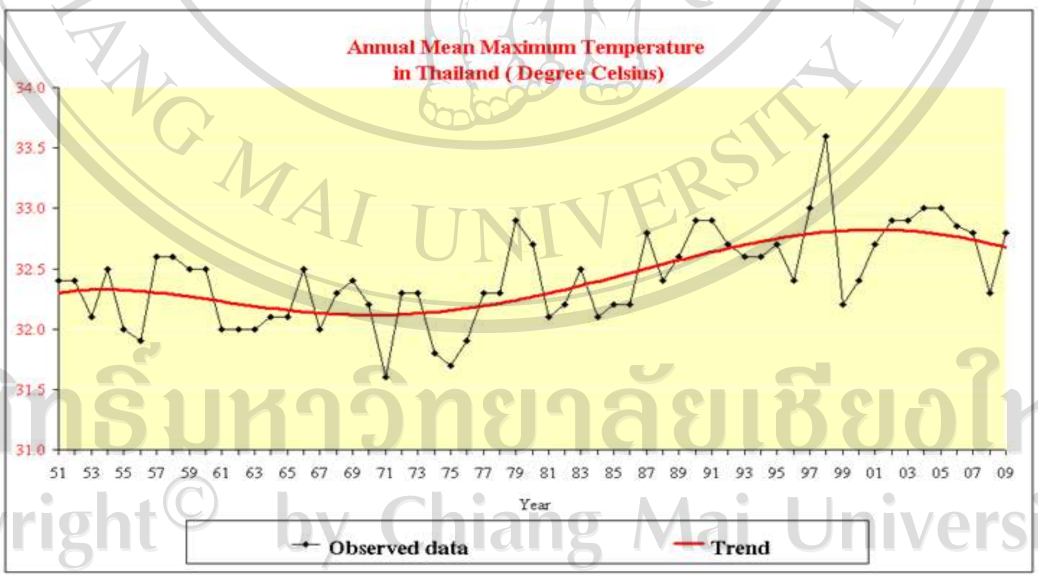

Figure 2.13 Annual mean maximum temperatures in Thailand (1951 – 2009), source from TMD, (2010).