

## CHAPTER 3 RESEARCH METHODOLOGY

Methodology of the research contains descriptions of survey method for thermal comfort in industrial buildings, instrumentation and measurements to measure the existing conditions of human comfort from their workplace in the buildings, and questionnaire to collect data of perception and attitudes from employees. Hypothesizing of the research from survey data and principals of energy-efficient design is indicated subsequently. As a result, analysis and evaluation of the potential of energy efficiency for industrial buildings by using simulation tools are done to probe into the model of the integrated design strategies in thermal comfort of industrial buildings for tropical climates such as Thailand.

### 3.1 Survey Industrial Buildings in Thailand

The survey of energy use in industrial buildings will be addressed to industrial buildings status in Thailand including boundary and target groups of the research.

#### 3.1.1 Industrial Building Status in Thailand

In Thailand, Ministry of Industry undertakes the works of industry and authorizes the two agencies involving in industrial buildings. There are the Industrial Estate Authority of Thailand (IEAT) who operates 12 industrial estates and jointly operates with developers 26 industrial estates, and the Department of Industrial Works (DIW) which controls the industrial buildings in outside of industrial estate in the entire kingdom of Thailand.

#### **Industrial Estate Zone**

Industrial estate means an area of land allocated for industrial factories to be set up in a well-organized manner. The area consists of industrial space, together with a complete range of facilities, public utilities and infrastructure such as roads, drainage, central wastewater treatment, flood protection, electricity, water supply and a telephone system. Additional necessary services available include post offices, banks, shopping centers, worker residential areas and petrol stations. There are 39 industrial estates in Thailand; total area, is 120,329 Rais (192,526,400 m<sup>2</sup>) scattering in 15 provinces. The total number of factories is approximately 3,300 buildings, total capital with approximate of 1.8 billion-million Bahts, and total employment of 465,000 persons [IEAT, 2009]. There are two types of industrial estate zones: General Processing Zone – designated for industrial and service operations or other activities beneficial to or connected with industrial and service operations, and IEAT Free Zone – designated for industrial and commercial operations or other activities beneficial to or connected with industrial and commercial operations to achieve benefits in terms of the economy, state stability, public well-being, environmental management or other necessary purposes

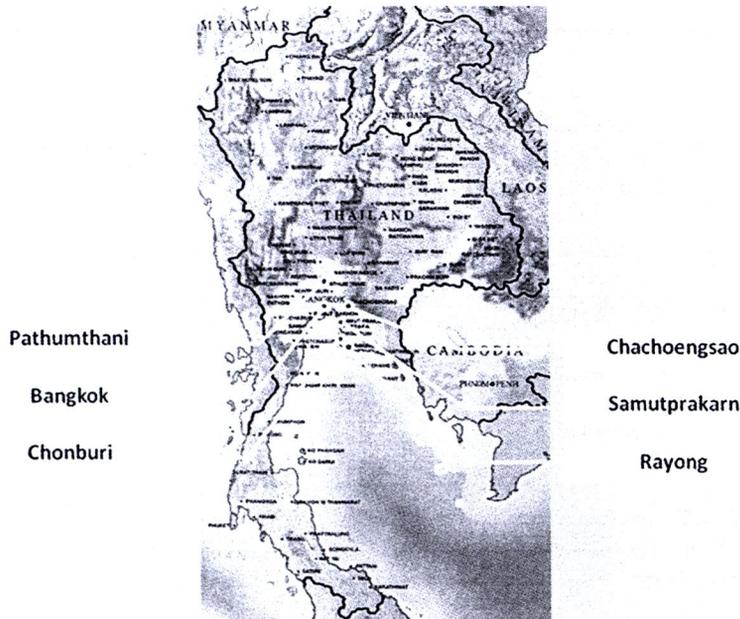
specified by the IEAT board. Supplies taken into an IEAT Free Zone are entitled to additional tax and fee privileges, in accordance with the appropriate legislation.

### **Outside of Industrial Estate Zone**

Regarding the Factory Act B.E. 2535 (1992), Department of Industrial Works (DIW) is a state agency who authorizes, manages, and encourages the works of industrial business including hazardous materials, production, environment, safety, and machine registration on the entire kingdom of Thailand excepts Industrial Estate Authority of Thailand (IEAT) which is an independent state enterprise. Industrial buildings in Thailand by the regulation of Factory Act B.E. 2535 (1992) are classified in three groups relying on size: small, medium, and large buildings respectively. In 2008, there are 126,658 manufactures scattering in all parts of Thailand [Department of Industrial Works, 2008], particularly in the capital city and major cities such as Bangkok, Khonkaen, Nakorn Ratchasima, Chaing Mai, Samutprakarn.

#### **3.1.2 Limitation of the study and Target groups**

The survey of monitored industrial buildings has to be concise, since time is restricted. Boundary of this study and target groups of the survey should be directly and inclusively suitable for the representatives of each industrial buildings in Thailand at present. Thus, the boundary of target groups is confined to three cases of the industrial buildings in large industrial estate zones. The first sample factory for monitoring is in Amata Nakorn Industrial Estate located in Chonburi, 57 kilometers east of Bangkok and 46 kilometers of Laem Chabang deep sea port, with 500 factories in the controlled environment. The second is in Nava Nakorn Industrial Park located in Pathumthani, 46 kilometers north of Bangkok and 60 kilometers of Klongtoey port, with over 200 factories in the controlled environment. And the third is Wellgrow Industrial Estate located in Chachoengsao, 36 kilometers east of Bangkok and 50 kilometers of Klongtoey port. The other three cases scatter in outside of industrial estate zone, which had to manipulate the facilities and utilities such as waste, water and electrical power supply by themselves in some areas, are selected to collect data in Bangkok and nearby area such as Pathumthani and Samutprakarn.



**Figure 3.1** Map of 6 monitoring factories in 6 cities in Thailand.

## 3.2 Instrumentation and Measurements

### 3.2.1 Temperature Measurement

Thermometer, Testo 860-T2 model, was used to collect data for the measurement of the surface temperature inside and outside the monitored buildings, as well as temperature of interior roof surface (beneath the roof) and exterior roof surface (on the roof). Process of measuring is conducted by presetting emissivity of selected materials and pressing the trigger perpendicularly to the surface being measured in long distance totally 9 points in each building.



**Figure 3.2** Thermometer of Testo 860-T2 model.

### 3.2.2 Air velocity and Relative Humidity Measurement

Thermo-anemometer, Testo 445 model, was used to collect data of air velocity as well as temperature interior and exterior of the monitored buildings. It was also used to measure relative humidity only inside the monitored buildings in the occupants'

working place, because in the buildings naturally ventilated, the relative humidity was not significantly different among inside and outside the buildings. Process of measuring is conducted by pressing enter button 20 seconds for self-calibrating, and then carefully holds the head-tube against the direction of wind to measure the air velocity, relative humidity and air temperature in totally 9 points per each building.



**Figure 3.3** Thermo-anemometer of Testo 445 model.

### 3.2.3 Lighting Illumination Measurement

Illuminance meter, Konica Minolta T-10 model, is used for measurement of lighting illumination of both ambient lights for pass way comparing with task lights for working location. Process of measuring is conducted by closing the cover cap and aligning the illuminance meter perpendicularly to the measured lighting at 0.75m (same as working level) above ground, afterwards open the cover cap 10 seconds for self-calibrating to measure the lighting illumination totally 9 points in each building.

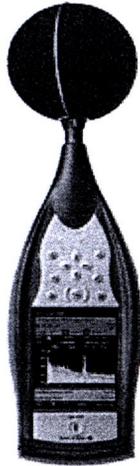


**Figure 3.4** Illuminance meter of Konica Minolta T-10 model.

### 3.2.4 Noise Level Measurement

Handheld analyzer of sound level meter, Bruel & Kjaer 2250 model, is used for measuring noise level of operating machines in the buildings that affects the occupants totally 9 points per in each building. Calibration of this instrument before measurement

is required for accurate values. It should be provided sound pressure at 1 kHz with avoiding handling vibrations to disturb the calibration. Pressing start calibration, the sensitivity is automatically calculated and displayed with the deviation from the last calibration. The calibration should be deviated less than  $\pm 1.5$  dB from the initial calibration.



**Figure 3.5** Handheld-sound level meter of Bruel & Kjaer model.

These measurements have been used to evaluate existing buildings performance of monitored buildings regarding human comfort in order to establish an integrated design model mentioned for the study in the further section.

### **3.3 Data Acquisition**

This chapter will indicate the results of data acquisition and measurements from six monitoring factories in six cities in Thailand as the representative of industrial buildings in tropical climate, as well as the experimental results of simulation from designed model. Then, discussion of the results in terms of integration of design strategies will be conducted to propose the design guideline in this research appropriate to tropical climate such as Thailand. The results of the investigation including results of data acquisition, results of measurement data, and experimental results of simulation which presented to select the great potential achieving human comfort in industrial buildings.

#### **3.3.1 Method of Data Acquisition**

For method of data acquisition in this research cluster random sampling method is used and divided into two parts. The first part is data collection in field survey by interviewing general employees who worked in production area, with questionnaires which queried for personal information to examine their backgrounds and knowledge of energy saving to investigate the awareness, physical materials of the buildings to examine their performances, and interviewing managerial employees regarding energy saving managements to study their company policies. Therefore, in addition to qualitative data from interview, quantitative measurement on relative humidity, air

velocity, noise level, illuminance level and temperature at different locations have been conducted. In data collection, the questionnaires were distributed to target employees totally 300 sets of 6 monitoring factories in 6 cities in Thailand including Bangkok, Pathumthani, Samutprakarn, Chachoengsao, Chonburi, and Rayong. 240 questionnaires of interview were distributed to general employees who worked in production area and 60 questionnaires of interview were distributed to managerial staff. The sample of questionnaire will be attached in appendix-A. The second part is measurements of the existing occupants' comfort factors in production area consisting of lighting illuminance of both ambient and task lights, noise level from manufacturing process, temperature between inside and outside the building, air velocity from natural ventilation in different locations of the work place and outside the building, and relative humidity at work place. Furthermore, the data was collected by observing the materials and performances of the monitored buildings to analyze thermal comfort of the buildings.

### **3.3.2 Background of Interviewees**

All 300 interviewees could be divided by gender into number of male, 204 persons and number of female, 96 persons. The age of interviewees is categorized; less than 26 years, 56 persons; 26-35 years, 185 persons; 36-45 years, 41 persons; 46-55 years, 14 persons; and more than 55 years, 4 persons. The position of interviewees is reviewed; temporary employees, 20 persons; general employees, 211 persons; chiefs, 41 persons; and managers, 28 persons. Lastly, the number of employees in each factory had been indicated that there are 503 employees of monitoring factory in Bangkok (BKK), 378 employees of monitoring factory in Pathumthani (PTT), 714 employees of monitoring factory in Samutprakarn (SMP), 452 employees of monitoring factory in Chachoengsao (CCS), 240 employees of monitoring factory in Chonburi (CBR), and 487 employees of monitoring factory in Rayong (RYG).

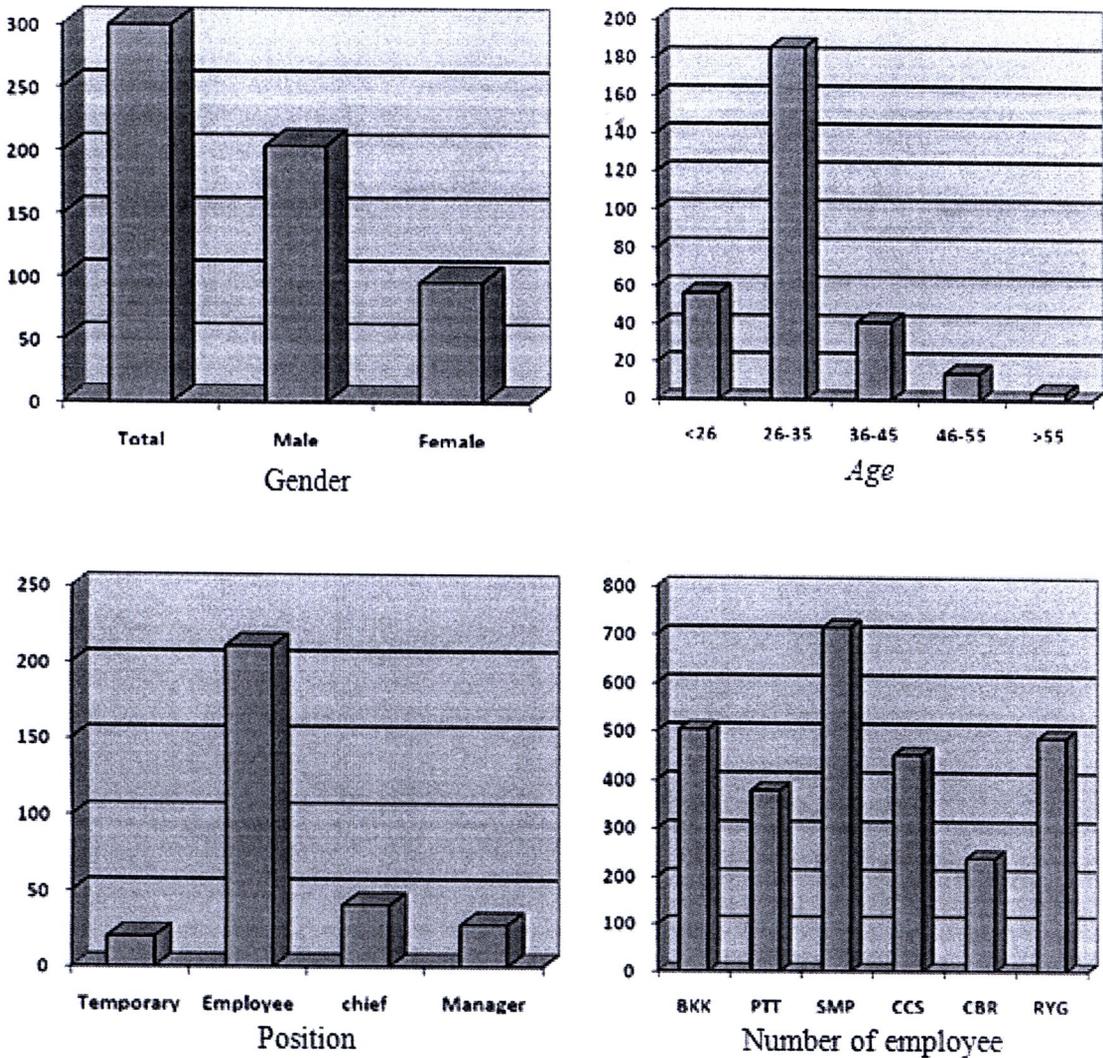


Figure 3.6 Background of the interviewees

### 3.3.3 Existing Building Materials

From existing building materials and performances of monitoring factories as shown in Table 3.1 considering with the result of existing environmental conditions on Table 4.3, it is exhibited that simply ventilation by natural wind is not enough to achieve thermal comfort because many factories used ventilation assisted by fan to increase air velocity in workplace and the other reason is some factories had located incorrect orientation. All of them are large buildings, thus the roof materials are more important than exterior wall. Many existing buildings selected metal sheet w/glass wool 25mm thick for roof materials.

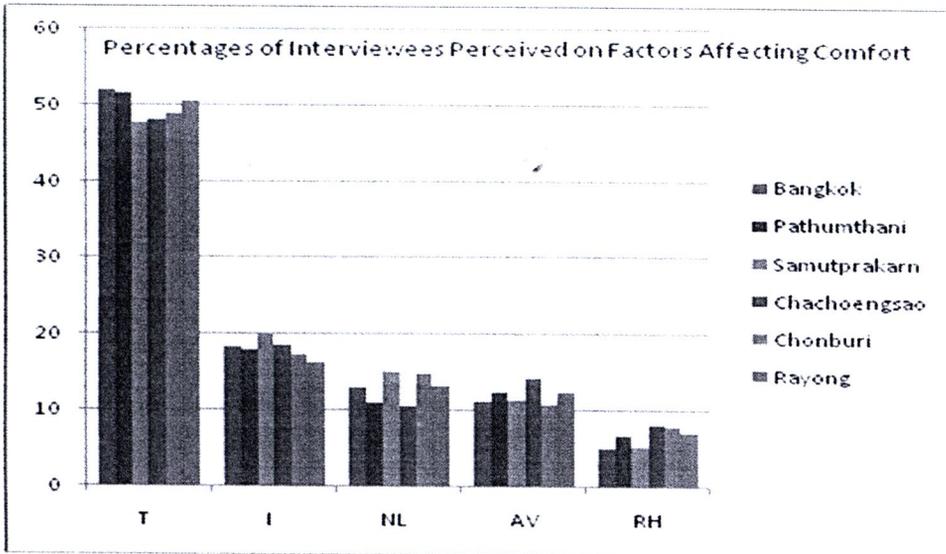
**Table 3.1** Existing building materials and performances of monitoring factories.

Location	Roof		Roof monitor area	Skylight			Ceiling	Wall		Opening ratio	Floor finish	Building size (W x L x H)	Building orientation	
	Material	U-value		Material	Visible transmittance	Thermal transmittance		Area	Material					U-value
Bangkok	metal sheet (aluminum) w/glass wool 25mm thick	0.26	N/A	Fiber glass (clear)	86%	73%	3.0%	N/A	CB glassed pane (white)	0.51	louver 9.7%	concrete tiled (light grey)	50m x 75m (1.1.5)	⊕ 
Pathumthani	metal sheet (aluminum)	0.9	N/A	Fiber glass (clear)	86%	73%	3.2%	N/A	metal sheet (aluminum) w/CB h-1m glassed pane (white)	1.18	louver 9.4%	hardwood on concrete (light grey)	50m x 100m (1.1.25)	⊕ 
Samutprakarn	metal sheet (aluminum)	0.9	N/A	Fiber glass (white)	45%	46%	2.5%	N/A	metal sheet (aluminum) w/CB h-1m glassed pane (white)	1.18	louver 10%	hardwood on concrete (green)	50m x 100m (1.2)	⊕ 
Chachoengsao	metal sheet (aluminum)	0.9	11.5%	Fiber glass (white)	45%	46%	3.4%	N/A	metal sheet (aluminum) w/CB h-1m glassed pane (grey)	1.18	louver 10.5%	hardwood on concrete (green)	90m x 120m (1.1.3)	⊕ 
Chonburi	metal sheet (aluminum)	0.9	10%	Fiber glass (white)	45%	46%	3.1%	N/A	metal sheet (aluminum) w/CB h-1m glassed pane (grey)	1.18	Minimum 1 w/od 9.2%	concrete tiled (green)	51m x 98m (1.1.6)	⊕ 
Rayong	metal sheet (aluminum) w/glass wool 25mm thick	0.26	5%	Fiber glass (white)	45%	46%	2.9%	N/A	metal sheet (aluminum) w/CB h-1m glassed pane (white)	1.18	louver 8.9%	hardwood on concrete (green)	40m x 60m (1.1.5)	⊕ 

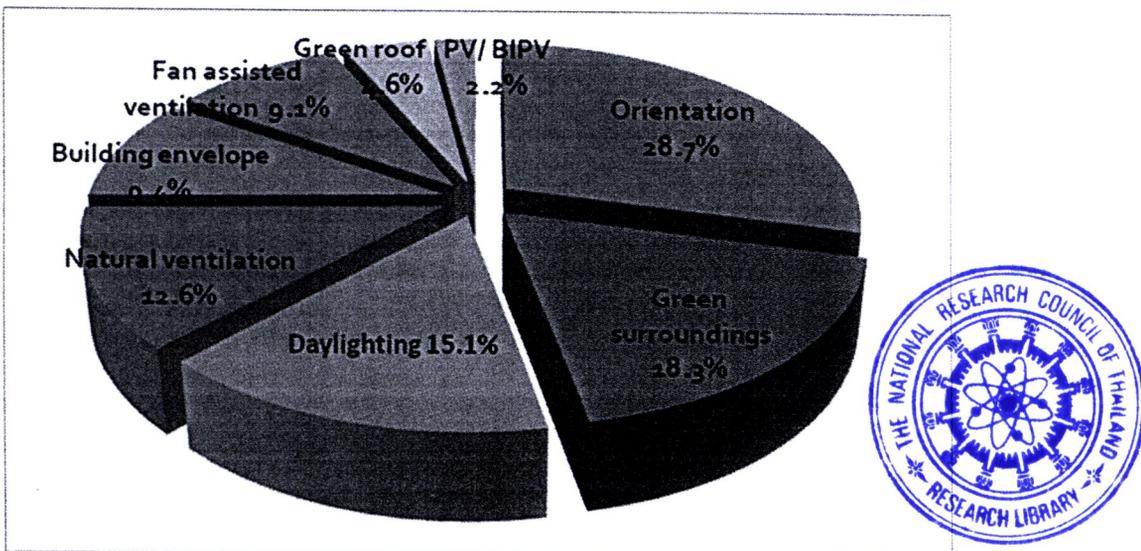
### 3.3.4 Results of Data Acquisition

The results of data acquisition from 300 questionnaires (240 questionnaires for operating employees and 60 questionnaires for managerial staffs) interviewing of 6 monitoring factories in 6 cities in Thailand including Bangkok, Pathumthani, Samutprakarn, Chachoengsao, Chonburi, and Rayong were indicated in the following.

The survey result of percentage of interviewees' agreement with design strategies and implementation for thermal comfort in monitoring factories from 300 interviewees in monitoring factories had indicated the most significant impacts on the occupants' comfort directly to their productivity was that 50% agreed with temperature (T), 19% agreed with illuminance level (I), 13% agreed with noise level (NL), 11% agreed with air velocity (AV), and 7% agreed with relative humidity (RH) respectively as shown in Figure 3.7.

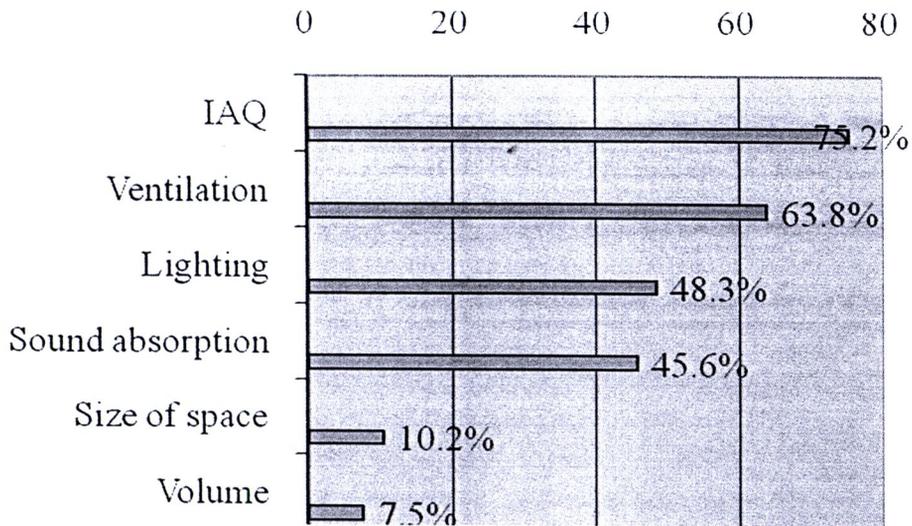


**Figure 3.7** Survey result of occupants' comfort impact directly to productivity of monitoring factories in 6 cities in Thailand.



**Figure 3.8** Survey result of percentage of interviewees' agreement on design strategies and implementation for thermal comfort in 6 monitoring factories.

Moreover, survey result of the design strategies implementation for thermal comfort exhibited that the occupants, favored of mostly the basic strategies with less investment, preferred strategies from good orientation, improvement in green surroundings, daylighting, and natural ventilation accordingly. The advanced strategies with more investment, such as outperformed building envelope, fan assisted ventilation, green roof, and PV/ BIPV installation are less preferred options respectively as shown in Figure 3.8. The interviewees had mainly understood the situation of the global warming. They thought that optimum environment such as aesthetic, temperature, lighting, noise level and air velocity could encourage them to increase more productivity.



**Figure 3.9** Survey results of discomfort conditions that should be improved in interviewees' attitude.

Approximate 50% of interviewees required the improvement of some of their environments and outperformed workplace from survey result of discomfort conditions in interviewees' attitude. In depth, most of them preferred improving IAQ (Indoor Air Quality), subordinating to ventilation, lighting and sound absorption respectively as shown in Figure 3.9 that should be improved for better working, whilst size of space and volume in work places were not significantly preferable. It was found that although there was a good potential to introduce natural ventilation, there was a problem of rain associated with the wind. In the tropical climate like Thailand, average rainy season is approximately 3-4 months which is significant in design and operation decision. Most manufactures decided to close louver to protect their interior buildings from the rain. There is a need in a wall design that can provide natural ventilation while protecting rain in order to use natural ventilation rather than additional active systems. With respect to sound, from observation, wall, floor and roof materials are hard surfaces such as aluminum sheet, metal sheet and concrete floor. A problem occurred on sound reflections from machines and rain resulting in difficulty in hearing among them.

### 3.3.5 Results of Measurement

The results of data acquisition from 300 questionnaires (240 questionnaires for operating employees and 60 questionnaires for managerial staffs) interviewing 6 monitoring factories in 6 cities in Thailand including Bangkok, Pathumthani, Samutprakarn, Chachoengsao, Chonburi, and Rayong were indicated in the following table. Half of them are typical factories that can be found generally in many parts of Thailand recently. And the other half of them are casting factories that have heat-generated system inside the buildings by production or machine such as furnace area where can generate heat towards 1,400°C at melting process. The human factors that affect to occupants' comfort including temperature, relative humidity, air velocity, illuminance level, and noise level that had been measured.

**Table 3.2** Survey results of average existing thermal comfort conditions of monitoring factories from 6 cities in Thailand measured in December

Location	Factory type	$T_{in}$ (°C)	$T_{out}$ (°C)	$T_{i/r}$ (°C)	$T_{e/r}$ (°C)	$T_{i/w}$ (°C)	$T_{e/w}$ (°C)	$AV_{in}$ (m/s)	$AV_{out}$ (m/s)	$AV_{fan}$ (m/s)	$RH_{in}$ (%)	$RH_{out}$ (%)
Bangkok	Typical	30.1	31.4	35.4	41.7	34.7	35.1	0.2	3.8	N/A	52.1	47.8
Pathumthani	Typical	30.7	32.2	37.1	40.5	35.8	36.7	0.2	3.7	0.5~1.0	50.8	47.2
Samutprakarn	Typical	31.6	32.8	36.9	40.1	35.6	36.3	0.4	6.7	N/A	48.3	42.5
Chachoengsao	Casting	32.9	34.3	40.1	43.2	37.7	38.5	0.1	1.5	1.0~1.2	43.2	41.2
Chonburi	Casting	32.5	32.8	44.7	45.9	38.3	39.8	0.3	4.1	1.2~2.2	50.2	45.0
Rayong	Casting	30.6	31.7	38.4	44.1	36.5	37.6	0.2	3.9	N/A	44.1	41.7

The survey result of existing environmental conditions of monitoring factories in Thailand measured in December as shown in Table 3.2 had revealed that the average temperature inside the buildings ( $T_{in}$ ) is little lower than average temperature outside the buildings ( $T_{out}$ ) around 1.2~2.4 °C, average at 1.8 °C. The average temperature of interior surface roof ( $T_{i/r}$ ) is lower than average temperature of exterior surface roof ( $T_{o/r}$ ) around 3.2~3.9, average at 3.5 °C, except the factory from Chonburi which is more than that of exterior surface roof because there is furnace area beneath the measured area that generated heat rather than other factories. The average temperatures of interior and exterior roofs ( $T_{i/r}$ ,  $T_{e/r}$ ) are higher than that of interior and exterior walls ( $T_{i/w}$ ,  $T_{e/w}$ ) due to exposure time of the sun. The relative humidity (RH) is measured with an average at 48.1%. The air velocity inside the buildings ( $AV_{in}$ ) is greatly different from air velocity outside the buildings ( $AV_{out}$ ) in average 3.7 m/s. Comparing with the standard of comfort condition under various air velocities for Thailand studied by Khedari et. al as shown in Table 3.3, average temperature 30.7~32.5 °C at 20~80% RH and air velocity 0.5~1 m/s should be appropriate. Air velocity of fan assisted ( $AV_{fan}$ ) can reduce temperature at workplace particularly at furnace area in heat-generated factories. In addition, the more thermal comfort is improved, the more IAQ of the factories as the survey result has been improved due to increasing air velocity will also assist ventilation.

**Table 3.3** Comfort condition for Thailand by Khedari (left) and lighting illumination comfort of Thai regulation (right).

T (°c)	RH (%)	AV (m/s)	Lighting illumination (Lx)	
22.0-29.5	20-80	0-0.25	Corridor	50
29.5-30.7	20-80	0.25-0.5	Warehouse	200
30.7-32.5	20-80	0.5-1.0	Packing	300
32.5-34.0	20-80	1.0-1.5	Office, assembly	400
34.0-36.0	20-80	1.5-2.0	QC	600
36.0-36.5	20-80	2.0-3.0	Accuracy test	1200

The average illuminance level of ambient light ( $I_{am}$ ) for these industrial buildings at common area in 6 monitoring factories is 254.5 Lx from average skylight areas, 3.01% of roof areas, definitely enough comparing with Thai regulation about function of corridor (50 Lx) and warehouse (200 Lx), and the Lighting illumination of task light ( $I_{ta}$ ) at workplaces in 6 monitoring factories of average 501 Lx from artificial light is enough, comparing with Thai regulation about function of assembly (400 Lx).

**Table 3.4** Existing condition of average lighting illumination under partly cloudy sky in 6 points of each monitoring factory.

Location	Factory type	$I_{am}$ (Lx)	$I_{ta}$ (Lx)
<b>Bangkok</b>	typical	270	514
<b>Pathumthani</b>	typical	267	521
<b>Samutprakarn</b>	typical	240	498
<b>Chachoengsao</b>	Casting	252	504
<b>Chonburi</b>	Casting	260	480
<b>Rayong</b>	Casting	238	489

All noise levels of existing state in monitoring factories do not exceed noise threshold of Thai regulation at 87 dB during 12 hrs, but they do exceed Equivalent Continuous Sound Level ( $L_{eq}$ ) (24 hrs) limited in 70 dB that may cause to hearing loss effect [USEPA, 2005]. Noise levels in monitoring factories should be improved by using outperformed materials. In facts, many factories protect their employees by using ear-plug or limiting their working time for this work activity.

**Table 3.5** Existing condition of noise level (left) and Thai noise threshold in monitoring factories (right).

Location	Factory type	NL (dB)	Working time		Leq (24hrs)
			NL(dB)	(hrs)	
Bangkok	typical	77.5	87	12	70
Pathumthani	typical	71.2	90	8	
Samutprakarn	typical	78.6	92	6	
Chachoengsao	Casting	73.7	95	4	
Chonburi	Casting	79.4	97	3	
Rayong	Casting	79.1	100	2	

### 3.4 Analysis of Data Acquisition

The acquisition data of industrial buildings in Thailand was revealed that the building environments had not been absolutely comfort condition; acoustical, visual, and thermal comfort for people who had been working in those buildings yet. The acoustics from production line is a problem that disturbed the employees, roof insulation can protect outside heat from the sun rather than roof without insulation 1.5~2 times and can improve this acoustics problem. Daylighting level from skylights is definitely enough comparing with Thai regulation, perhaps it is needed to reduce lighting level a bit by balancing the area of skylight and overall roof area. Acoustical and visual comfort can be improved by reducing ambient noise level with outperformed materials and building height design, as well as increasing ambient light level by designing and specifying proper materials with reducing exceeding skylight area to extenuate direct heat from the sun. Potential of outperformed thermal comfort can be achieved by maximizing human comfort in passive design such as designing building envelope to increase air velocity inside the buildings, since there is more than enough wind velocity from surrounding areas as shown in Table 3.2. Air velocities inside and outside ( $AV_{in}$ ,  $AV_{out}$ ) the buildings are much different in each factory due to machine obstruction and typical opening design, there is potential for developing to achieve human comfort. Relative humidity inside and outside ( $RH_{in}$ ,  $RH_{out}$ ) the buildings is rarely different; it is proper to comfort condition for Thailand. However, to apply natural ventilation, outdoor ambient temperature must be naturally treated to be as low as possible by green surrounding such as big trees, lawn, and pond. Moreover, another potential achieving thermal comfort in a passive way is to reduce mean radiant temperature (MRT) done by reducing temperature of roof and wall surfaces due to a great impact on thermal comfort. The more thermal comfort is improved, the more IAQ

of the industrial buildings as the survey result has been improved due to increasing air velocity will also assist ventilation. The thermal comfort conditions in steady state studied by the West such as ASHRAE-55, Olgyay, and Givoni are not proper to Thailand. Comparing with thermal comfort conditions in adaptive state studied by Khedari and by Jitkhajornwanich at temperature 25.6-31.5°C and RH 20-90% for air velocity 0.2-1 m/s, are more proper for Thailand climate.

On the contrary, potential of outperformed thermal comfort can also be achieved by minimizing energy use such as increasing air velocity inside the buildings optionally by fan assisted, increasing use of high effective machines and equipments, and increasing opening for natural ventilation flow. In addition, restraining task light level by separating working area from common area in production area is a significant method to minimize energy use in conventional industrial buildings.

### **3.5 Hypothesizing of the Experiment**

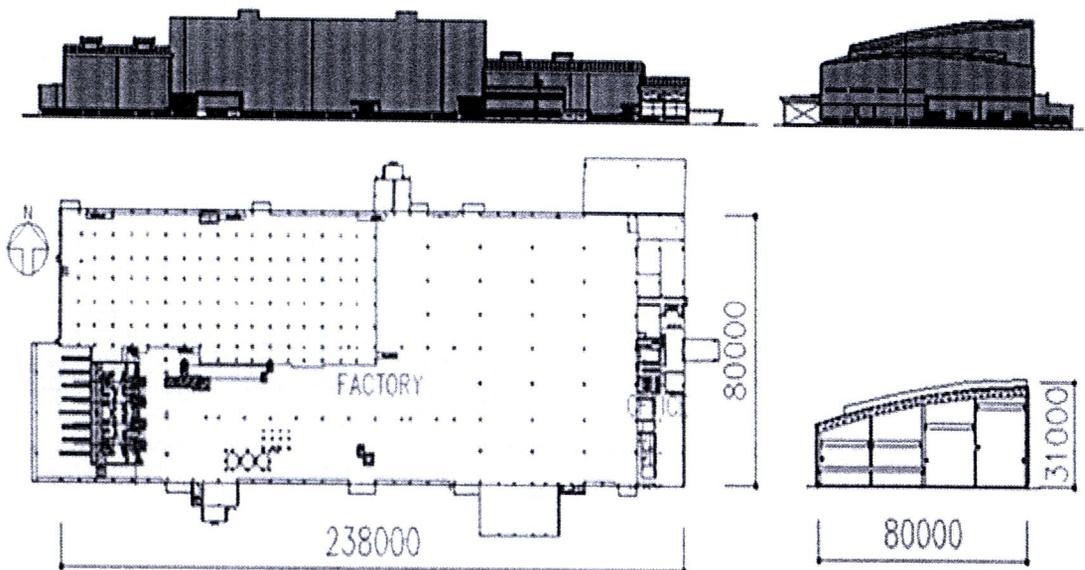
According to the theories and hypothesis of previous chapter, hypothesizing of this research is designated by demonstrating experimental design for the model of industrial building appropriate to tropical climate of Thailand, concurrently with data acquisition and measurements of the actual industrial buildings. Simulating their building performances to compare the results between experimental design and actual model of industrial buildings is a further proceeding of the research in order to analyze the potential of thermal comfort in these portions. Hypothesis of integrated design strategies is applied for an integrated study model differently from conventional industrial buildings. In this research, the hypotheses of integrated design strategies in maximized passive design are investigated by comparing with the conventional factories wall opening design to increase the air velocity and protect splash rain from rainy wind, roof monitor design to ventilate heat from production process in the building and open the indirect daylight into the building, and roof insulation to reduce MRT from great daily exposure of roof. Minimized active design (Lai, 2005) such as fan assisted ventilation, photovoltaic and BIPV for energy efficiency of industrial buildings in tropical climate will also be investigated in further research. The parameters of the experimental model derived from data acquisition composed of temperature inside and outside of the buildings, relative humidity, and air velocity in working location, as well as lighting illumination of both ambient and task lights will be investigated. Approach to the strategies does not only focus on minimizing energy consumption, but also has to focus on factors that contribute to perceived comfort.

### **3.6 Experimental Model of Industrial Buildings**

The study model of industrial buildings is modified from the actual concept design of a new factory project which had been designed and currently been constructed. Eliminating some actual parameters of the restraints, such as inflexible budget and returned payment period, is requisite for the experiment.

### 3.6.1 Conventional Base Case

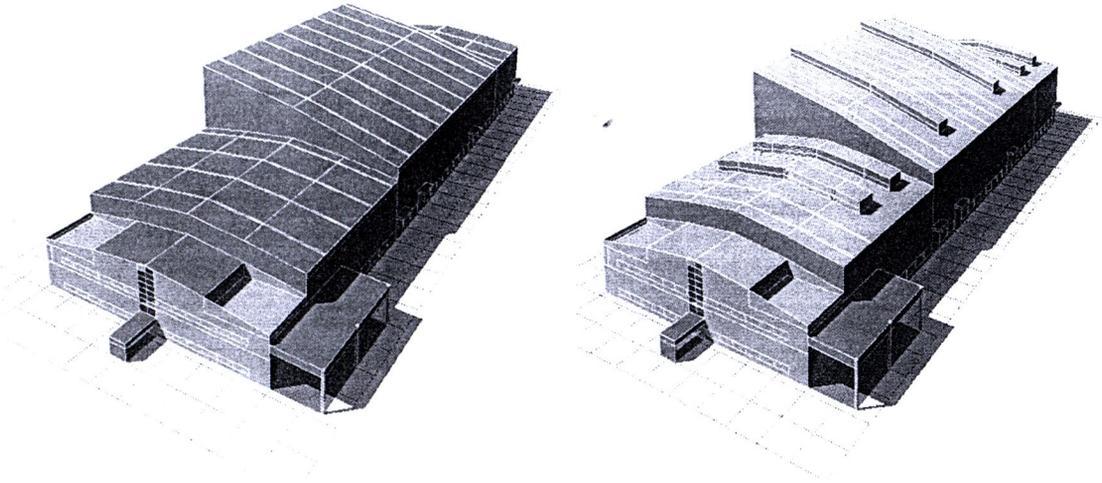
Integrated design model is taken into account that the mentioned building, constructed of sheet metal as shown in Figure 1, has a floor area of 18,050 m<sup>2</sup> and an internal volume of 38,2980 m<sup>3</sup> excluding office area which is not of passive design. The building occupied by 500 people is operated between 08:00 am and 20:00 pm. It contains high interior mass and a total electrical load of 20,000 kWh due to lighting and machines. The louvers and horizontal voids along the north, south and west walls, with a total opening area of 1,805 m<sup>2</sup> (10% of total floor area in consideration of Thai regulation) were used. The roof is equipped with roof monitors used for stack ventilation due to its height of 16m, 18m, and 31 m accordingly and with proposed area of skylights that affects illuminance level. In addition, roof and wall material and height will be proposed and investigated to improve surface temperature, wind velocity and acoustic parameters such as sound level and reverberation time. Finally, the total energy consumption will be compared.



**Figure 3.10** Schematic representative of integrated design model in case of the study.

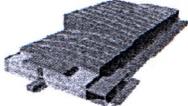
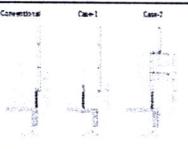
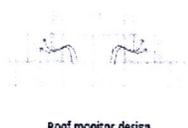
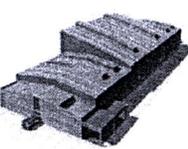
### 3.6.2 Experimental Design Cases

After setting up attributes of conventional case as a base case, the attributes in various cases in simulating experiments were changed to probe the roof monitor 13% of roof area in order to increase air velocity by stack ventilation in the middle area of the building. Installing glass wool 25mm to protect heat gain, reducing skylight area from 3.8% to 3% of roof area due to there is enough lighting from measurement of skylight, and designing horizontal voids of wall instead of louver 10% of floor area are potentials of improvement in achieving human comfort. The comparison of the images of simulating experiments between base case and integrated case will be indicated in Figure 3.11, and the comparison of experiment cases in various attributes of base case and another 4 cases of the experimental design will be shown in Table 3.8.



**Figure 3.11** Comparison of images of simulating experiments between base case and integrated case.

**Table 3.6** Comparison of proposed design experiment cases in various attributes.

Experiment	Roof	Roof monitor	Skylight	Ceiling	Wall	Opening	Floor	Image
<b>Base case:</b> Conventional	Metal sheet ( $U=0.9$ )	N/A	3.8% of roof area	N/A	Metal sheet w/CB mortar	Louver 10%	Hardener on concrete	
<b>Case-1:</b> Conventional Wall opening design	Metal sheet ( $U=0.9$ )	N/A	3.8% of roof area	N/A	Metal sheet w/VB mortar	Horizontal voids 10%	Hardener on concrete	
<b>Case-2:</b> Conventional Roof monitor design	Metal sheet ( $U=0.9$ )	13% of roof area	3% of roof area	N/A	Metal sheet w/CB mortar	Louver 10%	Hardener on concrete	 Roof monitor design
<b>Case-3:</b> Conventional Roof insulation	Metal sheet w/glasswool $t=25$ ( $U=0.26$ )	N/A	3.8% of roof area	N/A	Metal sheet w/CB mortar	Louver 10%	Hardener on concrete	 Roof insulation
<b>Case-4:</b> Conventional Opening Roof monitor Roof Insulation	Metal sheet w/glasswool $t=25$ ( $U=0.26$ )	13% of roof area	3% of roof area	N/A	Metal sheet w/VB mortar	Horizontal voids 10%	Hardener on concrete	

### 3.7 Calibrated Simulations of Study Model

The thermal comfort of study model has been investigated by the simulation tool of Autodesk Ecotect 2010 application that can help analytical approach in energy-efficient

design of the building performances of the strategies and the other simulation to investigate the air velocity in and around buildings is Flovent application.

**Ecotect** is the comprehensive and innovative building analysis software for various levels of simplicity or complexity even with the most basic massing model. A designer, who may be unfamiliar with the complexities of environmental analysis, can learn and begin to understand the environmental effects of the design decisions they make. Integration of energy efficient and sustainable design practices with the core of design processes is the key goal of the program. It provides a wide range of simulation and analysis functionality for visualizing and simulating performance of a study model within the context of the environment such as energy analysis, visual impact, solar analysis, shadows and reflection simulation, daylighting analysis, ventilation and airflow analysis, thermal analysis, acoustic analysis, photovoltaic array, carbon emission reporting, water usage and cost evaluation. Material information and assignment are important for this simulation tool. In this research, it has applied the environmental analysis and simulation of this software as follows;

**Energy Analysis:** to calculate the total energy use of the building model on an annual, monthly, daily, and hourly basis.

**Solar analysis:** to visualize incident solar radiation on windows and surfaces, showing differential incident solar radiation calculated over the period.

**Shadows and Reflections Simulation:** to display the sun's position and the path related to the model at the date, time, and location. As well as to view how sunlight enters through windows and moves around within a space.

**Daylighting Analysis:** to calculate daylight factors and illuminance levels at the point in model or over the analysis grid, in order to help determine potential savings due to daylight-linked lighting design.

**Thermal Analysis:** to calculate heating and sensible cooling loads for models with the zones or types of geometry, and analyze effects of occupancy, internal gains, infiltration, and equipment items.

**Shading Design:** to help design shading devices to meet complex shading requirements, it can also generate a shape to optimally shade a window for any specified period. Cutting planes will be generated following the path of the sun in order to cut profiles and produce site solar envelopes.

**Acoustic Analysis:** to generate options in range from simple statistical reverberation times to sophisticated particle analysis and ray tracing techniques, acoustic analysis is used.

**FloVENT** is the other simulation tool used in the research for airflow modeling analysis in and around building. It is Computational Fluid Dynamics (CFD) software which predicts 3D airflow, heat transfer and contamination distribution and comfort indices in both internal and external environments. In this research, it is applied for the airflow and natural ventilation analysis as well as simulation of this software to generate geometry and analysis grids and export them directly into other computational fluid dynamics (CFD) tools to calculate for display within the context of the original model.

Lastly, airflow both through and around buildings and complex urban environments is calculated, in order to compare the value of airflow when changing building envelope design of the ventilation opening. It is applied for the environmental analysis and simulation of this software as follows;

*Airflow Analysis: to demonstrate airflow representation by vectors or ribbons colored by temperature or speed. Airflow modeling consultancy can run effective simulations for the inside of the buildings and determine the comfort levels of the occupancies.*

*External Airflow Analysis: to model airflow around buildings and check the design requirements that can be important for many reasons, such as pedestrian comfort or contaminant dispersal.*

*Thermal Analysis: to analyze air temperature and surface temperatures as well as concurrent solution for convective, conductive and radiant heat transfer. Calculation of radiation exchange, view factor, and solar loading boundary will be made more understanding in thermal conditions.*