THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Master of Engineering (Environmental Engineering)

DEGREE

Environmental Engineering — **FIELD**

Environmental Engineering — **DEPARTMENT**

TITLE: Application of ISC-AERMOD Program for Evaluation of Air Pollutant Dispersion in Siriraj Hospital

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THESIS

APPLICATION OF ISC-AERMOD PROGRAM FOR EVALUATION OF AIR POLLUTANT DISPERSION IN SIRIRAJ HOSPITAL

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A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Engineering (Environmental Engineering)
Graduate School, Kasetsart University
2008

Komsak Rattanapirom 2008: Application of ISC-AERMOD Program for Evaluation of Air Pollutant Dispersion in Siriraj Hospital. Master of Engineering (Environmental Engineering), Major Field: Environmental Engineering, Department of Environmental Engineering. Thesis Advisor: Assistant Professor Narumol Vongthanasunthorn, D.Eng. 115 pages.

This research was to determine the direction of sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and carbon monoxide (CO) dispersion and their concentrations from the boiler stack at Siriraj Hospital by using ISC-AERMOD program. The SO_2, NO_2 and CO concentrations in the atmosphere and from the mobile sources surrounding Siriraj Hospital were also determined and used as the background concentrations for evaluating the values of their maximum concentrations in order to compare with the ambient air quality standard in Thailand. The prediction results from the stack revealed that the annual dispersion of SO_2, NO_2 and CO was directed from western to eastern of the hospital area. Also, the maximum average concentration of SO_2 for 1hr, 24hr and yearly, NO_2 for 1 hr, CO for 1hr and 8 hr were 110.401 $\mu g/m^3$, 20.085 $\mu g/m^3$, 8.297 $\mu g/m^3$, 7.233 $\mu g/m^3$, 0.205 $\mu g/m^3$, and 0.034 $\mu g/m^3$, respectively. The results showed that the maximum background average concentration of SO_2 for 1hr, 24hr and yearly, NO_2 for 1 hr, CO for 1hr and 8 hr were 28.913 $\mu g/m^3$, 28.853 $\mu g/m^3$, 28.825 $\mu g/m^3$, 111.975 $\mu g/m^3$, 2,513.508 $\mu g/m^3$; 2,442.821 $\mu g/m^3$, respectively.

As included the background and predicted maximum average concentrations for SO_2 for 1hr, 24hr and yearly, NO_2 for 1 hr, CO for 1hr and 8 hr, it was found that their maximum concentrations were 138.898 $\mu g/m^3$, 48.895 $\mu g/m^3$, 37.096 $\mu g/m^3$, 118.997 $\mu g/m^3$, 2,513.713 $\mu g/m^3$; 2,442.855 $\mu g/m^3$, respectively. As compared to the ambient air quality standards in Thailand, these concentrations are acceptable and have a slight effect on human health.

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Student's signature Thesis Advisor's signature

ACKNOWLEDGMENTS

First, I would like to grateful thank and deeply indebted to Assistant Professor Dr. Narumol Vongthanasunthorn, and Dr. Suchart Leungprasert, my thesis advisor and thesis co-advisor for advice, encouragement and valuable suggestion for completely writing of thesis. I gratefully Assistant Professor Dr. Surat Boulert, General Science Department, Faculty of Science, Chulalongkorn University for suggestion and supported for ISC-AERMOD program license in this research.

The meteorological and hourly air quality data used in this research was supported by Air Quality and Noise Management Bureau of Pollution Control Department, Thailand and I would like to thank Dr. Vanisa Surapipith for suggestion about the meteorological data for using in this research.

I would like to sincerely thank the Siriraj Hospital staffs for giving the boiler data. Also, I am heartfelt to my friends in Siriraj Hospital office, Environmental Engineering Program, Kasetsart University and General Science Department, Chulalongkorn University for their help in many ways.

I am thankful to Assist. Prof. Doctor Visit Vamvanij, Deputy Dean of the Faculty of Medicine, Siriraj Hospital and Doctor Luecha Boontaveekul for encouragements and supports for my work and my education. Finally, I am especially appreciated my parents, my aunt, my sisters for their continuing encouragements and supported expense in this education.

Komsak Rattnapirom

September 2008

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LIST OF ABBREVIATIONS

AERMIC	=	American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee
ARM	=	Ambient Ratio Method
BH	=	Building Height
BPIP	=	Building Profile Input Program
CCTV	=	Closed Circuit Television System
CO	=	Carbon monoxide
ENV	=	Environment
FSL	=	Forecast Systems Laboratory
GEP	=	Good Engineering Practice
HA	=	Hospital Accreditation
HC	=	Hydrocarbon
ISCST	=	Industrial Source Complex-Short Term
NO_2	=	Nitrogen Dioxide
NO_X	=	Nitrogen Oxide
O_3	=	Ozone
PBW	=	Project Building Width
Pb	=	Lead
PC	=	Personal Computer
PCD	=	Pollution Control Department
PM	=	Particulate Matter
ppm	=	Part per million
PRIME	=	Plume Rise Model Enchantments
PTT	=	Petroleum Authority of Thailand
SAMSON	=	Solar and Meteorological Surface Observational Network
SO_2	=	Sulfur Dioxide
STP	=	Standard Temperature (25°C) and Pressure (1atm)
UK	=	United Kingdom
USA	=	United Stage
US.EPA	=	United Stage. Environmental Protection Agency

LIST OF ABBREVIATIONS (Continued)

UNEP	=	United Nation Environmental Program
VOC	=	Volatile Organic Compound
WHO	=	World Health Organization

APPLICATION OF ISC-AERMOD PROGRAM FOR EVALUATION OF AIR POLLUTANT DISPERSION IN SIRIRAJ HOSPITAL

INTRODUCTION

Currently air pollution is one of the most important problems in Thailand for industries, households and surrounding areas. Air pollutants such as SO_2, NO_2 and CO are very harmful to human, animal and plant.

Hospital is the sensitive area for taking care of patients. Moreover, several chemicals and substances are used in this place for patient treatment, medical tool sterilization and performance of experiments in a laboratory. In addition, residual oil is used as fuel in a steam boiler resulting in releasing of air pollutants to the environment.

A majority of the air pollution in Siriraj Hospital comes from several sources such as formaldehyde from the pathology laboratory, glutaraldehyde from sterilized medical tools and inorganic substance (sulfur dioxide, carbon dioxide, nitrogen oxide) from fuel oil used in the boiler. These pollutants adversely affect human health.

Measurement of air pollution dispersion on the environment is difficult, complicated and expensive. Therefore, air dispersion model is an easy way used for simulation and assessment of directions and concentrations of air pollutants exposure to the environment.

The Hospital Accreditation (HA) is a standard for hospital, which is based on the patient safety and on the unexpected adverse events. The Environment for Health Promotion and Environment Protection (ENV 3) provide a regulation for “the organization demonstrates its commitment for the hospital to be a healthy and safe workplace, to support health promotion activities and to protect the environment”

(The Institute of Hospital Quality Improvement and Accreditation, 2006). As a result, the Siriraj Hospital must protect and improve environment by estimating the hospital waste that may affect on humans or communities.

To correspond with HA standard, it is necessary to predict air pollution dispersion and concentration in a hospital. This research aims to study and to assess the air pollutants exposure to the environment of the Siriraj Hospital by using ISC-AERMOD dispersion modeling in order to predict the concentration at different place.

OBJECTIVES

1. To determine the major sources of air pollutants and their concentrations from Siriraj Hospital exposure to the environment.

2. To simulate the dispersion and concentration of each air pollutant for the average 1-hour, 8-hour, 24-hour and annual using ISC-AERMOD model.

Scope of this study

This study was focused on the concentration of formaldehyde pollutant from a laboratory and SO_2, CO and NO_X from boiler and their background concentrations in Siriraj Hospital area. Then air dispersion model of ISC-AERMOD View (Recommended by US.EPA) was used to calculate the concentration of their pollutants at difference location. The average time was calculated by AERMOD model for 1 hr, 8 hr, 24 hr and 1 year, respectively. The impact of air pollutant was done by comparing with the Ambient Air Quality Standard of Thailand.

LITERATURE REVIEW

1. Air pollution

Air pollution is air condition that of undesirable material is present in air with large quantities and long time enough to cause harmful. The undesirable materials may damage human health, vegetation, animal and global environment. Those substances are probably an element or a compound occurring from natural or human activity. It is in the form of gas, liquid drop or particle. The major of air pollution includes particulate matter, lead (Pb), Carbon Monoxide (CO), Sulfur Dioxide (SO_2), Nitrogen Oxide (NO_X) and Ozone (O_3) (Noel de Nevers, 2000).

1.1 Air Pollution System

Air pollution system consists of 3 parts including emission source, atmosphere and receptor. Emission Source is the source of air pollution that is exposure to environment by type and amount of air pollutant released to the environment. Atmosphere is the system that supports air pollutant from the source and medium for the dispersion direction. The meteorological factor is the effect of characteristic of air pollutant dispersion such as temperature, wind speed, wind direction and topography. Receptor is the system that contacts with air pollutant and harmful to human, animal and other material. The damage or effect of air pollutants depends on high or low concentration and contact time. The composition of air pollutant system is shown in Figure 1 (Noel de Nevers, 2000)

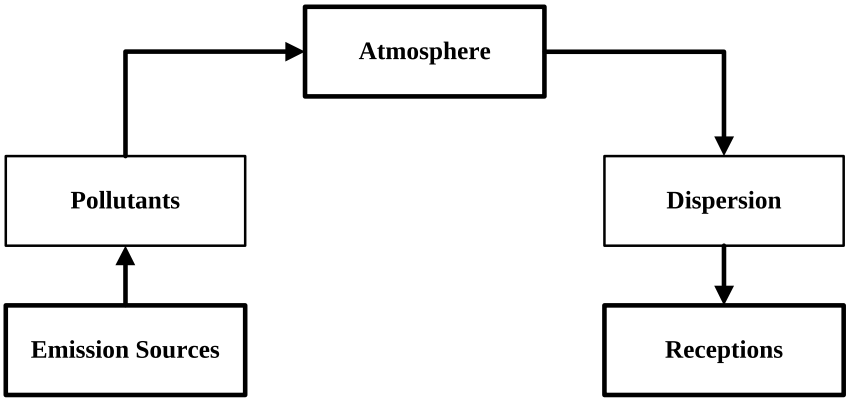

Figure 1 The air pollution system.

1.2 Sources of Air Pollution

The sources of air pollutants are separated to 2 types. The first source is the air pollutants from natural source such as wildfire, volcano explosion, etc. The second source is from human activity and can be separated into 2 types: mobile source and stationary source.

a) Mobile Source

The air pollution from motor vehicles is a large contributor and a serious problem in many large cities (WHO, 1994). Contributing to this problem is sulfur dioxide (SO_2), nitrogen oxide (NO_X) and carbon monoxide (CO), which is emitted as a byproduct of incomplete combustion of carbonaceous fuels (e.g., gasoline, diesel). The vehicles are normally classified in to 3 main engines which are Gasoline – Two Stroke Engine, Gasoline – Four Stroke Engine and Diesel Engine. These emissions contribute greatly to the air and are the primary cause of air pollution in many urban areas.

On-road or highway sources mean the vehicles used on roads for transportation of passengers or freight. On-road sources are further distinguished by size, weight, use, and horsepower. On-road vehicles are category of mobile sources includes light-duty vehicles, light-duty trucks, heavy-duty vehicles, and motorcycles, used for transportation on the road. On-road vehicles may be fueled with gasoline, diesel fuel, or alternative fuels such as alcohol or natural gas. The emission from mobile source in Bangkok was shown in Table 1.

Table 1 The emission load from mobile source in Bangkok in 1997.

Vehicle Types	Emission Load (ton/year)				
	SO_2	CO	NO_X	HC	PM
Motorcycle	786	112,308	976	163,677	2,871
Gasoline	4,250	134,311	34,133	35,886	701
Light Duty Diesel	1,679	34,821	65,836	15,739	6,366
Heavy Duty Diesel	3,068	68,311	163,703	17,671	10,663
Total	9,784	349,771	264,648	232,973	20,602

Remark: HC = Hydrocarbon, PM = Particulate matter
Source: Warapetcharayut (2004)

b) Stationary Source

The stationary source is the source that is not mobile such as industry or power plant, which air pollutant comes from their used fuel and comes from the production process (Department of Industrial Works, 2004). The combustion process of steam boiler causes SO_2, NO_X, CO and particulate matter emission.

(1) Steam Boiler

In this research a steam boiler in the Siriraj Hospital was interested. A boiler is a closed vessel in which water or other fluid is heated. The heated or vaporized fluid from the boiler is used in various processes or heating applications. The energy source for the boiler comes from several fuels such as wood, coal, oil, or natural gas.

(a) Boiler Oil

The Fuel oils burner uses the heavier petroleum products that are less volatile than gasoline. The boilers are divided into two classes: distillate and residual. A standard specification for five grades of fuel oil intended to use in different types of fuel-oil burning equipment under various climatic and operating conditions. The various grade numbers of fuel oils are listed in Appendix A. The important emission from fuel oil burner is sulfur dioxide because sulfur is the content in fuel oil and product of combustion. The sulfur content of fuel oil is shown in Appendix A.

2. Effect of Air Pollution

Air pollution may cause various effects depending upon the level of emission and type of emitted pollutants into the atmosphere, length of exposure and extent of interaction among pollutant. The costs of air pollutant in terms of damage to human health, vegetation and building and of reduced visibility are perceived as a serious problem in many developing countries (Gwilliam *et al*., 2004).

The air pollution principally affects the respiratory, circulatory and olfactory system (Boubel *et al*., 1994) UNEP & WHO (1944) reported that the adverse effects to human health can be occurred by direct inhalation and indirect exposure routes. The impact of air pollutants on human health are often assessed by dose-response relationships which provide information about the increase in premature mortality and different types of hospital records and ambient pollution data. The specific air pollutants and associated health effects are shown in Table 2.

Table 2 The Specific air pollutants and associated health effect.

Pollutants	Effects
CO	• Reduction in the ability of the circulatory system to transport O_2 • Impairment of performance on tasks requiring vigilance • Aggravation of cardiovascular disease
NO_2	• Increased susceptibility to respiratory pathogens
O_3	• Decrement in pulmonary function • Coughing chest discomfort • Increased asthma attacks
Lead (Pb)	• Neurocognitive and neromotor impairment • Heme synthesis and hematological alterations
Peroxyacyl nitrates, aldehydes	• Eye irritation
SO_2/PM	• Increased prevalence of chronic respiratory disease • Increase risk of acute respiratory disease
Odor	• Nausea, vomit, headache • Introduction of shallow breathing and coughing • Upsetting of sleep, stomach and appetite • Irritation of the eyes, nose and throat • Destruction of sense of well-being and enjoyment of food • Disturbance, annoyance and depression

Source: Sothea (2007)

3. Ambient Air Quality Standard

The Pollution Control Department (PCD) sets the primary ambient air quality standards for commonly occurring air pollutants that pose public health threats. These pollutants are known as criteria pollutants. Currently, PCD exist for six criteria pollutants-ground level ozone, Particulate Matter (PM), carbon monoxide, sulfur dioxide, lead and nitrogen dioxide. The ambient air quality standards are defined as the levels of air quality protect the public health and protect the public welfare from any known or anticipated adverse effects. The ambient air quality standard of Thailand is shown in Table 3.

Table 3 The Ambient Air Quality Standard of Thailand.

Pollutant	Average	Standard
1. Carbonmonoxide (CO)	1 hr 8 hr	Not exceed 30 ppm. (34.2 mg/m^3) Not exceed 9 ppm. (10.26 mg/m^3)
2. Nitrogen Dioxide (NO_2)	1 hr	Not exceed 0.17 ppm. (0.32 mg/m^3)
3. Ozone (O_3)	1 hr 8 hr	Not Exceed 0.10 ppm. (0.20 mg/m^3) Not Exceed 0.07 ppm. (0.14 mg/m^3)
4. Sulfur Dioxide[a] (SO_2)	1 year 24 hr 1 hr	Not exceed 0.04 ppm. (0.10 mg/m^3) Not exceed 0.12 ppm.(0.30 mg/m^3) Not exceed 0.3 ppm.(780 µg/m^3)
5. Lead (Pb)	1 month	Not exceed 1.5 µg/m^3
6. Particulate Matter (< 10 µ) (PM - 10)	24 hr 1 year	Not exceed 0.12 mg/m^3 Not exceed 0.05 mg/m^3
7. Particulate Matter (< 100 µ)	24 hr 1 year	Not exceed 0.33 mg/m^3 Not exceed 0.10 mg/m^3

Source: Pollution Control Department (2008)

Remark: 1. Short term average standard (1, 8 and 24 hrs.) is to prevent acute effect on for human health.

2. Long term average standard (1 month and 1 year) is to prevent long term or chronic effect on human health.

[a] 1- hr SO_2 Standard

- 1.3 milligram/cubic meter for Mae Moh area
- 0.78 milligram/cubic meter, for elsewhere

4. Air Pollutants Emission Inventory

This study interested in the air pollutants emission from Siriraj Hospital area such as CO, SO_2 and NO_2. The details for three air pollutants are explained in following section.

4.1 Carbon monoxide

Carbon monoxide (CO) is a colorless, odorless, poisonous gas. Its molecules consist of one carbon atom covalently bonded to one oxygen atom. There are two covalent bonds and a coordinate covalent bond between the oxygen and carbon atoms. A product of incomplete burning of hydrocarbon-based fuels, carbon monoxide consists of a carbon atom and an oxygen atom linked together.

Carbon monoxide results from incomplete combustion of fuel and is emitted directly from vehicle tailpipes. Incomplete combustion is most likely to occur at low air-to-fuel ratios in the engine. Nationwide, two-thirds of the carbon monoxide emissions come from transportation sources, with the largest contribution coming from highway motor vehicles. In urban areas, the motor vehicle contribution to carbon monoxide pollution can exceed 90 percent (U.S. EPA, 1993). Since CO is a reactive gas that does not persist in the atmosphere, CO concentrations can vary greatly over relatively short distances. Elevated concentrations are usually limited to locations near crowded intersections, congested roadways, parking.

Carbon monoxide (CO) causes its harm to human's health by binding with the hemoglobin in our blood, forming carboxyhemoglobin (COHb). CO attaches to hemoglobin roughly 220 times more strongly than does oxygen, so that small amount of CO in the air we breathe can cause significant amount of our hemoglobin to be tip up as COHb. The hemoglobin thus tied up cannot serve its normal function, to transport oxygen in the blood (as oxyhemoglobin, O_2Hb). Thus as the blood's ability to transport oxygen decline, various parts of the body suffer oxygen deprivation.

4.2 Sulfur Dioxide

Sulfur dioxide (SO_2) is a colorless gas with a pungent odor. It is a liquid when under pressure, and it dissolves in water very easily.

The sulfur dioxide in air about 99% comes from human sources. The main source of sulfur dioxide in the air is industrial activity that processes materials that contain sulfur, e.g. the generation of electricity from coal, oil or gas that contains sulfur. Some mineral ores also contain sulfur, and sulfur dioxide is released when they are processed. In addition, industrial activities that burn fossil fuels containing sulfur can be important sources of sulfur dioxide.

The sulfur dioxide is also present in motor vehicle emissions, as the result of fuel combustion. If burn the fuels, the contained sulfur will mostly from sulfur dioxide;

$$S_{\text{(in fuel)}} + O_2 \rightarrow SO_2 \tag{1}$$

Sulfur dioxide affects human health when it is breathed in. It irritates the nose, throat, and airways to cause coughing, wheezing, shortness of breath, or a tight feeling around the chest. The effects of sulfur dioxide are felt very quickly and most people would feel the worst symptom in 10 or 15 minutes after breathing it in.

The health effects of sulfur dioxide (SO_2) in high concentrations can result in breathing problems with asthmatic children and adults who are active outdoors. Exposure to very high levels of sulfur dioxide can be life threatening. Exposure to 100 parts of sulfur dioxide per million parts of air (100 ppm) is considered immediately dangerous to life and health. Other effects associated with longer-term exposure to sulfur dioxide, in conjunction with high levels of particulate soot, include respiratory illness, alterations in the lungs' defenses and aggravation of existing cardiovascular disease.

The Environmental Effects of sulfur dioxide and nitrogen oxides are the major precursors of acid rain, which has acidified soils, lakes and streams, accelerated corrosion of buildings and monuments, and reduced visibility. Sulfur dioxide also is a major precursor of fine particulate soot, which poses a significant health threat.

4.3 Nitrogen Oxide

Nitrogen oxides represent a mixture of gases designated by the formula NO_x The mixture includes nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen trioxide (N_2 O_3), nitrogen tetroxide (N_2 O_4), and nitrogen pentoxide (N_2O_5). Most released nitrogen oxides are nitric oxide and nitrogen dioxide caused by human activity.

At ambient temperatures, the oxygen and nitrogen gases in air will not react with each other. In an internal combustion engine, combustion of a mixture of air and fuel produces combustion temperatures high enough to drive endothermic reactions between atmospheric nitrogen and oxygen in the flame, yielding various oxides of nitrogen. In areas of high motor vehicle traffic, such as in large cities, the amount of nitrogen oxides emitted into the atmosphere can be quite significant. The three primary sources of NO_X in combustion processes;

a) Thermal NO_X

Thermal NO_X is formed by free nitrogen and oxygen from the combustion air combining with each other. This only happens at the high temperatures encountered in flames; the normally stable molecules of nitrogen dissociate into atoms, which are very reactive, and readily join with similarly dissociated oxygen atoms to form NO. The reaction for producing NO in flames is;

$$N_2 + O_2 \leftrightarrow 2NO \qquad (2)$$

So, the equation 2 was reversible reaction, but the ratio of NO which transformed to molecular of nitrogen and oxygen would be occur very low , NO can reaction with oxygen to occur is nitrogen dioxide in high combustion area. The reaction for producing NO2 is;

$$NO + \frac{1}{2} O_2 \leftrightarrow NO_2 \qquad (3)$$

The important factor which has affects to NO_X as;

- The combustion temperature.
- The detention time of combustion gases to present in high temperature area.
- The oxygen amount in combustion area.

In combustion process, the flame temperature would be exceed 1600 °K, at high temperature the NO would be more produce, some time the concentration is more than 1000 ppm. The detention time of combustion gas to present in flame area is short. So, the NO that occurred from combustion gases was gone oxidized to NO_2 less than 5%.

b) Fuel NO_X

The major source of NO_X production from nitrogen-bearing fuels such as certain coals and oil can contribute to the total NO_X formed during the combustion process. The extent of conversion of fuel nitrogen to NO_X is dependent on the local combustion characteristics and the initial concentration of nitrogen-bound compounds. Fuel-bound nitrogen-containing compounds are released into the gas phase when the fuel droplets or particles are heated during the devolatilization stage.

c) Prompt NO_X

Prompt refers to the NO_X that from very quickly as a result of the interaction of nitrogen and oxygen with some of the active hydrogencarbon species such as NH (nitrogen monohydride) and HCN (hydrogen cyanide) derived from the fuel in the fuel-rich part of flames. They are not observed in flames of fuel. They cannot be formed by simply heating oxygen and nitrogen; the participation of some active hydrocarbon species from the fuel is required.

d) Ambient Ration Method

The U.S. Environmental Protection Agency (EPA) recommends a tiered approach for modeling ambient nitrogen dioxide (NO_2) impacts from point sources. The second tier uses the Ambient Ratio Method (ARM), where the ratio of modeled NO_2 to oxides of nitrogen (NO_X) is assumed to equal the existing NO -to-NO_X ratio. EPA has established a national default ARM value by using the NO_2/NO_X ratio of 0.75 (Keowampau, 2006).

5. Air Dispersion

The dispersion of air pollutant is dilute process, which change a place between air and air pollutant as normal air mass has movement, if air pollutant contain in air mass and carry together, while air mass at without pollutant will replace. The dispersion in molecular level, that has less effect about 1,000 times we will see that, dispersion process of air pollutant, its role for dilute air pollutant, that not true dispersion theory. But, that is dispersion from air turbulent and wind directions are effect to air dispersion (Panich *et al*., 2001).

6. Air Dispersion Model

Air Dispersion model is referred to a tool utilized to predict the potential air quality impact of a proposed source on the local environment through computer simulation using mathematical formulations to characterize the atmospheric process that disperse a pollutant emitted by a source of interest (Robert H. *et al*., 1999). In other words, it is a computer program or a series of mathematical equations used to simulate the transport, diffusion, chemical transformation, physical interactions, and removal of pollutants in the atmosphere with the typical solutions being expressed as concentrations for some time period at "receptor" locations.

In order to be able to calculate the concentration of a pollutant of interest, air dispersion models require certain input of data which typically includes:

6.1 Meteorological conditions such as wind speed and direction, the amount of atmospheric turbulence or stability class and the ambient air temperature.

6.2 Characteristics of emission source, such as source location and height, source vent stack diameter and exit velocity.

6.3 Local topography of the source location and the receptor location.

6.4 The location, height and width of any obstructions (such as buildings or other structures) in the path of the emitted gaseous plume.

As the model can provide information about pollutant impacts on the areas most influenced by emissions from a specific source; not only is it typically used to determine whether existing or proposed new industrial facilities are or will be in compliance with national ambient air quality standards, but it is also used to assist in the design of effective control strategies to reduce emissions of harmful air pollutants. Therefore, it is important to governmental agencies tasked with protecting and managing the ambient air quality and is considered a potent tool in making a variety of air quality decisions which are based on the air quality expected under a range of possible scenarios (U.S. EPA, 2005).

There is currently an array of air dispersion models that have been used in different jurisdictions around the world to handle a wide range of modeling conditions. Generally, air dispersion models can be divided into a number of categories, depending upon what sort of criteria is used, for instance, model characteristics, model complexity, model function, model application, accuracy of the result, mathematical equations used and amount of data input requirements, is used in classification (Siriprasert, 2008).

7. Gaussian Plume Model

Having been used in the USA since the mid-1960s, Gaussian plume model is considered as a widely-used, well-understood, easy-to-apply and internationally-approved computational approach to calculating the concentration of a pollutant at a certain point (Panich *et al*., 2000) It is basically a group of formulae based on the assumption of steady-state conditions. That is, the Gaussian-plume dispersion formulae do not depend on time, although they do represent an ensemble time average. The meteorological conditions are assumed to remain constant during the dispersion from source to receptor, which is effectively instantaneous. Emissions and meteorological conditions can vary from hour to hour but the model calculations in each hour are independent of those in other hours. Owing to this mathematical derivation, it is common to refer to Gaussian plume models as steady-state dispersion models. In practice, however, the plume characteristics do change over time, because they depend on changing emissions and meteorological conditions. Steady-state models calculate concentrations for each hour from source data and meteorological conditions that are uniform across the modeling domain. Thus, they simulate hourly-average concentrations (Siriprasert, 2008).

This model basically describes the transport and mixing of the pollutants by assuming that plume spread, and dispersion of pollutants within it, results from molecular diffusion, and because of diffusion, pollutant concentrations in both the horizontal and vertical plume dimensions are distributed normally in bell-shaped curve (U.S. EPA, 2005). Below is a picture showing the Gaussian distribution of concentrations in the horizontal and vertical directions with the maximum concentration at the center of the plume.

From Figure 2 was showed in below, the X-directed mean wind speed, the cross wind or azimuth will be specified by the Y-direction and the vertical by the Z-direction. The Gaussian Plume Equation is as follows;

$$C(x,y,z) = \frac{Q}{2\pi\sigma_y\ \sigma_z\ \mu} exp\left[-\left(\frac{y^2}{2\sigma_y^2}\right)\right]\left\{exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right]\right\} \quad (4)$$

Where: C(x,y,z) is the concentration of the emission (g/m^3) at any point x meters downwind of the source, y meters laterally from the centerline of the plume, and z meters above ground level. Q is the quantity or mass of the emission in g/s. u is the wind speed in m/s, H is the height of source and plume rise in meter, σy is the standard deviations of a statistically normal plume in the lateral dimension and σz is the the standard deviations of a statistically normal plume in the vertical dimension.

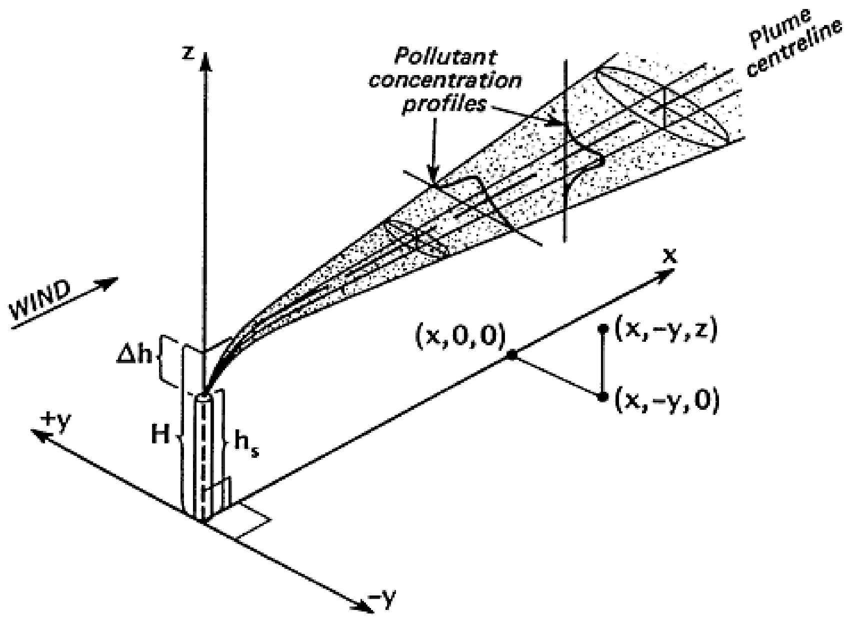

Figure 2 Typical Gaussian Plume Dispersion of Pollutants from an Elevated Source.
Source: Ministry for the Environment of New Zealand (2004)

8. U.S. EPA's Air Dispersion Model

There have been a number of air dispersion models available and/or accepted for use in many countries worldwide. Many of these were developed and/or accepted by the U.S. EPA, for use in managing ambient air quality in the USA. Currently, the U.S. EPA has approved a number of models for regulatory application, and lists them in Appendix A of the Guideline on Air Quality Models (U.S. EPA, 2005). These are divided into three main categories as shown below.

8.1 Preferred/Recommended Models

The recommended models are refined air dispersion models that are currently listed in the Guideline on Air Quality Models and are required to be used for State Implementation Plan revisions for existing sources and for New Source Review and Prevention of Significant Deterioration programs in the USA. In other words, they are air dispersion models that are well accepted and commonly used in many countries, not only in the USA.

8.2 Alternative Models

The alternative models refer to air dispersion models that are not listed in the Guideline on Air Quality Models, but can be utilized in regulatory applications as alternatives to the preferred/recommended models with case-by-case justification to the Reviewing Authority. Some of them were once accepted as recommended models, but they have already been withdrawn due mainly to availability of superior model i.e. AERMOD modeling system.

8.3 Screening Models

The screening models are referred to models that are regularly used before applying refined/recommended models to determine whether refined modeling is required or not. Its data input requirement and complexity and much less than that of refined models.

9. Model Selection

The extent to which a specific air dispersion model is suitable for the evaluation of air toxic source impacts depends upon several factors, such as the nature of the pollutant (e.g., gaseous, particulate, reactive, inert), the meteorological and topographic complexities of the area, the complexity of the source distribution, the spatial scale and resolution required for the analysis, and the level of detail and accuracy required for the analysis. This study select program while U.S.EPA recommended using for predicts air pollutions.

9.1 Industrial Source Complex-Short Term (ISCST)

The most commonly used model for air quality modeling is the US EPA's Industrial Source Complex - Short Term model, now in its third version (ISCST3). The ISCST3 model is a steady-state Gaussian plume model, which can be used to assess primary pollutant concentrations and depositions from a wide variety of sources. It may be applied in urban or rural areas, and has optional features to account for settling and dry deposition of particles, reactive decay, and limited terrain elevations.

9.2 AERMOD Model

The AERMOD model is introduced by the American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC), AERMOD Model is a steady-state Gaussian plume model useful for the computation of pollutant dispersion applicable to rural and urban; flat and complex terrain; surface and elevated release; and multiple sources such as point, area, line etc, of emissions. This model assumes the probability distribution function for the concentration of a pollutant to be Gaussian both in the vertical as well as horizontal directions in a stable boundary layer.

This model is intended to be useful for the simulation of short-range (0.50 km) pollutant dispersion. For the flow over complex terrain, this model uses the concept of dividing plume streamline. In urban areas, AERMOD Model accounts for the dispersive nature of the convective like boundary layer that forms during the nighttime by enhancing the turbulence resulting from an urban heat flux (Siriprasert, 2008). AERMOD Model includes two data preprocessors for streamlining data input. These are AERMET and AERMAP.

AERMET is a preprocessor for organizing available meteorological data into a format suitable for use, and then calculating atmosphere parameters needed by AERMOD, such as atmospheric turbulence characteristics, mixing heights and friction velocity.

AERMAP is a preprocessor for simplifying and standardizing terrain data input for AERMOD to generate location and height data for each receptor location, and to simulate the effects of air flowing over hills and around hills (U.S. EPA, 2005).

U.S. EPA has proposed a more advanced steady-state Gaussian plume replacement model, ISC-AERMOD, to provide improved accuracy compared to ISCST3. The ISC-AERMOD was developed to replace the Industrial Source Complex -Short Term model (ISCST3) and now AERMOD Model would be contain of ISC-AERMOD View package program.

9.3 CALPUFF

CALPUFF is in the process of being proposed by US EPA as a guideline model for long-range transport of primary pollutants and for sulfates and nitrates. The model is a multi-layer, multi-species non-steady-state Gaussian puff dispersion model. CALPUFF is designed to be applied on scales of tens of meters to tens of kilometers (near-field) and from tens of kilometers to hundreds of kilometers (far field). It includes algorithms for sub-grid scale effects, such as terrain impingement, as well as, longer range effects, such as pollutant removal due to wet scavenging, dry deposition, and reactive decay. CALPUFF can handle various types of emission source characterization, such as points and area.

This model designed to model the dispersion of gases and particles using space and time varying meteorology based on similarity equations, turbulence, emission strengths, transformation and removal. It is able to model four different source types: point, line, volume and area using an integrated puff formulation incorporating the effects of plume rise, partial penetration, buoyant and momentum plume rise, stack effects and building effects using either the Schulman–Scire or Huber–Snyder methods. The model calculates dry deposition using the resistance method with inputs for deposition velocities and wet removal using a scavenging coefficient approach as a function of precipitation intensity and type (Holmes *et al*., 2006).

From the regulatory air dispersion models listed above, only ISCST3 , AERMOD and CALPUFF models can be used for this research in which a source of interest. So, it is necessary to compare advantages and disadvantages of each of these three models, and then use this information as a basis for deciding which one is the most suitable for estimating the concentrations of pollutants released in Siriraj Hospital. The Table 4 is illustrating the comparison between the three models.

Table 4 Comparison of ISCST3, AERMOD and CALPUFF Models.

Characteristics	ISCST3	AERMOD	CALPUFF
Type of Model	Steady state model (Gaussian Plume Model)	Steady state model (Gaussian Plume Model)	Nonsteady state model (Lagrangian puff)
Status of Model in Thailand	Displaced by AERMOD on Nov 9, 2006, and now not demonstrative in Thailand.	Currently accepted by the U.S. EPA as regulatory model, and demonstrative used for industrial source in Thailand.	Accepted by the U.S. EPA as regulatory model since 2003, and demonstrative used for power plant source in Thailand.
Model Range	Recommended for assessing either short range or long range transport of pollutants	Recommended for assessing short range transport of pollutants (within 50 km)	Used in all regulatory applications including the long-range (300 km)
Components	Has only one main component: ISCST3. No need for preprocessors and postprocessors.	Consists of one main component: AERMOD, and two preprocessors: AERMAP and AERMET	Consists of three main components: CALPUFF, CALMET and CALPOST
Downwash Effect	Not included within the model	Included within the model	Included within the model
Output Frequency	1hr, 8 hr, 24hr and 1 year.	1hr, 8 hr, 24hr and 1 year.	> 1hr, 1hr, 8 hr, 24hr and 1 year.

Table 4 (Continued)

Characteristics	ISCST3	AERMOD	CALPUFF
Meteorological Data	Simple meteorological model	Simple meteorological model	Diagnostic 3-dimensional meteorological model
Complexity of Model	Slightly sophisticated	Slightly sophisticated	Very sophisticated due to large number of variables associated with this model
Accuracy of Result	Up to 50% error	AERMOD takes the effects of complex terrain into accounts when predicting the dispersion and concentration of air pollutants of interest. Therefore, its accuracy is an improvement over ISC3's ability to predict measured concentrations	-
Type of Pollutants	Applicable to primary pollutants or non-reactive pollutants	Applicable to primary pollutants or non-reactive pollutants	Allowed for the estimation primary and secondary pollutant

Table 4 (Continued)

Characteristics	ISCST3	AERMOD	CALPUFF
Input Requirement	Used with a minimum of requirements for input data	Requires more input data than ISCST3 does e.g. urban population for urban option and some surface characteristics (Bowen ratio and surface roughness)	Requires a lot more input data than for a plume model e.g. upper air sounding data, over water data and precipitation rate
Effect of Wind Speed	Not recommended to use for calm conditions	Not recommended to use for calm conditions	Can be used for calm conditions
Type of Terrain	Provides substantial over prediction in complex terrain, and so it is recommended for calculating air quality impacts in regions of flat terrain only.	Can be used for either flat or complex terrain, but the more complex the terrain is, the more erroneous the result of the model.	Can be used for either flat or complex terrain.
Skill Requirement	Relatively simple to use	As simple to use as ISCST3 if excludes AERMAP	Very complicated to use
Scale	Local and Regional	Local and Regional	Regional
Atmospheric Stability	Boundary Layer Scaling	Boundary Layer Scaling	Boundary Layer Scaling

Table 4 (Continued)

Characteristics	ISCST3	AERMOD	CALPUFF
Source Type	Multiple point, area, line and volume sources	Multiple point, area, line and volume sources	Multiple point, area, line and volume sources
Cost of Use Model	Less costly	Less costly	Costly as required more input data. The commercial model is far more expensive than a plume model.

Source : Holmes and Morawska (2006); Siriprasert (2007)

The ISCST3, AERMOD and CALPUFF are able to simulate the air pollutants formation in Siriraj Hospital. When you compared ISCST3 and AREMOD, both of the models are steady-state, plume dispersion models that were developed for the U.S. Environmental Protection Agency (U.S. EPA) to support regulatory air modeling programs. These models were specifically developed to simulate air pollution resulting from emissions from industrial sources. The models can simulate the impact of an area source of contaminant release, such as emissions from a heap leach field. The models use meteorological data averaged over 1 hour periods of time to estimate 1 hour steady-state concentrations of air contaminants. The research ‘s Kenneth G. in year of 2005 did to measurable concentrations of hydrogen cyanide were detected in ambient air samples, the concentrations predicted by the ISCST3 model exceeded the measured values by 1.33 to 2.95 fold. The air concentrations of hydrogen cyanide predicted by AERMOD were closer to the measured values. The ratio of the AERMOD predicted to measured concentrations ranged from 0.37 to 1.12, and the average concentration ratio was 0.76 (Kenneth G. *et al*., 2006).

The results showed for AERMOD was better than ISCST3, because the result of AERMOD similar to measure, and AERMOD was developed as a next generation model to ISCST3, and it incorporates more complex algorithms and concepts, such as planetary boundary layer theory, and advanced methods for handling complex terrain, in Table 5 is showed the results compared between ISTSC3 and AERMOD.

Table 5 Ambient air concentrations of hydrogen cyanide (ppb) and the ratio of predicted to measured concentrations (P/M).

Measured	ISCST3	P/M	AERMOD	P/M
0.26	0	0	0	0
0.51	1.37	2.71	0.50	0.98
0.63	1.84	2.95	0.70	1.12
1.86	2.48	1.33	0.90	0.49
0.26	0.75	3.13	0.20	0.86
0.60	1.07	1.83	0.22	0.37
Average ratio [a]		2.39		0.76

Note: [a] Average ratio of non-zero samples, Kenneth (2005).

When you compare ISC-AERMOD and CALPUFF, CALPUFF is better than ISC-AREMOD View in term of technical and accuracy, but CALPUFF has complex for prepare format of meteorological, while ISC-AERMOD can used several format for selection to prepare the meteorological such as SAMSON, MET144 etc. The function for operation of CALPUFF is difficult more than ISC-AERMOD View and this research is determination to primary pollutants not secondary components of pollutants as power plant and this research used in small area. Last reason, ISC-AERMOD was recommended by the “Office of Natural Resources and environmental Policy and Planning” for used to predict the dispersion and the concentration of air pollutants in an EIA report. Based on these considerations, ISC-AERMOD View was selected as the air dispersion model for this study.

10. ISC-AERMOD View Model

The ISC-AERMOD View is a user-friendly interface for four U.S. EPA air dispersion model of ISCST3 model, ISC-PRIME model, AERMOD model and AERMOD-PRIME model. The ISC-AERMOD View is consisting of AERMET View, BPIP View, and RAMMET View preprocessor program for used in ISC-AERMOD and Percent View, POST View, BPIP 3D View and WRPLOT View output processor program for expressing the output result.

The ISC-AERMOD model is the next-generation air dispersion model that incorporates concepts such as planetary boundary layer theory and advanced methods for handling complex terrain. The ISC-AERMOD model includes a wide range of options for modeling air quality impacts of pollution sources, making it a popular choice among the modeling community for a variety of applications. The following sections provide a brief overview of the options available in the ISC-AERMOD View model.

Since the ISC-AERMOD View model is especially designed to support the EPA's regulatory modeling programs, the regulatory modeling options will be the default mode of operation for the model. These options include the use of stack-tip downwash, and a routine for processing averages when calm winds or missing meteorological data occur. The model also includes non-default options for suppressing the use of stack-tip downwash, and to disable the date checking for non-sequential meteorological data files. The latter option is needed to facilitate evaluation of the model. The user can specify several short term averages to be calculated in a single run of the ISC-AERMOD View model, as well as requesting the overall period (e.g. annual) averages.

The ISC-AERMOD View contains basically the same options as the ISCST3/ISCPRIME model with a few exceptions, which are described below (Ontario Ministry of the Environment, 2005):

The ISC-AERMOD View requires two types of meteorological data files, a file containing surface air data and upper air sounding data. These two files are produced by the AERMET that is meteorological pre-processor program for used in ISC-AERMOD. For applications involving elevated terrain, the user must also input a hill height scale along with the receptor elevation. The AERMAP is terrain pre-processing program can be used to generate hill height scales as well as terrain elevations for all receptor locations. The urban option in ISC-AERMOD results in altering dispersion parameters due to the urban heat island effect. The urban population is an input to this option.

10.1 Basic input data requirements for ISC-AERMOD View

The ISC-AERMOD View interface uses the five pathways, these pathways are follow as;

a) Control Pathway (CO)

The control pathway provides the overall control of the model run. These include the dispersion options, averaging time options, terrain height options etc. The CO pathway must be the first pathway in the runstream input file.

b) Source Pathway (SO)

Where define the sources of pollutants emission. In this pathway the ISC-AERMOD View program must specify the location of the source and source parameter. The ISC-AERMOD View can selection the emission source in eight source types as point, volume, area, open pit, polygon area, circular area, flare and line sources. In this study would be explain a point source and line source, because both source were used in this research.

(1) Point source input

The ISC-AERMOD POINT source algorithms are used to model releases from stacks and isolated vents, and order input for point source are summarized below:

- Point emission rate in gram/second.
- Release height above ground in meters.
- Stack gas exit temperature in degrees °K.
- Stack gas exit velocity in m/s.
- Stack inside diameter in meters.

(2) Line source input

The ISC-AERMOD View handle line sources as volume sources, this model can automatically generate these volume sources to represent the line source. At the present time ISC-AERMOD View used the line source represented by separated volume source, example of line sources are railway, conveyor belts and road. The order inputs for line source are summarized below:

- Length of side in meter.
- Emission rate in gram/second.
- Type of volume source; that content 2 option selection. The first is surface base, if select this option the emission height (Release height above ground) is approximately zero. The second is elevated, if select this option the emission height (Release height above ground) is greater than zero.
- Building Height; if the line source is adjacent to a building then will need to specify the building height. The building height will be used to calculate the Initial Vertical Dimension of the source, Table 6 is show the equation for calculate the Initial Vertical Dimension.
- X-Coordinate for the node in meter.
- Y- Coordinate for the node in meter.

Table 6 Summary of suggested procedures for estimating Initial Lateral Dimension (σ_{yo}) and Initial Vertical Dimension (σ_{zo}) for volume and line sources.

Type of Source	Procedure for Obtaining Initial Dimension
Initial Lateral Dimension (σ_{yo})	
Single Volume Source	(σ_{yo}) = length of side divided by 4.3
Line Source Represented by Adjacent Volume	(σ_{yo}) = length of side divided by 2.15
Line Source Represented by Separated Volume Sources	(σ_{yo}) = center to center distance divided by 2.15
Initial Vertical Dimensions (σ_{zo})	
Surface-Based Source (he - 0)	(σ_{zo}) = vertical dimension of source divided by 2.15
Elevated Source (he > 0) on or Adjacent to a Building	(σ_{zo}) = building height divided by 2.15
Elevated Source (he > 0) not on or Adjacent to a Building	(σ_{zo}) = vertical dimension of source divided by 4.3

Source: U.S. Environment Protection Agency, 1995 User's Guide for the Industrial Source Complex (ISC3) Dispersion Models – Volume I, EPA-454/B-95-003a.

c) Receptor Pathway (RE)

The ISC-AERMOD View model has considerable flexibility in the specification of receptor locations. The user has the capability of specifying multiple receptor networks in a single run, and may also mix Cartesian grid receptor networks and polar grid receptor networks in the same run. This is useful for applications where the user may need a coarse grid over the whole modeling domain, but a denser grid in the area of maximum expected impacts. There is also flexibility in specifying the location of the origin for polar receptors, other than the default origin at (0, 0) in x, y, coordinates. A Cartesian grid network is array of points identified by their x (east-west) and y (north-south) coordinates. A polar network is an array of points identified by direction and distance from a user-defined origin. The default units for receptor elevations for the ISC-AERMOD View model are in meter (United States Environmental Protection Agency [US.EPA], 2004).

d) Meteorology Pathway (ME)

The ISC-AERMOD View model utilizes a file of surface boundary layer parameters and a file of profile variables including wind speed, wind direction, and turbulence parameters. These two types of meteorological inputs are generated by the meteorological preprocessor for ISC-AERMOD View, which is called AERMET View (US.EPA, 2004).

e) Output Pathway (OP)

The output pathway defines the output options for the model run. The basic types of printed output available with ISC-AERMOD View are:

(1) Summaries of high values (highest, second highest, etc.) by receptor for each averaging period and source group combination;

(2) Summaries of overall maximum values (e.g., the maximum 50) for each averaging period and source group combination; and

(3) Tables of concurrent values summarized by receptor for each averaging period and source group combination for each day of data processed. These "raw" concentration values may also be output to unformatted (binary) files.

One of these options for AERMOD is to output an unformatted ("binary") file of all concentration values as they are calculated. These files are often used for special post processing of the data. In addition to the unformatted concentration files, AERMOD provides options for two additional types of file outputs. One option is to generate a file of (X,Y) coordinates and design values (e.g., the second highest values at each receptor for a particular averaging period and source group combination) that can be easily imported into many graphics plotting packages to generate contour plots of the concentration values (US.EPA, 2004).

11. Building Downwash

Buildings and other structures near a relatively short stack can have a substantial effect on plume transport and dispersion, and on the resulting ground-level concentrations that are observed. There has long been a “rule of thumb” that a stack should be at least 2.5 times the height of adjacent buildings. Beyond that, much of what is known of the effects of buildings on plume transport and diffusion has been obtained from wind tunnel studies and field studies.

When the airflow meets a building (or other obstruction), it is forced up and over the building. On the lee side of the building, the flow separates, leaving a closed circulation containing lower wind speeds. Farther downwind, the air flows downward again. In addition, there is more shear and, as a result, more turbulence. This is the turbulent wake zone and following showed in Figure 3.

If a plume gets caught in the cavity, very high concentrations can result. If the plume escapes the cavity, but remains in the turbulent wake, it may be carried downward and dispersed more rapidly by the turbulence. This can result in either higher or lower concentrations than would occur without the building, depending on whether the reduced height or increased turbulent diffusion has the greater effect.

The ISC-AERMOD View model includes algorithms to model the effects of buildings downwash on emissions from nearby or adjacent point sources. The building downwash algorithms do not apply to volume or area sources. The ISC-AERMOD View model uses direction-specific information for all building downwash cases (US.EPA, 2004). The model used support the effect of building downwash is explained in next sections.

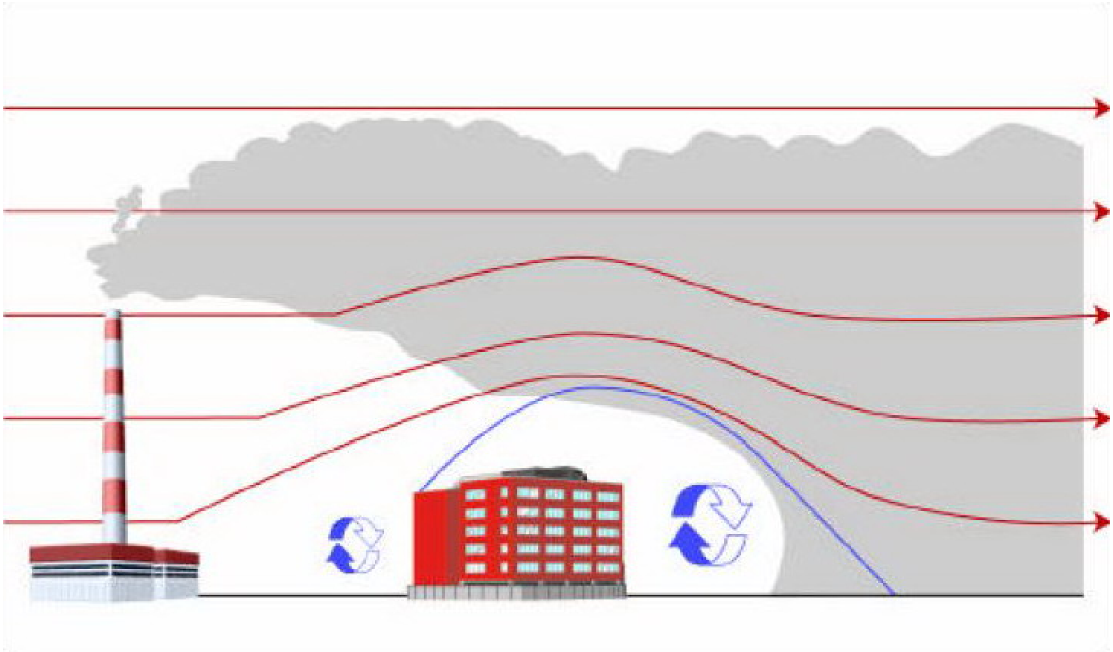

Figure 3 The building downwash concept where the presence of buildings forms localized turbulent zones that can readily force pollutants down to ground level.

Source : Lakes Environmental Consultants Inc. (2003)

12. BPIP-PRIME / BPIP View program

The U.S. EPA Building Profile Input Program – Plume Rise Model Enhancements (BPIP-PRIME) was designed to incorporate enhanced downwash analysis data for use with the U.S. EPA ISC-PRIME and current ISC-AERMOD models. Similar in operation to the U.S. EPA BPIP model, BPIP-PRIME uses the same input data requiring no modifications of existing BPIP projects. The following information is required to perform building downwash analysis within BPIP View program;

- X and Y location for all stacks and building corners.
- Height for all stacks and buildings (meters). For building with more than one height or roofline, identify each height (tier).

- Base elevations for all stacks and buildings.

The BPIP User's Guide provides details on how to input building and stack data to the program. The BPIP model is divided into two parts. The part one based on the GEP technical support document, this part is designed to determine whether or not a stack is subject to wake effects from a structure or structures. Values are calculated for GEP stack height and GEP related building heights (BH) and projected building widths (PBW). Indication is given to which stacks are being affected by which structure wake effects. The part two calculates building downwash BH and PBW values. These can be different from those calculated in part one. The calculations are performed only if a stack is being influenced by structure wake effects.

In addition to the standard variables reported in the output of BPIP, BPIP-PRIME adds the following;

- BUILDLEN: Projected length of the building along the flow.
- XBADJ: Along-flow distance from the stack to the center of the upwind face of the projected building.
- YBADJ: Across-flow distance from the stack to the center of the upwind face of the projected building.

13. AERMET View

The AERMET View program is a meteorological preprocessor which prepares hourly surface data and upper air data for use in the U.S. EPA air quality dispersion model such as ISC-AERMOD View. The AERMET was designed to allow for future enhancements to process other types of data and to compute boundary layer parameters with different algorithms.

The AERMET processes meteorological data in three stages; the first stage (Stage1) extracts meteorological data from archive data files and processes the data through various quality assessment checks. The second stage (Stage2) merges all data available for 24-hour periods (surface data, upper air data, and on-site data) and stores these data together in a single file. The third stage (Stage3) reads the merged meteorological data and estimates the necessary boundary layer parameters for use by ISC-AERMOD.

The results of these process two files are written for used in ISC-AERMOD; the first is a surface file (SFC) of hourly boundary layer parameters estimates and the second is a profile file (PFC) of multiple-level observations of wind speed, wind direction, temperature, and standard deviation of the fluctuating wind components.

The meteorological data used in this research including the hourly surface air data and upper air data, both data will explain on next sections.

13.1 The Hourly Surface Air Data

The hourly surface data are meteorological data that are measured at the earth's surface (technically, somewhere between the ground level and 10m). This data contains physical parameters that are measured directly by instrumentation, such as temperature, dew point, wind direction, wind speed, cloud cover, and ceiling height. In Thailand the hourly surface data are reported by Thai Meteorological Department and Pollution Control Department.

a) SAMSON Format

The Solar and Meteorological Surface Observational Network (SAMSON) data contains all of the required meteorological variables for concentration, dry and wet particle deposition, and wet vapor deposition. For the required of SAMSON format would be explain in Appendix C.

13.2 The Upper Air Data

The upper air data are meteorological data that are measured in the vertical layers of the atmosphere. Upper air data are usually measured by twice daily radionsonde soundings, taken at 00 and 12Z (Greenwich Time). The upper air soundings are plotted data from balloons. The balloon records temperature, humidity and winds and these are plotted versus pressure/height to give details on the vertical structure of the atmosphere. In Thailand the upper air data are reported by Thai Meteorological Department and can download form website of University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html) or http://raob.fsl.noaa.gov/.

a) FSL Format

The official FSL data format is similar to the format used by the National Severe Storms Forecast Center (NSSFC) in Kansas City. The first 4 lines of the sounding are identification and information lines. For the FSL format indicates in each parameter would be explaining in Appendix C.

14. RAMMET View

The RAMMET View or PCRAMMET program is a meteorological preprocessor which prepares NWS data for use in the various U.S. EPA air quality dispersion models such as ISC-PRIME and ISC AERMOD. The PCRAMMET is also used to prepare meteorological data for use by the CAL3QHCR model, and for use by the CALPUFF puff dispersion model when used in screening mode. The operations performed by PCRAMMET include;

- Calculating hourly values for atmospheric stability from meteorological surface observations.
- Interpolating the twice daily mixing heights to hourly values.

- Optionally, calculating the parameters for dry and wet deposition processes.
- Outputting data in the standard (PCRAMMET unformatted) or ASCII format required by regulatory air quality dispersion models.

The input data requirements for PCRAMMET depend on the dispersion model and the model options for which the data is being prepared. The minimum input data requirements for PCRAMMET are the twice-daily mixing heights and the hourly surface observations of: wind speed, wind direction, dry bulb temperature, opaque cloud cover, and ceiling height.

For dry deposition estimates, station pressure measurements are required. For wet deposition estimates, precipitation type and precipitation amount measurements for those periods where precipitation was observed are required.

MATERIAL AND METHODS

The air dispersion model used for this research is the ISC-AERMOD View. The meteorology data, building downwash data, emission data, and emission rate are the input data to ISC-AERMOD View. Then, the data is processed and calculated by ISC-AERMOD View model. The results are expressed in terms of concentration and dispersion contour line.

Materials

1. Pc or Note book computer	1 Set
2. CCTV camera	2 Pieces
3. ISC-AERMOD View program	1 Set
4. Gas Toxic Analyzer	1 Piece
5. AutoCAD version 2007 program	1 Set
6. Microsoft Office 2007 program	1 Set

Methods

1. Data Collection

This research was to determine the air pollutants occurred from the activity at Siriraj Hospital by using chemical substance data. From collected data, it was found that Formaldehyde and other air pollutants from fuel burned were determined mostly. In this research, air pollution from boiler was studied because the combustion of fuel oil-boiler emitted inorganic substance such as sulfur dioxide, carbon monoxide and nitrogen oxide everyday (16 hours per day) with high amount. This research aims to study and assess the air pollution exposed to the environment by using ISC-AERMOD View program. The stacks boiler in hospital area located at:

1.1 Syamindry Building in which steam is used for cloth sterilization and the exhausted gas is released from the 15^{th} floor (height is 65 m).

1.2 Laundry Building that is used for cloth washing and the exhausted gas is released from the laundry building at the stack height of 16 m.

2. Emission Stack Data Preparation

The measurement emission data of SO_2, NO_2, and CO in year of 2007 were used for execution of ISC-AERMOD View program with the information used US.EPA 6 for measurement SO_2, US.EPA 7 for measurement NO_2 and combustion analyzer model “TELEGAN Sprint V1” for measurement CO. From these emission data, it is necessary to change the unit from emission concentration (ppm) to emission rate (g/s) in order put in ISC-AERMOD View by the following equations;

$$\mathrm{Cp} = \frac{\mathrm{Cstp} \times \mathrm{P(atm)} \times \mathrm{T(s)}}{\mathrm{T(atm)} \times \mathrm{P(s)}} \tag{5}$$

$$\mathrm{Cm} = \frac{\mathrm{Cstp} \times \mathrm{MW}}{24.45} \tag{6}$$

Where, Cp is the sampling site concentration in ppm, Cstp is the concentration at STP in ppm, Cm is the concentration in mg/m^3, P (atm) is the atmosphere pressure in mmHg, P(s) is the sampling site pressure in mmHg, T(atm) is the ambient temperature in °K, and T(s) is the sampling site temperature in °K.

An important parameter that is available for being input data to ISC-AERMOD View program is emission temperature (°K), stack release height (m), stack internal diameter (m) and emission velocity (m/s). An emission velocity in this research is calculated following the Equation 7.

$$\text{Emission Rate} = \mathrm{Cm} \times \mathrm{V} \times \mathrm{A} \tag{7}$$

Where, Cm is the concentration of pollutants in mg/m^3, V is the velocity in m/s and A is inside diameter in meter.

The data for velocity are the flow rate of dry air inside stack shown in Equation 8.

$$Q_{sd} = 3600(1 - B_{ws}) \times V_s \times A \times \left(\frac{T_{std}}{T_{s(avg)}} \right) \left(\frac{P_s}{P_{std}} \right) \qquad (8)$$

Where, Q_{sd} is the flow rate of dry air inside stack (which is obtained from the combustion equation) in m^3/hour, B_{WS} is moisture in air (%), V_S is velocity in side stack in m/s, A is cross-section area of stack inside diameter in meter, T_{std} is 25°C + 273 = 298°K, $T_{s(avg)}$ is the absolute temperature in °K, P_S is the absolute temperature (P_{bar} + P_g) in mmHg, P_g is the static pressure inside stack in mmHg, P_{bar} is the atmospheric pressure in mmHg and P_{std} is 760 mmHg.

The flow rate of dry air in stack (Q_{sd}) was obtained from amount of fuel oil used per day, fuel content and the combustion equation is as follow;

$$Ao = 8.89c + 26.7\left[h - \frac{0}{8} \right] + 3.3s \qquad (9)$$

$$m = \frac{21(N_2)}{21(N_2) - 79(O_2 - 0.5(CO))} \qquad (10)$$

$$A = m \times Ao \qquad (11)$$

$$G' = m(Ao) + 5.6h + 0.7o + 0.8n \qquad (12)$$

Where, Ao is the amount of theoretical air in m^3/kg, m is the compression air ratio, A is the amount of essential air in m^3/kg, G' is the amount of dry gases in m^3/kg, c, h, o, n and s is the carbon mass, hydrogen mass, oxygen, nitrogen mass and sulfur mass in fuel in % by mass respectively.

For the static pressure inside stack (P_g) used in Equation 4 can be calculated from the Equation 13;

$$P_{atm} - P_g = C \times a \times H\left[\frac{1}{To} - \frac{1}{Ti}\right] \quad (13)$$

Where, C is 0.0342, a is the atmospheric pressure in Pa, H is the stack height in meter, T_O is the outside stack temperature in °K and Ti is the average in side stack temperature in °K.

3. Meteorological Data Preparation

The meteorological data included surface air data and upper air data in a period of one year (from 1 January to 31 December 2007) for AERMET program. The surface air data from Pollution Control Department were selected from Intrapitak station which is located nearly Siriraj Hospital. The mostly and ceiling height data were obtained from Thai Meteorological Department at Don Mung Station. The upper air data used in AERMET program came from the website of University of Wyomming at the selected station number 48455. Then, it is necessary to prepare data before using in AERMET program. The steps for surface air data and upper air data preparation are described in following sections.

3.1 Surface Air Data

The information of Pollution Control Department was added as a table in Microsoft Excel and set in the format of SAMSON. The RAMMET View program was used to prepare surface air data. A file type .SAM was prepared. The SAMSON format was explained in Appendix C.

3.2 Upper Air Data

The information of upper air data downloaded from the website was prepared as a table in Microsoft Excel and rearranged the data in types of FSL format and saved as selected space delimited (.INP file). The FSL format was explained in Appendix C.

3.3 Execution of AERMET program

The surface air data and upper air data from previous steps were input to AERMET program. The meteorology in last steps would give two files consisted surface file (file type .SFC) and profile file (file type .PFL) for ISC-AERMOD View. The steps for preparing meteorology data are shown in Figure 4.

4. Building Downwash Data Preparation

This section is an explanation of a building downwash file for used in ISC-AERMOD View program. This research required a dimension of building around stacks boiler in hospital area, the data for required for width, length and height and a map of hospital from AutoCAD program was required in kind of DFX format. Next step was to use BPIP View program for processor data by inserting a map, input stacks boiler position and building data into BPIP View program. Last step was to run BPIP View program and obtain a building downwash file (.PRO) for using in ISC-AERMOD View program. Detail of building downwash output file from BPIP View program able is explained in Appendix E.

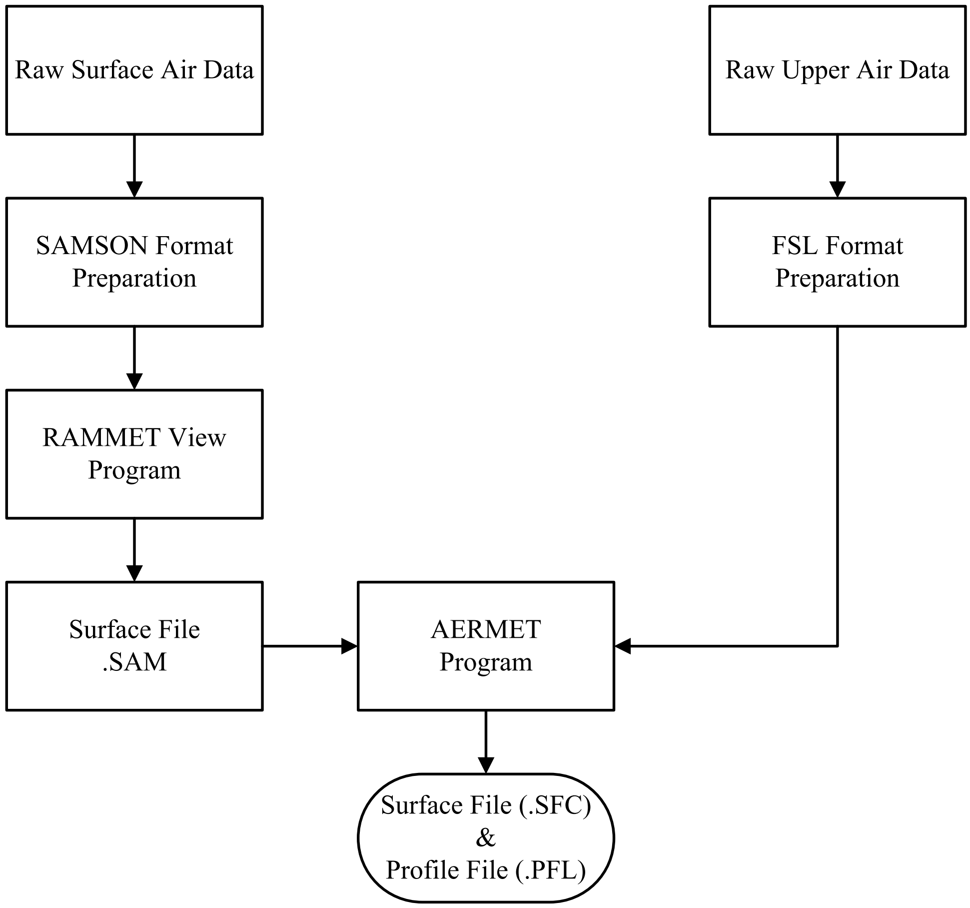

Figure 4 The process for meteorology files preparation for used in ISC-AERMOD View program.

5. Execution of ISC- AERMOD View Program

This step is to apply information such as stack emission data, meteorological data and building downwash data input in ISC-AERMOD View program by using meteorology data in period of one year (1 January to 31 December 2007) for calculating concentration and dispersion contour of annual SO_2, 24 hour SO_2, 1 hour CO, 8 hour CO and 1 hour NO_X. Furthermore, this study would try to vary a stack boiler height and varied a building for inspect the change of concentration, dispersion contour and compared with actual condition. The procedure and prepared data for execution of ISC-AERMOD View program are illustrated in Figure 5.

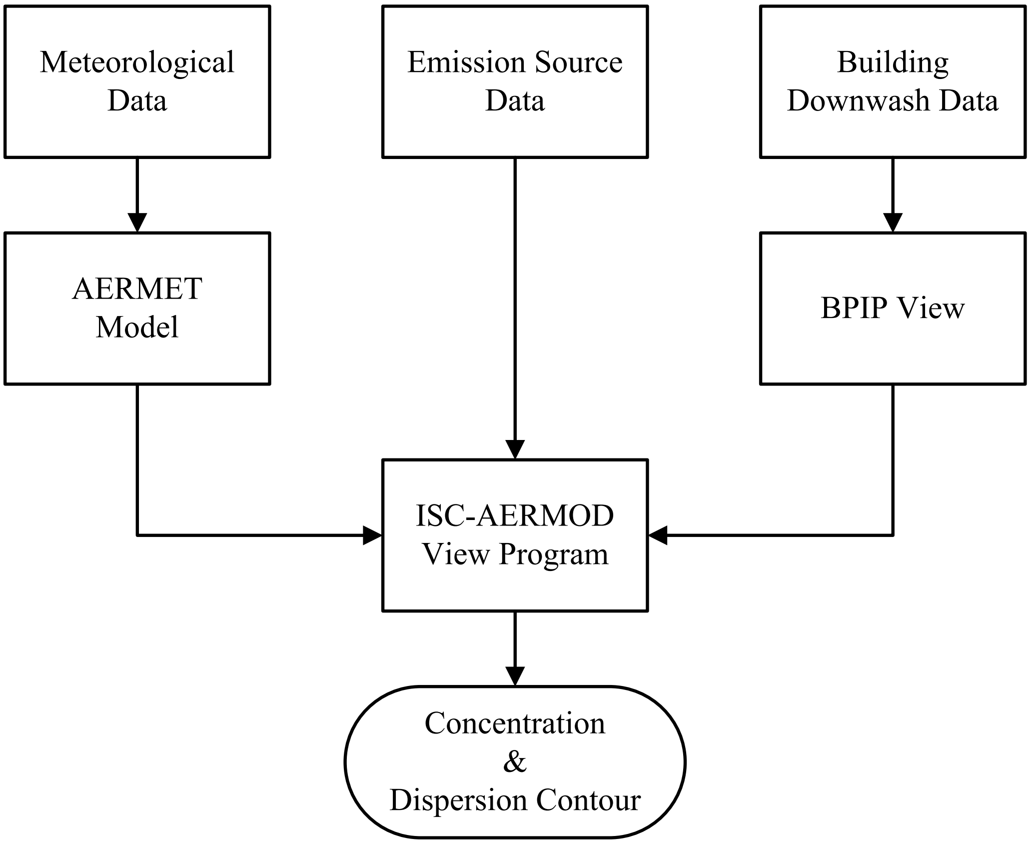

Figure 5 The procedure and prepared data for executed of ISC-AERMOD View program.

6. Determination of Background Concentration

The background concentrations required form 2 sources are atmospheric concentration and local concentration (mobile source), the step of determination would be explained in following sections.

6.1 Determination of Atmosphere concentration

The atmospheric concentration can be defined by using hourly air quality data in period of one year (1 January to 31December 2007) from Intrapitak Observation Station of Pollution Control Department. From that information, a percentile 90 of SO_2, CO and NO_X was calculated for representing of atmospheric concentration that carries away to Siriraj Hospital area.

6.2 Determination of Local Concentration

The local concentration from mobile source used in this research was the concentration that travels on an outside road and inside road in Siriraj Hospital area.

The local concentration was obtained from counted amount of vehicles in period of 24 hours recorded by using CCTV camera. In this study, the CCTV camera was installed on internal and external road as follow Arunamarin road, Phran nok road, Rail road, Internal main A road and Internal main B road. The position of roads in this study is illustrated in Figure 6.

After finishing the record on amount of vehicle, next step was to use factor data of air pollution release from each kind of vehicle (Table 7) to consider separate type of vehicle. This is because, each kind of vehicle has emitted an air pollution unequally, depending engine type, fuel and velocity etc. This research used average counted vehicle per hour, estimated velocity and separated vehicles in 4 types as follow;

a) Motorcycle
b) Gasoline engine car such as taxi and sedan.
c) Diesel engine car such as pickup
d) Large diesel engine car such as bus and truck more than 6 wheels.

From amount of vehicle in each type and velocity data, it is possible to calculate emission rate of SO_2, CO and NO_X for ISC-AERMOD View program. The emission factor used in this study in listed in Table 7.

For emission factor from Pollution Control Department and Air Quality Review and Assessment in Salford in Table 7 emission rate is calculated by Equation 14 and 15.

$$CEF = N \times EF \tag{14}$$

$$\text{Emission Rate} = CEF \times V \tag{15}$$

Where CEF is composite emission factor (g/km), N is amount of car in 1 hour, and EF is emission factor (g/km), V is average velocity (km/hour).

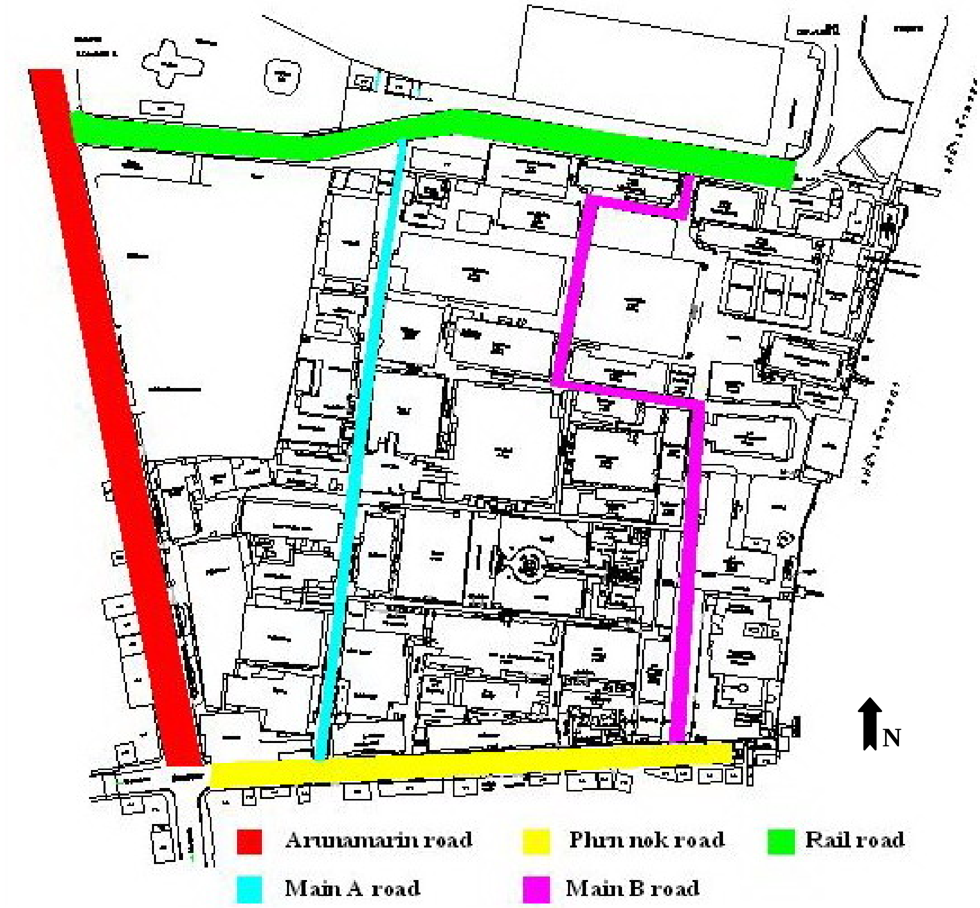

Figure 6 Location where vehicle count was carried out in this research.

Emission rate data input for ISC-AERMOD View program was selected from emission source in line source type and the meteorology data in period of one year (1 January to 31December 2007) was used to define a concentration of annual SO_2, 24 hour SO_2, 1 hour CO, 8 hour CO and 1 hour NO_X, respectively.

6.3 Collection Concentration

The atmospheric concentration was added with local concentration in order to get the background concentration. After that the background concentration was added with the concentration from stack boiler continuously.

Table 7 The type of vehicle and emission factor.

Type of Vehicle	Velocity (km/hour)	SO_2 *	CO	NO_X
		(gram / kilometer / vehicle)		
Motorcycle	5	0.007856	17.2*	0.51
	10	0.007856	17.2*	0.46
	20	0.007856	17.2*	0.43
	30	0.007856	17.2*	0.46
	40	0.007856	17.2*	0.53
	50	0.007856	17.2*	0.58
Gasoline Engine	5	0.045683	151.76	2.25
	10	0.041938	86.12	1.93
	20	0.035309	44.82	1.68
	30	0.029825	32.25	1.69
	40	0.025486	26.01	1.81
	50	0.022292	21.79	1.93
Diesel Engine	5	0.041372	4.04	1.86
	10	0.038069	3.15	1.63
	20	0.032143	2.03	1.32
	30	0.027127	1.40	1.12
	40	0.023021	1.04	1.01
	50	0.019824	0.82	0.96

Table 7 (Continued)

Type of Vehicle	Velocity (km/hour)	SO_2 *	CO	NO_X
		(gram / kilometer / vehicle)		
Large Diesel Engine	5	0.041372	25.03	31.76
	10	0.038069	19.55	27.93
	20	0.032143	12.57	22.50
	30	0.027127	8.67	19.15
	40	0.023021	6.42	17.22
	50	0.019824	5.10	16.36

Source : Pollution Control Department (1997)
*Salford Government (2004)

7. Air Quality Impact Assessment

The background concentrations and the concentrations of air pollutants from the stack boilers were compared to the ambient air quality standards of Thailand in order to determine the air quality impacts at Siriraj Hospital. The Ambient Air Quality Standard of Thailand is described in Table 3. The background concentration was added to the concentration from the stack boiler by adding as similar grid spacing. Table 8 shows examples for calculating the actual air pollutants concentration.

Table 8 The example grid spacing for calculating the actual air pollutants.

1	50 (20)	**3**	30 (15)
2	10 (30)	**4**	5 (35)

Note : The value in the bracket is the background concentration.

For example in Table 8, the summation in grid spacing 1, 2, and 4, which is the actual concentration of each grid spacing, were 70, 40, 45 and 40 $\mu g/m^3$, respectively.

8. The Variation Source and Building Condition

The test results from the variation of source and building condition were the concentration of air pollutants. The calculation for concentration from both conditions is as follow;

The first test was done by varying the stack height from 6 to 26 meter at Laundry stack (16 meters) and fixing the Syamindry stack (65 meters). The concentration of air pollutants was obtained by using AERMOD-PRIME calculation.

The second test was to vary the building height surrounding the stacks by adding or reducing the building height to 10 m of every building. The concentration of air pollutants was obtained by using AERMOD-PRIME calculation.

RESULTS AND DISCUSSION

This study was performed in Siriraj Hospital area and the study results were divided into 7 parts including study location, air pollutants measurement, meteorological data, actual condition results (from stack boiler), background concentration results, air quality impact assessment and variation of the stacks and building condition.

1. Location study

The Siriraj Hospital is located on the area of 123,200 m^2 and consists of 76 buildings. The working staffs are 13,000 and more than 5,000 patients visiting here every day. The following figure shows the aerial photograph of the Siriraj Hospital area.

Figure 7 The aerial photography of the Siriraj Hospital area.

From Figure 7, it was found that the northern part of the hospital is connected to Bangkok Noi Canal, the eastern contacts to Chaophraya River, the southern contacts to Phan Nok Road and the western contacst to Arunamarin Road.

1.1 Building Downwash Data

The results of building dimension around the stack boiler are obtained by using BPIP-PRIME program to create the file used in AERMOD-PRIME which is shown and explained in Appendix E. The three dimensional simulation of building for the Siriraj Hospital area was shown in Figure 8.

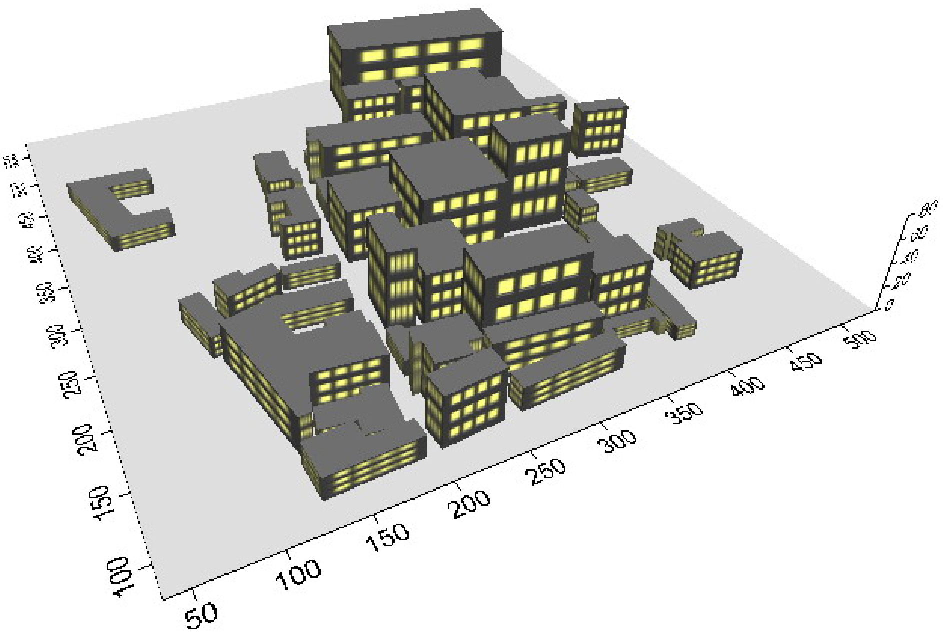

Figure 8 The simulation of buildings in the Siriraj Hospital.

2. The Air Pollutants Measurement

The air emission source in the Siriraj Hospital came from 2 sources including chemical source and fuel source used in steam boiler or exhaust gases from stack boiler. Two emission sources in Siriraj Hospital are described in following section.

2.1 Chemical Sources

There are several chemicals used in the laboratory of Siriraj Hospital. The major used chemical is formaldehyde from pathology laboratory and autopsy. The amount of formaldehyde used in pathology laboratory and autopsy is equal to 845 and 250 liter/day, respectively. However, from the measurement of formaldehyde by using Gas Toxic Analyzer it was found that formaldehyde concentration are 1.80 ppm and 0.01 ppm from pathology and autopsy, respectively. These concentrations are quite low and no effect to the environment. Therefore, formaldehyde is not concerned in this study.

2.2 Stack Boiler

The steam boiler used at the Siriraj Hospital is the boiler using fuel oil grade No. 1 that is operated for 16 hours per day. The SO_2, CO and NO_2 were measured from the boiler.

a) Syamindry Building

The steam boiler at Syamindry Building has a capacity of 260 steam horse power and amount of fuel oil used equal to 390 liters per day approximately. The measurement of air pollutants indicated that SO_2, CO and NO_2 concentration were 73.40 ppm, 34 ppm, and 53 ppm, respectively. The stack inside diameter, the stack height and the stack temperature is 0.4 m, 65 m, and 459 °K, respectively. Following the Equation 9 to 12, the flow rate of dry gas was 454.80 m^3/hour, the stack pressure (P_g) obtained from Equation 13 was 758 mmHg and the velocity from

Equation 8 was 0.528 m/s. From provided data and Equation 5 to 7, the emission rate of SO_2, CO and NO_2 were 0.0165, 0.0020 and 0.0089 g/s, respectively.

b) Laundry Division

The steam boiler at Laundry Division has a capacity of 500 steam horse power and amount of fuel oil used equal to 2,050 liters per day approximately. The measurement of air pollutants indicated that SO_2, CO and NO_2 concentration were 263.10 ppm, 6 ppm, and 27.7 ppm, respectively. The stack inside diameter, the stack height and the stack temperature is 0.6 m, 16 m, and 405 °K, respectively. Following Equation 9 to 12 the flow rate of dry gas was 1741.767 m^3/hour, the stack pressure (P_g) obtained from equation 13 was 759.631 mmHg and the velocity from Equation 8 was 1.28 m/s. From Equation 5 to 7, the emission rate of SO_2, CO and NO_2 were 0.3666, 0.0036 and 0.0277 g/s, respectively. The source parameters from Syamindry and Laundry which required for input in the ISC-AERMOD are showed in Table 9.

Table 9 The source parameter for using in ISC-AERMOD.

Parameter	Syamindry Source	Lanudry Source
SO_2 emission rate (g/s)	0.0165	0.3666
CO emission rate (g/s)	0.0020	0.0036
NO_2 emission rate (g/s)	0.0089	0.0277
Velocity (m/s)	0.528	1.28
Temperature (°K)	459	405
Stack Inside Diameter (m)	0.4	0.6
Stack Height (m)	65	16

3. Meteorological Data Condition

The meteorological data used in this study was collected by the Pollution Control Department (PCD) 2007 and the Thai Meteorological Department (TMD) 2007 for hourly surface data during period from January 1 to December 31, 2007.

From the meteorological data, the average temperature, average relative humidity and average station pressure was 29.35°C, 77.74% and 757.85 mmHg, respectively. From wind data, the average velocity is equal to 1.61 m/s and the average velocity in each season is equal to 1.66 m/s (summer), 1.64 m/s (rainy) and 1.50 m/s (winter), respectively. The WRPLOT program was used to prepare the wind-rose to show the meteorological characteristics by rotating 180° to change from wind direction to flow direction. The wind-rose or wind direction frequency in period of 1 year is showed in below:

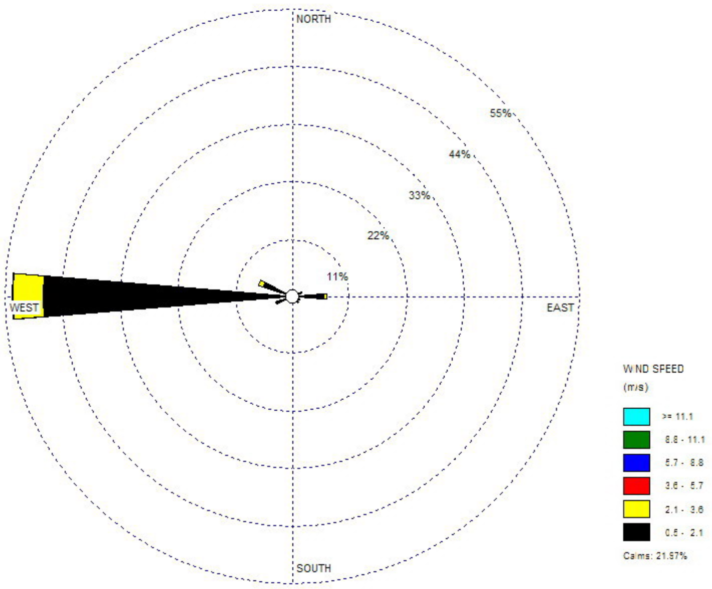

Figure 9 The frequency of wind direction in period of 1 year (2007).

From Figure 9, the wind directions are from the west to the east of the Siriraj Hospital area. The wind class frequency distribution in period of 1 year of the wind velocity of 5.7 – 3.6 m/s, 3.6 – 2.1 m/s, 2.1 -0.5 m/s and calms wind equal to 0.3%, 7.2%, 70.5% and 22%, respectively (Figure 10).

The wind direction frequency and the wind class frequency distribution of each season are shown in Appendix C. The wind class results for 1 year period (2007) are shown in Figure 10.

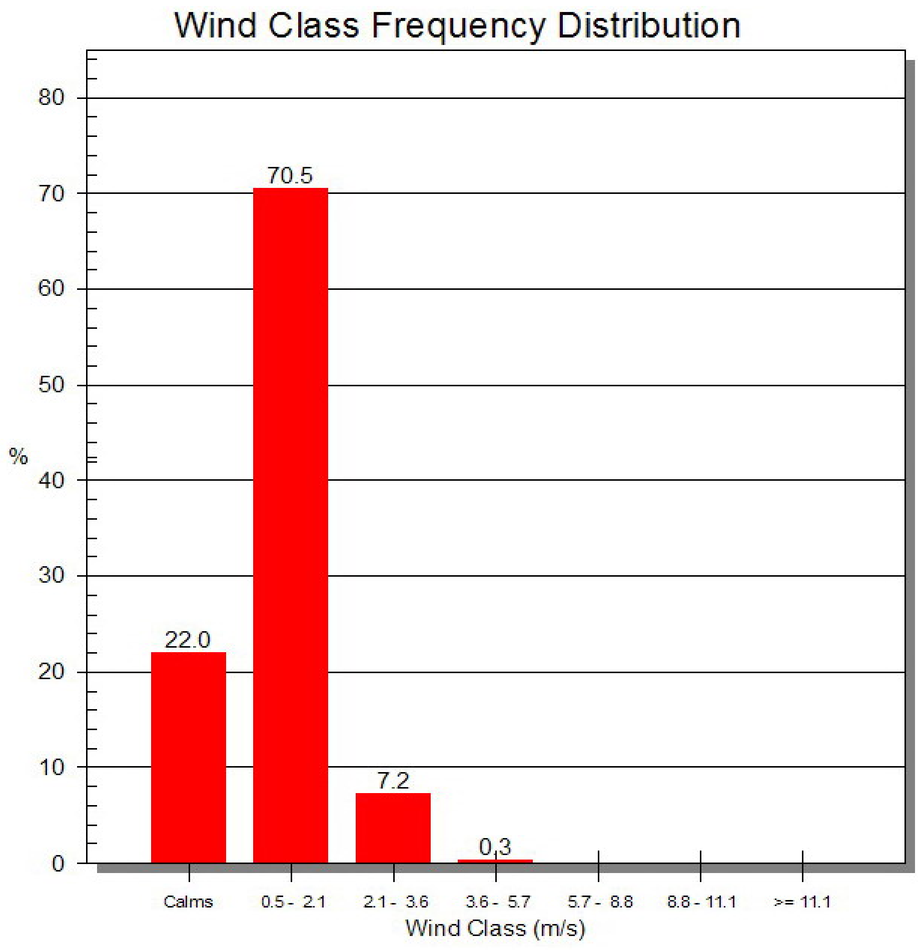

Figure 10 The wind class frequency distribution in period of 1 year (2007).

4. The Air Pollutants for Stack Boiler

The emission data and the meteorological data were used as input for ISC-AERMOD View by selecting AERMOD-PRIME to calculate the air pollutants in 1st hour, 8th hour, 24th hour and annual concentration. The results of three air pollutants emitted from the stack boiler, the dispersion contouring line and the maximum location concentration were discussed.

4.1 Sulfur Dioxide (SO_2)

The maximum SO_2 concentration of 1-hour average for exhausted air was about 110.041µg/m^3. The following figure showed the typical SO_2 dispersion of 1-hour average from the stack boiler at Siriraj Hospital.

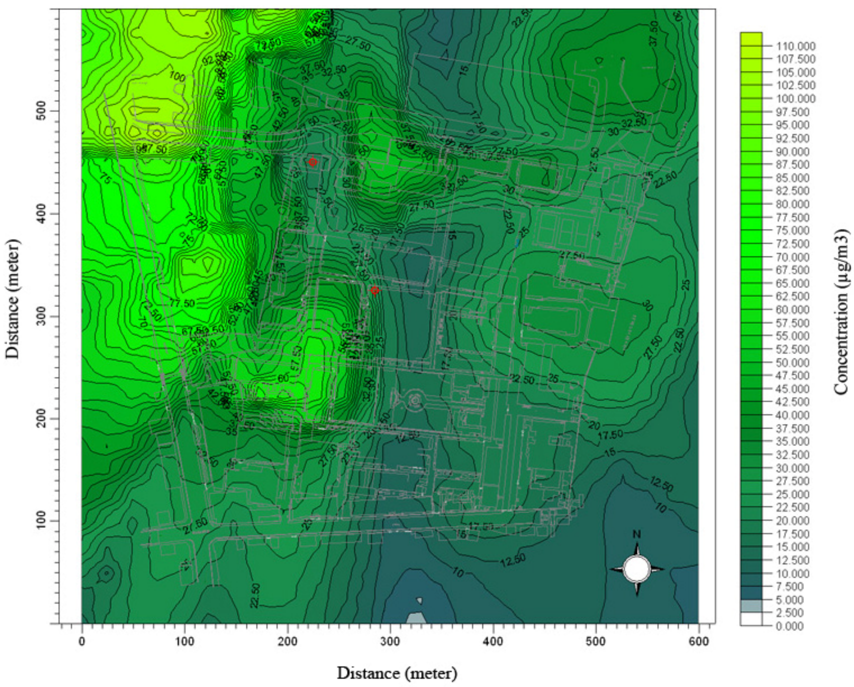

Figure 11 Typical SO_2 Dispersion of 1-hour average in Siriraj Hospital.

From Figure 11, SO_2 was dispersed from the east to the west of the hospital area (Chaophraya River to Arunamrin Road), and the distance from the

Syamindry Stack and from the Laundry stack to the concentration maximum location at Amarin Temple was 258 m and 152 m, respectively.

The maximum SO_2 concentration of 24-hour average for exhausted air was about 20.085µg/m^3. The following figure showed the typical SO_2 dispersion of 24th hour from the stack boiler at Siriraj Hospital. The 24-hour average of SO_2 was dispersed from the eastern to the western of the hospital area (Chaophraya River to Arunamrin Road), and the distance from the Syamindry Stack and from the Laundry stack to the concentration maximum location at Amarin Temple School was 210 m and 127 m, respectively. The typical SO_2 dispersion of 24-hour average in Siriraj Hospital area was showed in Figure 12.

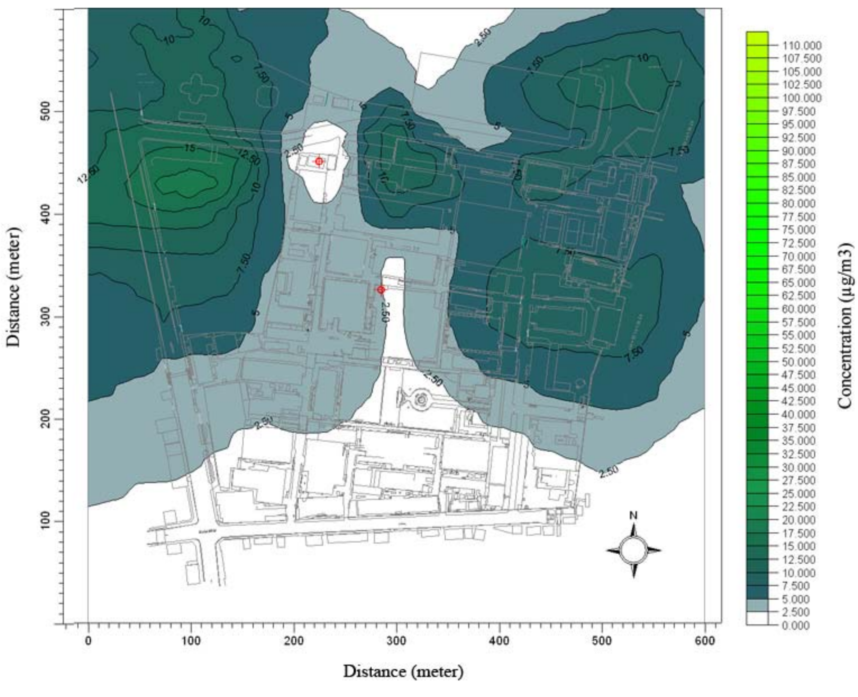

Figure 12 Typical SO_2 Dispersion of 24-hour average in Siriraj Hospital.

The maximum SO_2 concentration of annual average for exhausted air was about 8.297 µg/m^3. The Figure 13 showed the typical SO_2 dispersion of annual average from the stack boiler in Siriraj Hospital.

The annual average of SO_2 was dispersed from the west to the east of the hospital area (Arunamrin Road to Chaophraya River), and the distance from the Syamindry Stack and from the Laundry stack to the concentration maximum location at Car park and Sport Club Building was 126 m and 75 m, respectively. The typical SO_2 dispersion of annual average in Siriraj Hospital area was showed in Figure 13.

Considering the average concentration of SO_2 from the stack boiler in each season, the 1-hour average of SO_2 concentration for summer, rainy and winter was 109.931, 106.193 and 110.041 $\mu g/m^3$, respectively. The 24-hour average of SO_2 concentration for summer, rainy and winter was 14.105, 14.011 and 20.085 $\mu g/m^3$, respectively. The period SO_2 concentration for summer, rainy and winter was 8.885, 8.906 and 6.595 $\mu g/m^3$, respectively.

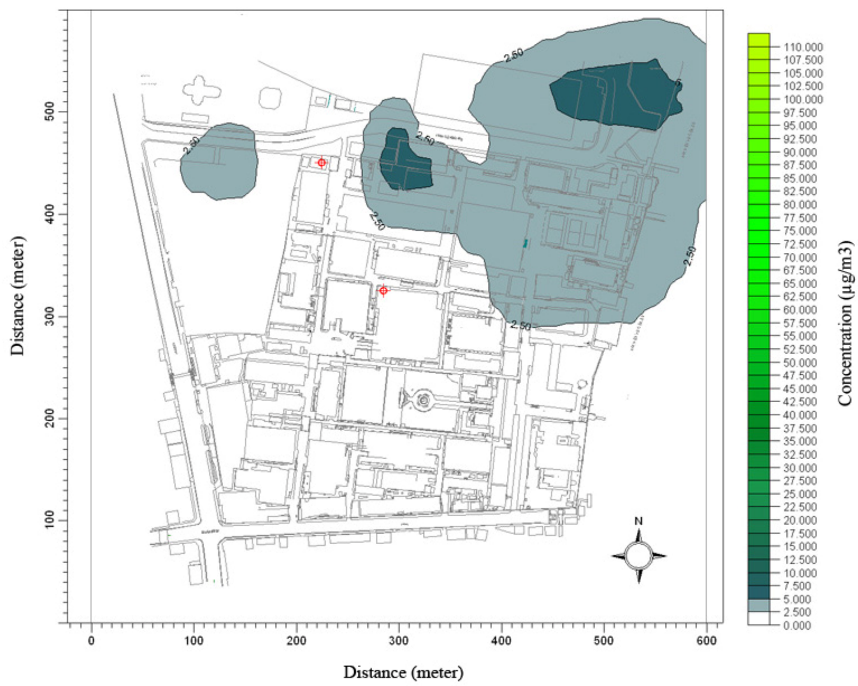

Figure 13 Typical SO_2 Dispersion of annual average in Siriraj Hospital.

The 1-hour and 24-hour average of SO_2 for each season was dispersed from the east to the west of the hospital area (Chaophraya River to Arunamrin Road), the period of SO_2 dispersion for each season similar to the SO_2 dispersion by using 1 year period of the meteorological data. In addition, the maximum SO_2 concentrations of 1-hour average, and 24-hour average of SO_2 for summer and winter season were similar to a 1 year period at the same location, while the 1-hour average and 24-hour average of SO_2 for rainy season affected the maximum concentration in difference grid space.

For winter season, maximum concentration of 1-hour and 24-hour of SO_2 was took place on December 14, 2007 at 20:00 hours and November 7, 2007 at 24:00 hours for wind speed equal to 1 m/s and calm wind (wind speed < 1 m/s) condition, respectively.

4.2 Carbon Monoxide (CO)

The maximum CO concentration of 1-hour average for exhausted air was about 1.024 $\mu g/m^3$. The following figure showed the typical CO dispersion of 1-hour average from the stack boiler at Siriraj Hospital.

From Figure 14, the 1-hour average of CO was dispersed from the east to the west of the hospital area (Chaophraya River to Arunamrin Road), and the distance from the Syamindry Stack and from the Laundry stack to the concentration maximum location at Amarin Temple School was 244 m and 150 m, respectively.

The maximum CO concentration of 8-hour average for exhausted air was about 0.362$\mu g/m^3$. The following figure showed the typical CO dispersion of 8-hour average from the stack boiler at Siriraj Hospital.

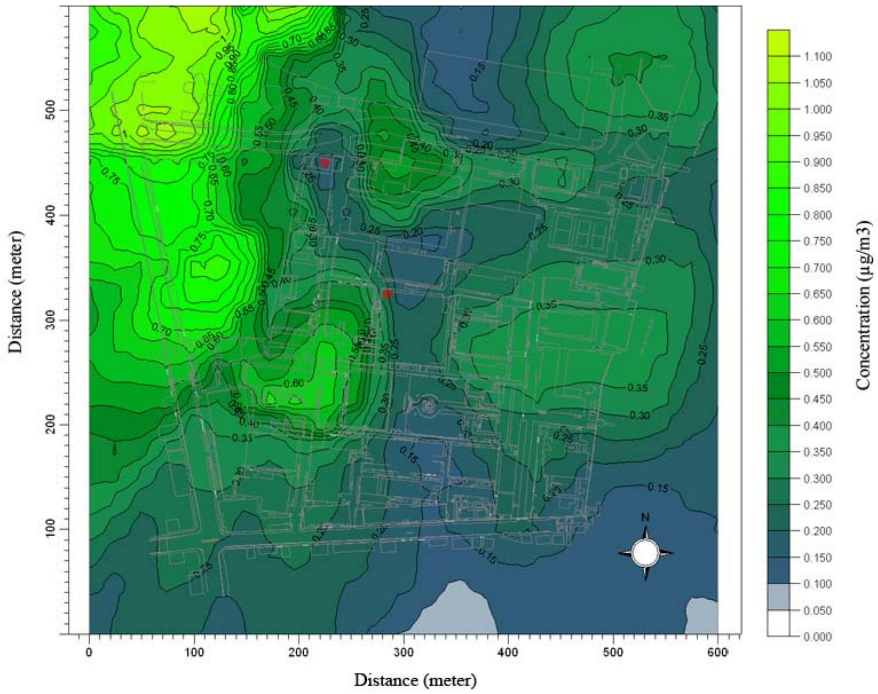

Figure 14 Typical CO Dispersion of 1-hour average in Siriraj Hospital.

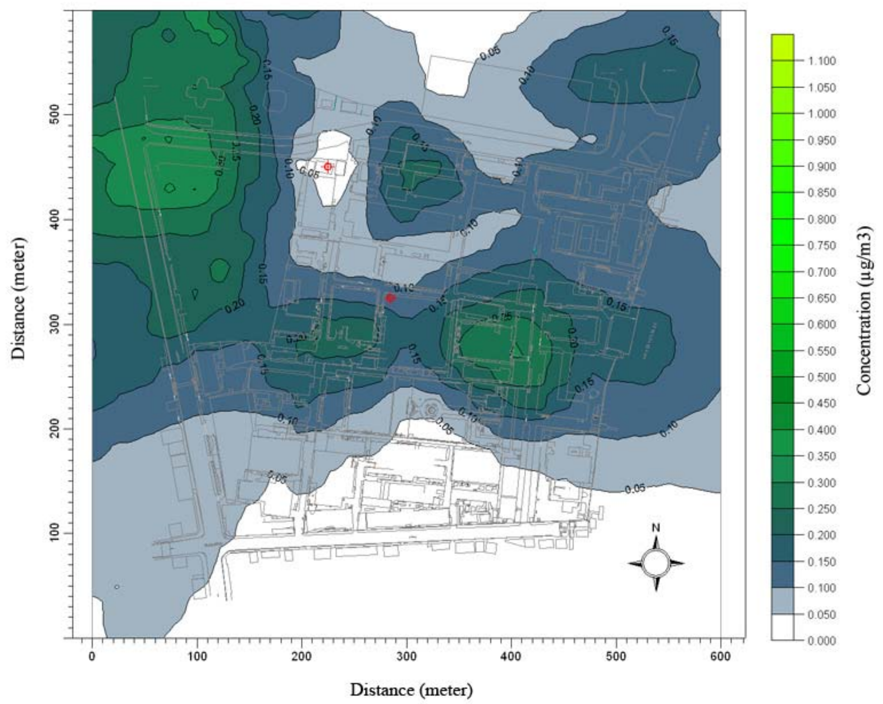

Figure 15 Typical CO Dispersion of 8-hour average in Siriraj Hospital.

From Figure 15, the 8-hour average CO was dispersed from the east to the west of the hospital area (Chaophraya River to Arunamrin Road), and the distance from the Syamindry Stack and from the Laundry stack to the concentration maximum location at Amarin Temple School was 244 m and 150 m, respectively.

The annual average CO concentration for exhausted air was about 0.084 $\mu g/m^3$. The typical CO dispersion of annual average from the stack boiler at Siriraj Hospital was showed in Figure 16.

The annual average CO was dispersed from the west to the east of the hospital area (Arunamrin Road to Chaophraya River), and the distance from the Syamindry Stack and from the Laundry stack to the concentration maximum location at Medical Technical Building was 118 m and 230 m, respectively.

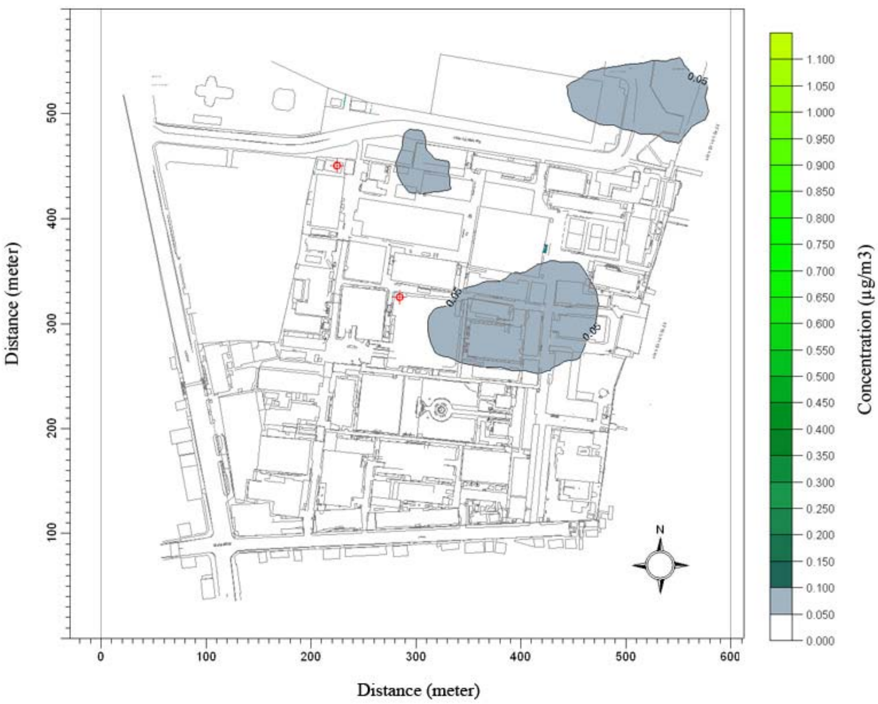

Figure 16 Typical CO Dispersion of annual average in Siriraj Hospital.

Considering the concentration of CO from the stack boiler in each season, the 1-hour average of CO concentration for summer, rainy and winter was 1.097, 1.062 and 1.024 μg/m^3, respectively. The 8-hour average of CO concentration for summer, rainy and winter was 0.358, 0.290 and 0.362 μg/m^3, respectively. The period CO concentration for summer, rainy and winter was 0.089, 0.090 and 0.072 μg/m^3, respectively.

The 1-hour average and 8-hour average of CO dispersed for each season was similar to the CO dispersed by using the meteorological of 1 year period. The 1-hour average and 8-hour average of CO concentration, the maximum location are difference in grid space, but the maximum location would be not change.

The maximum concentration of 1-hour average and 8-hour average CO was found for winter season. The maximum CO concentration of 1-hour average was taken place on December 14, 2007 at 20:00 hours where calm wind (wind speed < 1 m/s) condition, while 8-hour average was taken place on Febuary 1, 2007 at 8:00 hours where wind speed and wind direction was 2 m/s and 89 degree angle, respectively.

4.3 Nitrogen Dioxide (NO_2)

The maximum NO_2 concentration of 1-hour average for exhausted air was about 8.340 μg/m^3. The following figure showed the typical NO_2 dispersion of 1-hour average from the stack boiler at Siriraj Hospital.

From Figure 17, the 1-hour average of NO_2 was dispersed from the east to the west of the hospital area (Chaophraya River to Arunamrin Road), and the distance from the Syamindry Stack and from the Laundry stack to the concentration maximum location at Amarin Temple School was 258 m and 152 m, respectively.

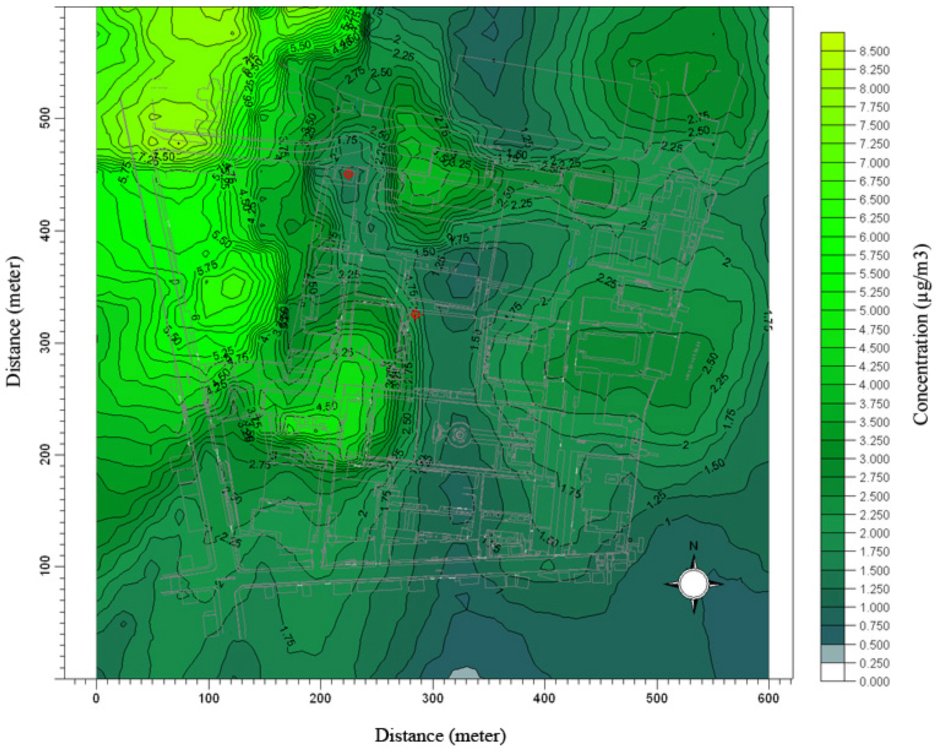

Figure 17 Typical NO_2 Dispersion of 1-hour average in Siriraj Hospital.

The maximum NO_2 concentration of annual average for exhausted air was about 0.630 µg/m^3. The typical NO_2 dispersion of annual average from the stack boiler at Siriraj Hospital area was showed in Figure 18.

The annual average of NO_2 was dispersed from the west to the east of the hospital area (Arunamrin Road to Chaophraya River), and the distance from the Syamindry Stack and from the Laundry stack to the concentration maximum location at Car park and Sport Club Building was 126 m and 75 m, respectively.

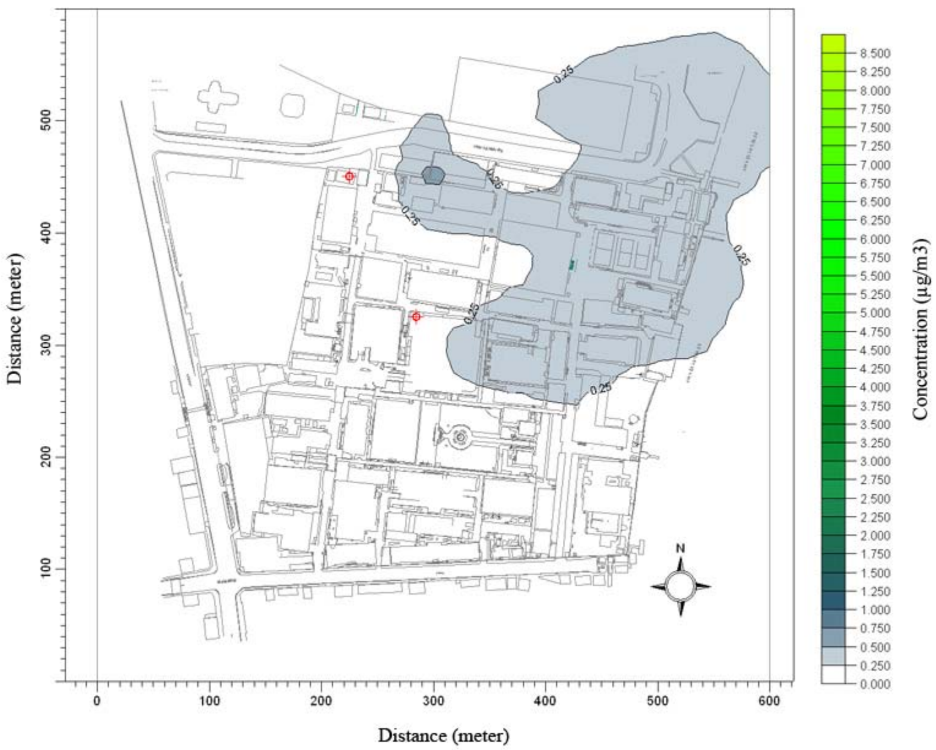

Figure 18 Typical NO_2 Dispersion of annual average in Siriraj Hospital.

Considering the concentration of NO_2 from the stack boiler in each season, the NO_2 concentration of 1-hour average for summer, rainy and winter was 8.328, 8.057 and 8.340 $\mu g/m^3$, respectively. The NO_2 concentration of annual average for summer, rainy and winter was 0.673, 0.675 and 0.501 $\mu g/m^3$, respectively. The NO_2 dispersed for each season was similar to the NO_2 dispersed by using the meteorological of 1 year period. The NO_2 concentration maximum locations are difference in grid space, but the maximum location would be not change.

From the results it was found that the maximum NO_2 concentration of 1-hour average for winter. The maximum NO_2 concentration of 1-hour average was took place on December 14, 2007 at 20:00 hours where calm wind (wind speed < 1 m/s) condition.

The all average concentration of three air pollutants concentration (1-hr SO_2, 24- hrs SO_2, annual SO_2, 1-hr CO, 8-hrs CO and 1-hr NO_2) from stack boiler was tendencies to not exceeded the ambient air quality standard of Thailand.

5. Background Concentration

The Background concentrations in this research were used from two sources. The first source is atmospheric concentration and the second source is local concentration or mobile source concentration.

5.1 Atmospheric Concentration

The hourly air quality data in one year period (from 1 January 2007 to 31 December 2007) receiving from the observation station of Pollution Control Department (PCD) nearly Siriraj Hospital (Intrapitak Station). All hourly air quality data showed a number of hours equal to 8760 hours, the valid data of SO_2, CO and NO_2 was 7,234; 8,273; and 8,361 hours respectively, while the missing data of SO_2, CO and NO_2 was 1,526; 487; and 399 hours respectively. Using this data input for SPSS program to calculated the concentration at percentile of 90.

The hourly air quality information obtained from Intrapitak station showed that the atmospheric concentration of SO_2, CO and NO_2 were 28.775 (11 ppb); 2,060.085 (1.80 ppm); and 94.011 $\mu g/m^3$ (50 ppb), respectively for the percentile of 90 for 1 year period in 2007.

5.2 Local Concentration

The local concentration (mobile source) was received by emission rate from the vehicle and calculated by using AERMOD program. The amounts of vehicle for each type by counting in 5 roads are showed in Table 10. In addition the average velocity in Arunamarin Road, Phan Nok Road, Rail Road, Internal Main A and Internal Main B was 30.25, 22.50, 32.50, 16.83 and 19.81 km/hr, respectively.

Using the information in Table 10 and the average velocity for calculated the emission rate by following Equation 14, Equation 15 and Table 7. The emission factor and emission rate of air pollutants was showed in Table 11. The example of emission rate calculation is showed in Appendix B.

Table 10 The amount and type of vehicles in the Siriraj Hospital area for 24 hours period counted.

Type of Vehicles	A	B	C	D	E
Motorcycle	15,504	7,386	5,438	3,536	1,660
Gasoline Engine	37,248	18,480	7,578	6,550	4,174
Diesel Engine	7,596	3,270	4,654	1,984	1,144
Large Diesel Engine	1,764	42	290	12	30
Total	62,112	29,178	17,960	12,082	7,008

Note: The amount of vehicle in amount per day.

External roads: A is Arunamarin Road, B is Phan Nok Road and C is Rail Road.

Internal roads: D is Main A and E is Main B.

Table 11 The emission factor and emission rate of air pollutants from the vehicles.

Road	Composit Emission Factor (g/km)			Emission Rate (g/s)		
	SO_2	CO	NO_X	SO_2	CO	NO_X
A	0.027	24.052	1.812	2.3×10^{-4}	0.202	0.0152
B	0.029	32.985	1.305	1.6×10^{-4}	0.206	0.0073
C	0.006	19.303	1.448	5.4×10^{-5}	0.174	0.0130
D	0.028	29.653	1.297	1.3×10^{-4}	0.138	0.0060
E	0.030	31.101	1.393	1.7×10^{-4}	0.171	0.0076

Note: External roads: A is Arunamarin road, B is Phan Nok road and C is Rail road.

Internal roads: D is Main A and E is Main B.

From the emission rate in Table 11 was added to the AERMOD program and executed by selecting the line source and the meteorological data for one year period. The concentration and dispersion results of three air pollutants are explaining follow as;

a) Sulfur Dioxide (SO_2)

The maximum SO_2 concentration of 1-hour average for local (mobile source) air pollutants was 0.138 µg/m^3. The 1-hour average of SO_2 was dispersed from the roads to the hospital area, and the distances refer from the Siriraj Junction to the concentration maximum location at the end of Phran Nok Road was 313 m. The typical SO_2 dispersion of 1-hour average from the local source at Siriraj Hospital area was showed in Figure 19.

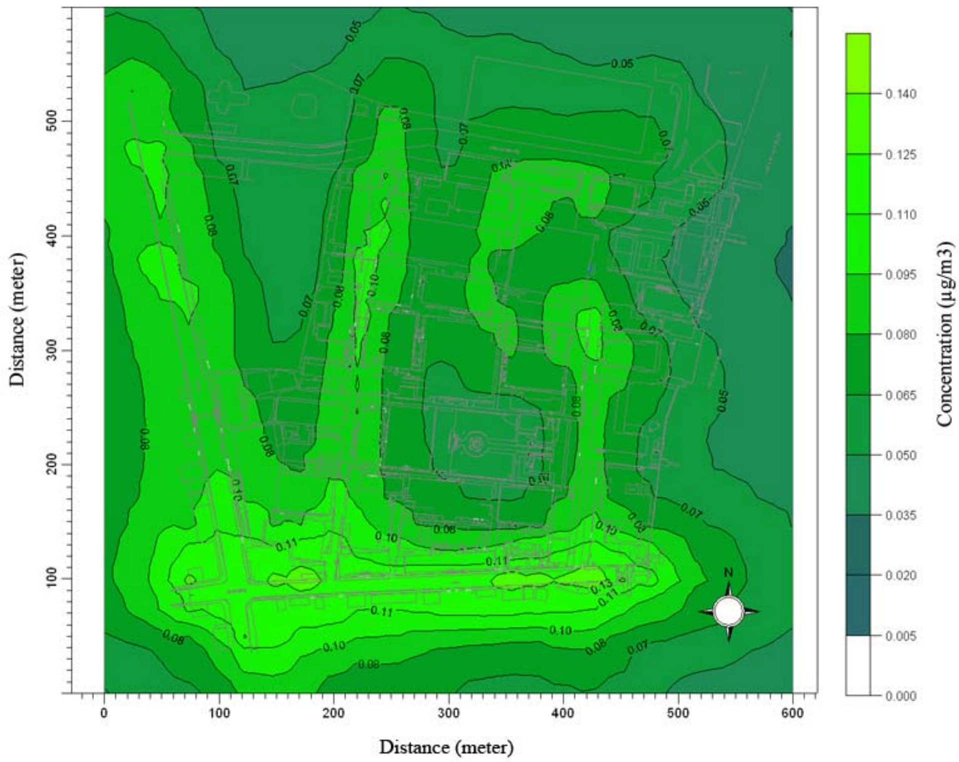

Figure 19 Typical SO_2 dispersion of 1-hour average from the local source.

From Figure 19 to expressing for the maximum SO_2 concentration of 1-hour average was took place on August 29, 2007 at 07:00 hours where calm wind (wind speed < 1 m/s) condition.

The maximum SO_2 concentration of 24-hour average for local (mobile source) air pollutants was 0.078 µg/m^3. The 24-hour average of SO_2 was dispersed from the roads to the hospital area, and the distances refer from the Siriraj Junction to the concentration maximum location at on Phran Nok Road was 238 m. The typical SO_2 dispersion of 24-hour average from the local source at Siriraj Hospital area was showed in Figure 20.

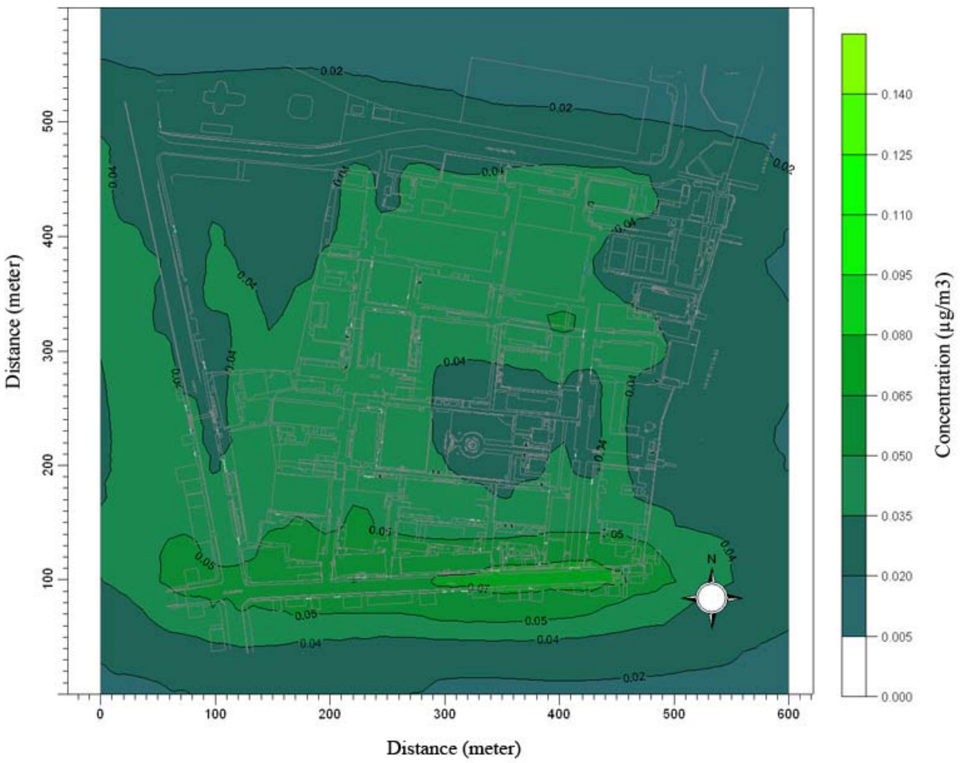

Figure 20 Typical SO_2 dispersion of 24-hour average from the local source.

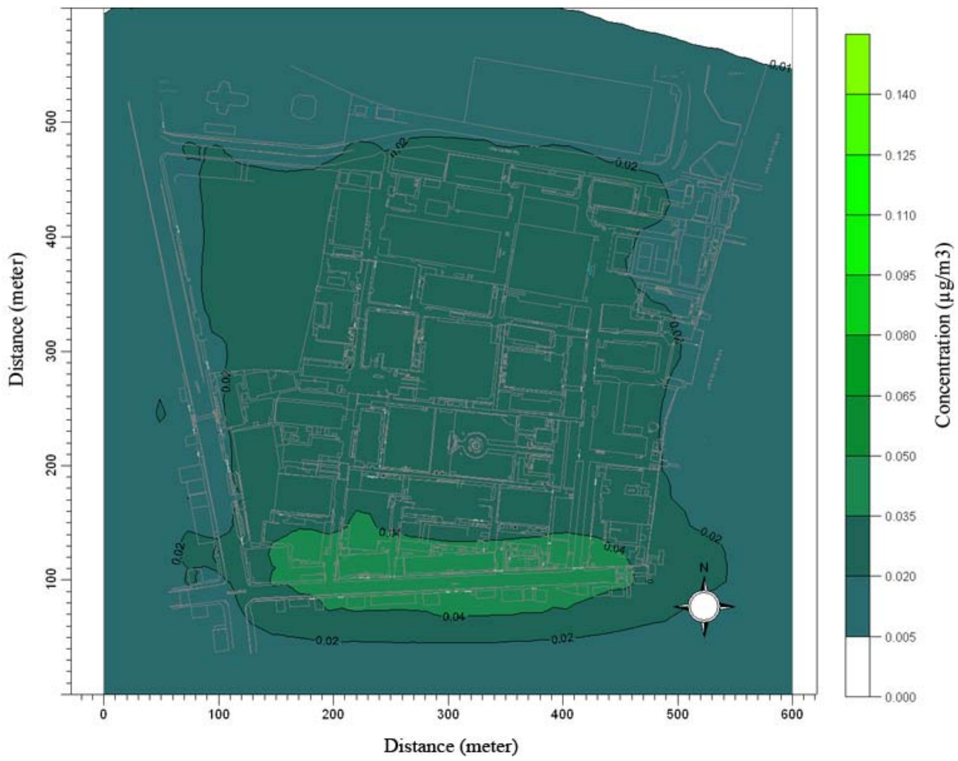

Figure 21 Typical SO_2 dispersion of annual average from the local source.

From the results to expressing in Figure 20 the maximum SO_2 concentration of 24-hour average was taken place on 2007/12/02 at 24:00 hours where wind speed and wind direction was 1 m/s and 268 degree angle, respectively.

From Figure 21 showed the maximum SO_2 concentration of annual average for local (mobile source) air pollutants was 0.05 µg/m^3. The annual average of SO_2 was dispersed from the roads to the hospital area, and the distances refer from the Siriraj Junction to the concentration maximum location at on Phran Nok Road was 238 m.

b) Carbon Monoxide (CO)

The maximum CO concentration of 1-hour average and 8-hour average for local (mobile source) air pollutants were 453.423 µg/m^3 and 382.736 µg/m^3, respectively. The 1-hour average and 8-hour average of CO were dispersed from the roads to the hospital area, and the distances refer from the Siriraj Junction to the concentration maximum location at the end of Phran Nok Road was 313 m. The Figure 22 was showed the typical CO dispersion of 1-hour average.

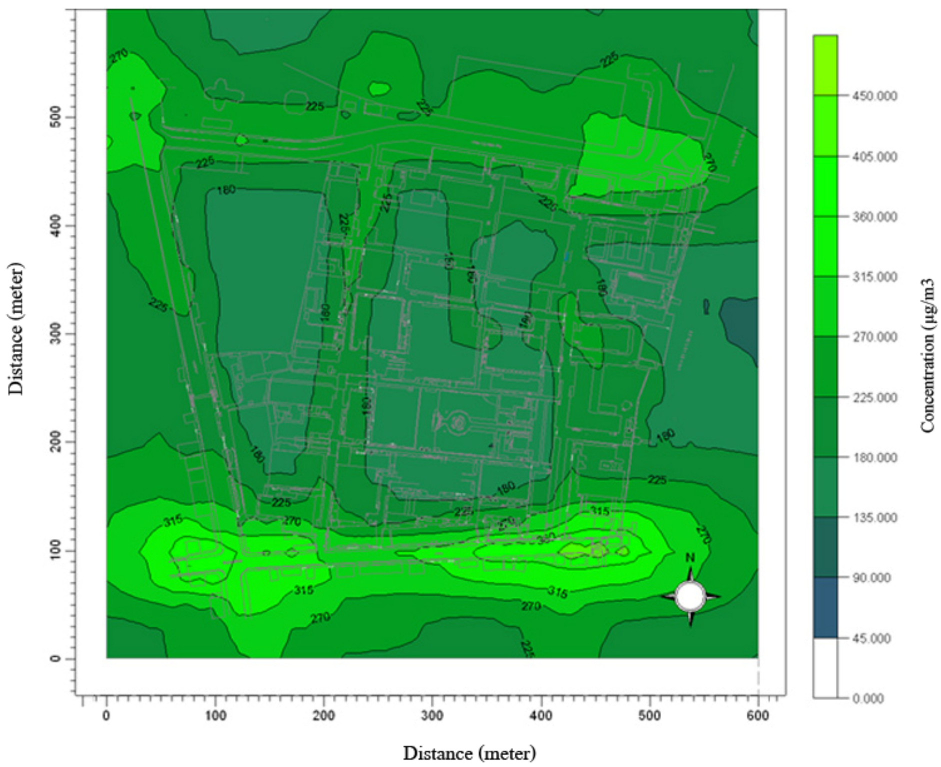

Figure 22 Typical CO dispersion of 1-hour from the local source.

From the results in Figure 22 to expressing for the maximum CO concentration of 1-hour average was took place on Febuary 19, 2007 at 07:00 hours, where calm wind (wind speed < 1 m/s) condition, while 8-hour average CO was taken place on October 4, 2007 at 08:00 hours, where the wind speed and wind direction was 1 m/s and 267 degree angle, respectively. The typical CO dispersion of 8-hour average from the local source at Siriraj Hospital area is showed in Figure 23.

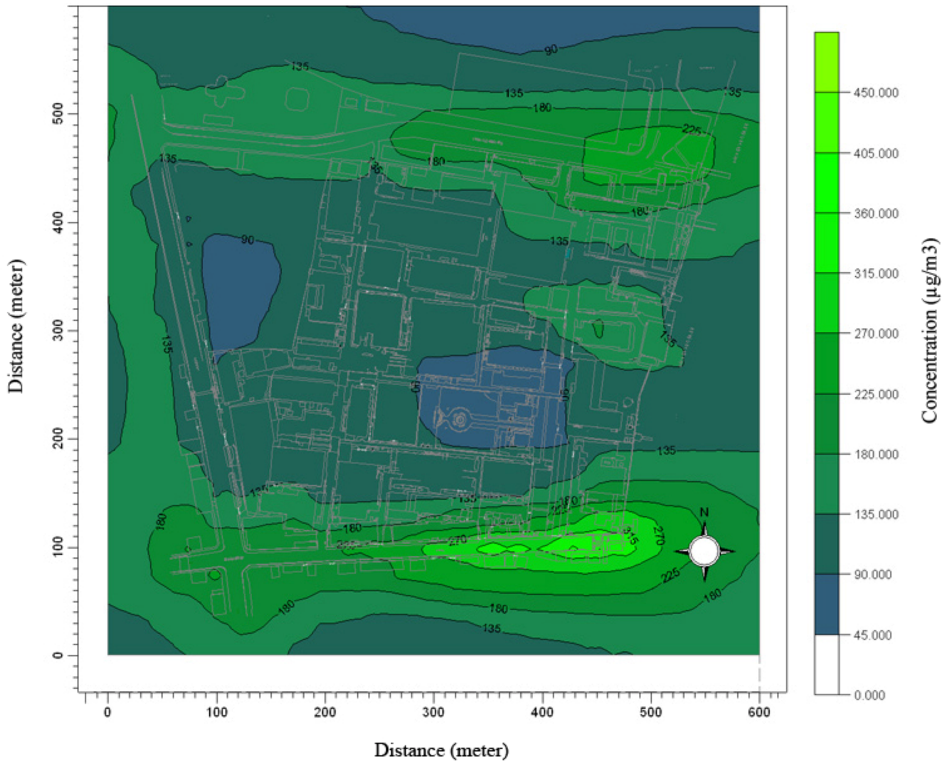

Figure 23 Typical CO dispersion of 8-hour from the local source.

c) Nitrogen Dioxide (NO_2)

The maximum NO_2 concentration of 1-hour average for local (mobile source) air pollutants was 17.964 µg/m^3. The 1-hour average NO_2 was dispersed from the roads to the hospital area, and the distances refer from the Siriraj Junction to the concentration maximum location at on the Arunamarin Road was 40 m. The typical NO_2 dispersion of 1-hour average from the local source at Siriraj Hospital area was showed in Figure 24.

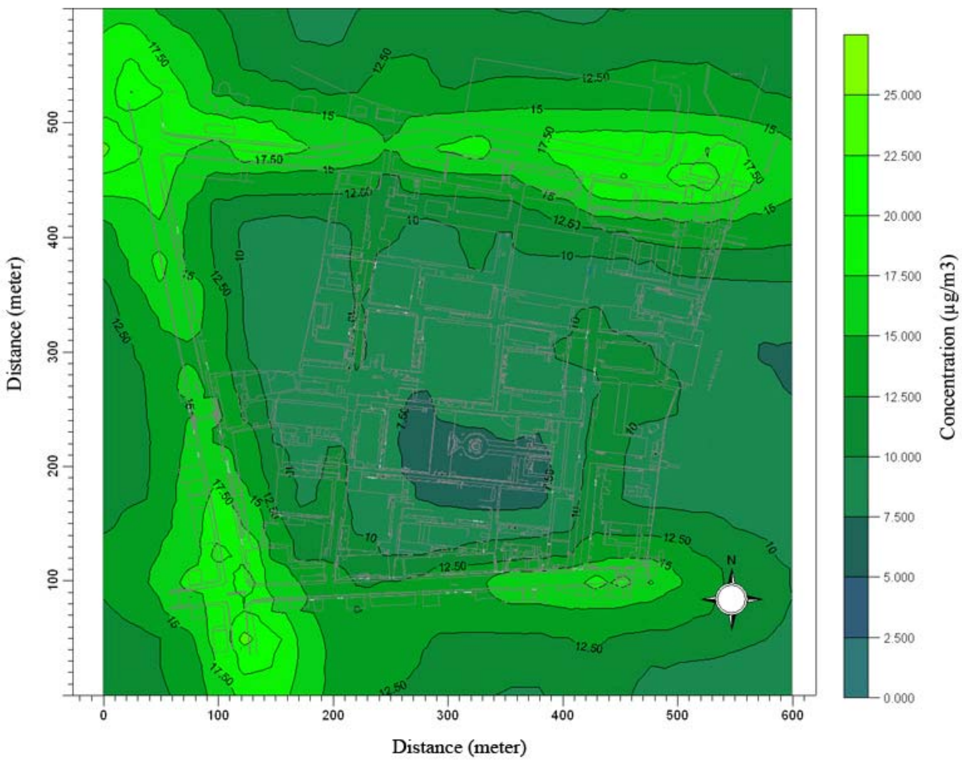

Figure 24 Typical NO_2 dispersion of 1-hour average from the local source.

From the results to expressing for the maximum NO_2 concentration of 1-hour average was took place on October 28, 2007 at 23:00 hours, where calm wind (wind speed < 1 m/s) condition.

Last step of determination to the background concentration was added the atmospheric concentration with the local concentration, the results of three air pollutant in the Siriraj Hospital area by according with ambient air quality standard of Thailand was showed in Table 12.

From the information in Table 12, the local concentration of three pollutants was less than the atmospheric concentration at blowing from other area. The SO_2, CO and NO_2 concentration for this table would be added with the air pollutants from stack boiler in next sections.

Table 12 The background concentration results for The Siriraj Hospital area.

Air Pollutants	Average	Atmospheric ($\mu g/m^3$)	Local ($\mu g/m^3$)	Background ($\mu g/m^3$)
SO_2	1st Hour	28.775	0.138	28.913
	24th Hours	28.775	0.078	28.853
	1 year	28.775	0.050	28.825
CO	1st Hour	2,060.085	453.423	2,513.508
	8th Hours	2,060.085	382.736	2,442.821
NO_2	1st Hour	94.011	17.964	111.975

6. Air Quality Impact Assessment

The actual concentration of three air pollutants in the Siriraj Hospital area was received by added the background concentration to the stack boiler concentration on grid by grid and compare the concentration with the ambient air quality standard of Thailand. The actual concentration of air pollutants was showed in table below.

Table 13 The actual concentration of air pollutants in the Siriraj Hospital area.

Air Pollutants	Average	Background ($\mu g/m^3$)	Stack ($\mu g/m^3$)	Actual ($\mu g/m^3$)
SO_2	1st Hour	28.913	110.401	138.898
	24th Hours	28.853	20.085	48.895
	1 year	28.825	8.297	37.096
CO	1st Hour	2,513.508	0.205	2,513.713
	8th Hours	2,442.821	0.034	2,442.855
NO_2	1st Hour	111.975	7.233	118.997

The results from Table 13 are received by compared the three air pollutants concentration at grid spacing by grid spacing. The actual concentrations of three air pollutants compared to the ambient air quality standard of Thailand are showed in table below.

Table 14 The Actual concentration compared with the ambient air quality standard of Thailand.

The Air Pollutants	Average	Actual (mg/m^3)	Ambient Standard (mg/m^3)
Sulfur Dioxide (SO_2)	1^{st} Hour	0.138	0.78
	24^{th} Hours	0.048	0.30
	1 year	0.037	0.10
Carbon monoxide (CO)	1^{st} Hour	2.513	34.20
	8^{th} Hours	2.442	10.26
Nitrogen Dioxide (NO_2)	1^{st} Hour	0.118	0.32

From Table 14, the concentration of air pollutants obtained from the ISC-AERMOD program and background concentrations are less than the ambient air quality standards of Thailand. These three air pollutants have no effect to the Siriraj Hospital staffs. The actual maximum concentration location for Siriraj Hospital area is showed in Figure 25.

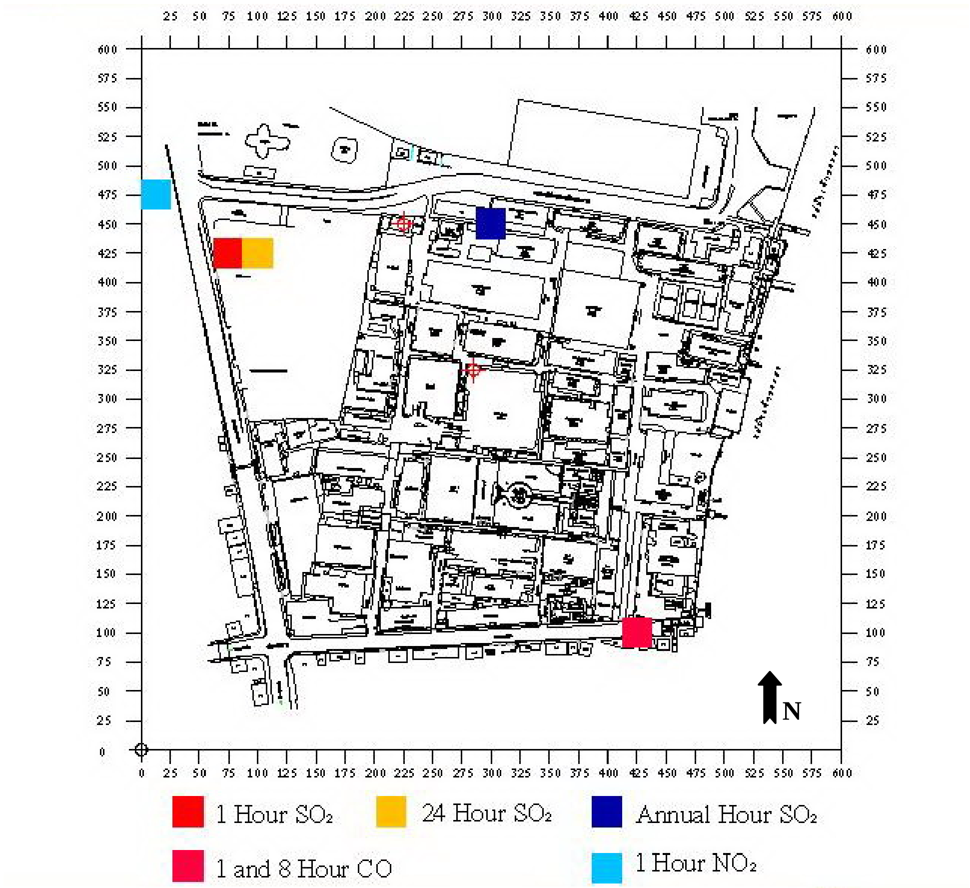

Figure 25 The actual maximum concentration location of air pollutants in Siriraj hospital area.

7. The Variation of Stack and Building Condition

7.1 The variation of stack height

The results of varied a stack boiler received from varied a stack height at Laundry Division from 6 to 26 m (the actual stack height is 16 m) and fix a stack height at Syamindry building (65 m) and calculated the concentration by using AERMOD-PRIME. From the annual concentrations of SO_2, NO_2 and CO decreased as the height increase and the percent of the SO_2, NO_2 and CO concentration as reduced from varied of a stack height at 6 to 16 m were 77%, 76.9% and 76.38%, respectively. Also, when the stack height was pass about16 m, the concentrations of SO_2 and NO_2 were slightly decreased. The concentration of CO was almost constant at each height of the stack and when considerate the percent of the SO_2, NO_2 and CO concentration as reduced from varied of a stack height at 16 to 26 m were 30.30%, 29.50% and 3.50%, respectively. The maximum concentration location of SO_2 and NO_2 was 50 m, 75 m and 285 m, from Laundry Division stack at a stack height of 6 to 11 m, 12 to 18 m and 19 to 26 m, respectively, while the maximum concentration location of CO was 50 m, 75 m and 230 m, from Laundry Division stack at a stack height of 6 to 10 m, 11 to 15 m and 16 to 26 m, respectively. The graph for plotted from the results of annual concentration by a stack height is showed as Figure 26.

7.2 The variation of building height

The results obtained from varying a building height around 2 stacks place by up and down 10 m every building and calculating the concentration by using AERMOD-PRIME. The annual concentration of SO_2, NO_2 and CO at each building height for three air pollutants did not change. The maximum concentration location of SO_2 and NO_2 was 75 m, from Laundry Division stack at each building height, while the maximum concentration location of CO was 75 m and 230 m, from Laundry Division stack at a building height of up 1 to 10 m, and actual to down 10 m, respectively. The graph for plotted from the results of annual concentration by varying a building height is showed as following Figure 27.

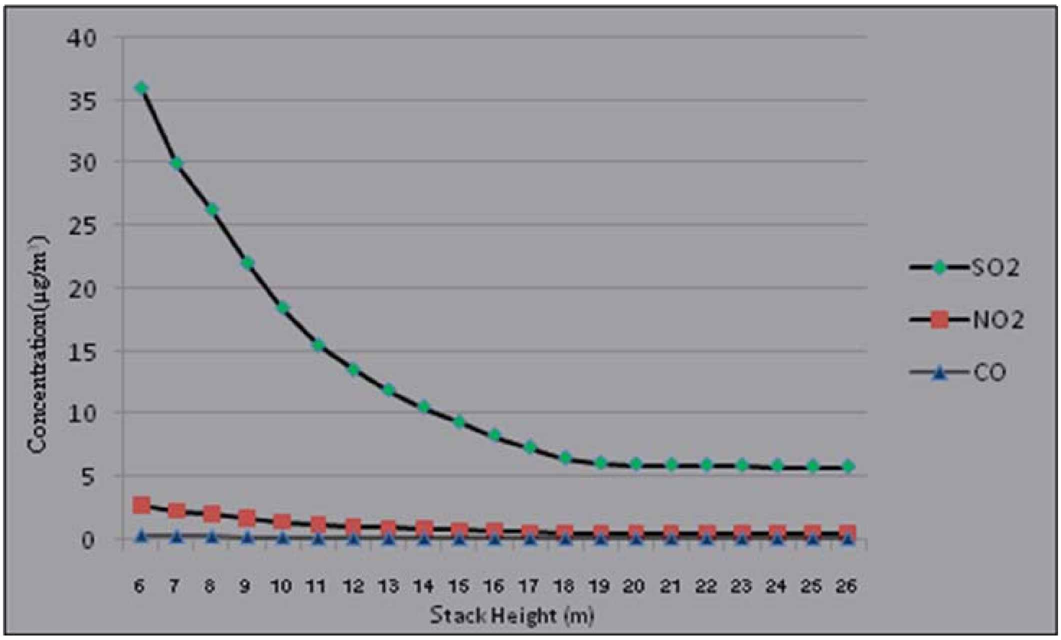

Figure 26 The graph from annual concentrations by varied stack height (6 to 26 m).

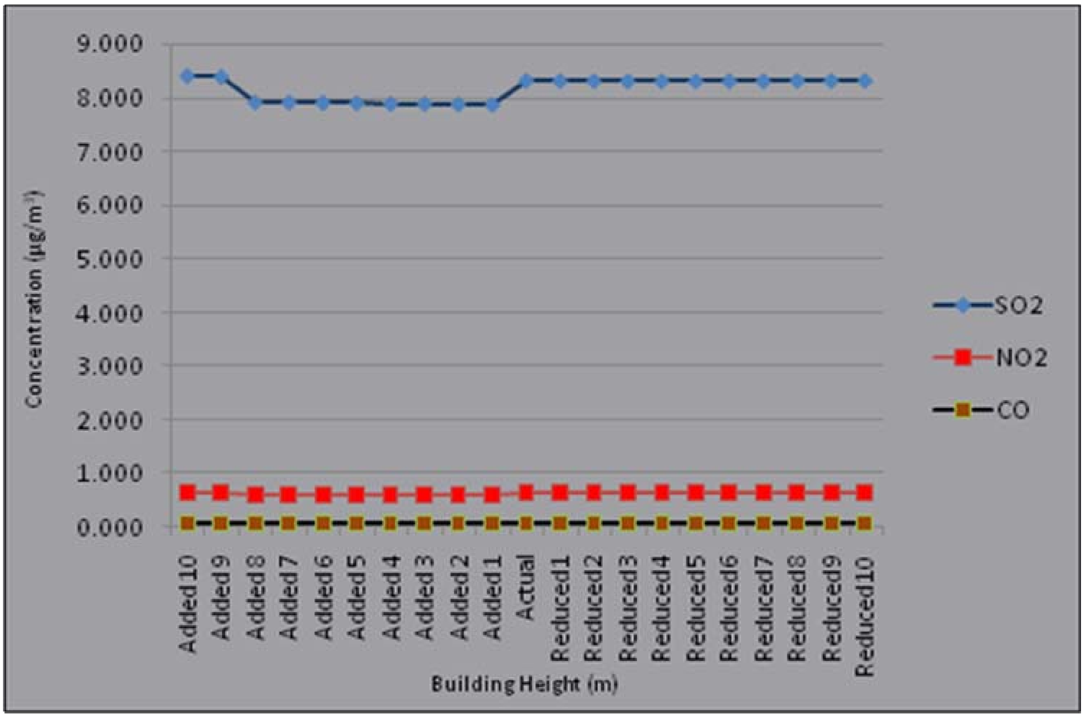

Figure 27 The graph from annual concentrations by varied building height (up and down 10 m).

CONCLUSION AND RECOMMENDATIONS

Conclusion

1. The major air pollutants from the Siriraj Hospital were occurred from the background (the air pollutants from the atmospheric concentration and local concentration such as vehicle), the boiler stack and chemical, respectively.

2. The concentration of SO_2 from the stack was higher than the background concentration while the concentration of CO and NO_2 from the stack was less than the background concentration.

3. The 1-hour average concentration of SO_2, NO_2, and CO was dispersed from the east to the west of the hospital area. The 8-hour and 24-hour average concentration of CO was dispersed from the east to the west of the hospital area, while the annual average concentration of SO_2, NO_2, and CO was dispersed from the western to the eastern of the hospital area.

4. The maximum 1-hour average concentration of SO_2, NO_2, and CO in the hospital area occurred when the wind speed less than 1 m/s.

5. The annual maximum concentration location of SO_2 and NO_2 was at Car Park and Sport Club building, while annual maximum concentration of CO occurred at Medical Technical Building.

6. From the meteorological data of 2007, the 1-hour, 8-hour and 24-hour average concentration of three air pollutants reached the maximum concentration in winter season.

7. The local concentration of 1-hour average SO_2, 24-hour average SO_2, annual average SO_2, 1-hour average CO and 8-hour average CO was highest at Phran

Nok Road, while local concentration of 1-hour average NO_2 was highest at Arunamarin Road.

8. The local concentration of three pollutants in the hospital was less than the atmospheric concentration that blowing from other area.

9. The actual air pollutants concentrations in the Siriraj Hospital area were less than the Ambient Air Quality Standard of Thailand.

10. The stack height affects on the air pollutants concentration in the hospital area. Also, when the stack height was about 16 m, the concentrations of three air pollutants were slightly decreased.

11. The building height has a slight effect to the air pollutant concentration in hospital area. However, the 1-hour average concentrations of three air pollutants tend to increase when increasing a building height.

Recommendations

1. Further research should be carried out to determine the risk assessment for staffs of Siriraj Hospital by using overall data such as air pollutants releasing from the boiler stack and chemical substances in laboratory.

2. The emission source measurement is very important to determine emission rate and input to the air dispersion model. In this study, there was no fully measurement data. In further study, the emission source profile of all parameter should be measured fully, so that the results would be more accurate and consistent with the simulation.

3. Further research to determine the dispersion and concentration of air pollutants from stack boiler should be done by using different application of air

dispersion model such as CALPUFF and the dispersion and concentration of air pollutants from vehicle by traffic models such as CALINE4 and HIWAY2.

4. Further research to determine the measurement of ambient air concentration around the Siriraj Hospital area should be carried out for comparing the result from the ISC-AERMOD program.

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APPENDICES

Appendix A

Fuel oil grade

Appendix Table A1 Fuel oil grades established by the Petroleum Authority of Thailand (PTT)

Fuel oil	**Description**
Bunker Type 1 or Bunker A, or 600 (Fuel 600, 2% sulphur)	Bunker A is high quality with low viscosity, and convenient to use. It is appropriate for middle and small industries e.g. hotel or hospital in communities due to the complete combustion and low soot.
Bunker Type 2 or Bunker B, or 1500 (Fuel 1500, 2% sulphur)	This type has medium viscosity and suitable for large furnace in medium and large industries having efficient combustion system and engine. Bunker B is the most commonly used and it is cheaper than Bunker A.

Source : Petroleum Autholity of Thailand (2008)

Appendix Table A2 The specific content of fuel oil using in steam boiler at Siriraj Hospital.

Specific Content Parameters	Specific Data
API gravity @ 60°F, upper	17.7
API gravity @ 60°F, lower	17.7
Specific gravity @ 15.6/15.6°F, upper	0.9484
Specific gravity @ 15.6/15.6°F, lower	0.9484
Kinetic Viscosity @ 50°F, upper, mm^2/s	76.95
Kinetic Viscosity @ 50°F, Lower, mm^2/s	78.68
Flash point (P.M.), °C	67
Sulphur content, % wt	1.73
Pour point, °C	-21

Appendix Table A2 (Continued)

Specific Content Parameters	Specific Data
Gross heat of combustion, BTU/lb	18,918
Ash, % wt	0.02
Water and Sediment, % Volume	0.1
Micro method carbon residual, % wt	-
Carbon, % mass	87
Hydrogen, % mass	11.3
Nitrogen, % mass	0.24
Oxygen, % mass	-

Source : The report of PTT submit to the Laundry Division of Siriraj Hospital (2007)

Appendix B

The example for calculation

1. The example for calculation of a stack boiler source

This section are showed the calculation of amount of dry gases, a stack pressure, exit velocity and emission rate for input to AERMOD program in this research. The example calculations are express on Laundry Division stack and following showed as;

Amount of dry gas

From the measurement data, the percent of volumetric of $CO_2 + SO_2$, O_2 and CO was 12.3%, 4.9%, and 0.59%, respectively.

Solve the amount of theoretical air in m^3/kg, used Equation 9 and fuel contents from Appendix Table A2 input to the Equation 9, the result is showed in below.

$$Ao = 8.89c + 26.7\left[h - \frac{0}{8}\right] + 3.3s$$

$$Ao = 8.89(0.87) + 26.7\left[0.113 - \frac{0}{8}\right] + 3.3(0.0164)$$

$$Ao = 10.808\ \frac{m^3}{kg}$$

Amount of Nitrogen in dry gas as;

$$N_2 = 100 - ((CO_2 + SO_2) + (O_2) + (CO))$$

$$N_2 = 100 - (12.3 + 4.9 + 0.59)$$

$$N_2 = 82.21\%$$

Solve the compression air ratio by using Equation 10, the result is showed in below.

$$m = \frac{21(N_2)}{21(N_2) - 79(O_2 - 0.5(CO))}$$

$$m = \frac{21(0.8221)}{21(0.8221) - 79(0.049 - 0.5(0.0059))}$$

$$m = 1.266$$

Solve the amount of essential air in m^3/kg by using Equation 11, the result is showed in below.

$$A = m \times Ao$$

$$A = 1.266 \times 10.808$$

$$A = 13.70 \frac{m^3}{kg}$$

Solve the amount of dry gas by using Equation 12 and fuel contents in Appendix Table A2, the results is showed in below.

$$G' = m(Ao) + 5.6h + 0.7o + 0.8n$$

$$G' = 13.70 + (5.6 \times 0.113) + 0 + (0.8 \times 0.0024)$$

$$G' = 14.334 \frac{m^3}{kg}$$

Amount of fuel oil using per day equal to 2,050 liters/day and the specific gravity of fuel oil were 0.9484. The amount of fuel oil using per day in unit of kilogram/day are following as;

$$\text{Amount of Fuel oil} = 2{,}050 \frac{\text{liters}}{\text{day}} \times 0.9484 \frac{\text{kg}}{\text{liter}}$$

$$\text{Amount of Fuel oil} = 1944.22 \frac{\text{kg}}{\text{day}}$$

The boilers in this research are operated at 16 hours per day, the amount of fuel oil per hour equal to;

$$\text{Amount of Fuel oil} = 1944.22\ \frac{\text{kg}}{\text{day}} \times \frac{1\ \text{day}}{16\ \text{hr}}$$

$$\text{Amount of Fuel oil} = 121.51\ \frac{\text{kg}}{\text{hour}}$$

The amounts of dry gas in term of m^3/hr are received from calculation below;

$$\text{Amount of dry gas} = 121.51\ \frac{\text{kg}}{\text{hour}} \times 14.334\ \frac{\text{m}^3}{\text{kg}}$$

$$\text{Amount of dry gas} = 1741.767\ \frac{\text{m}^3}{\text{hour}}$$

Approximate a stack pressure by using Equation 13 and input the data as C, atmospheric pressure, a stack height, outside stack temperature and average in side stack temperature were 0.0342, 101,324.72 Pa, 16 meters, 298 °K, and 405 °K, respectively. The result of stack pressure is showed in below.

$$P_{atm} - P_g = C \times a \times H\left[\frac{1}{To} - \frac{1}{Ti}\right]$$

$$P_{atm} - P_g = 0.0342 \times (1.013 \times 10^5) \times 16\left[\frac{1}{298} - \frac{1}{405}\right]$$

$$P_{atm} - P_g = 49.155\ \text{Pa}$$

To convert the unit from Pa to mmHg, the pressure was 0.3687 mmHg.
However;

$$P_{atm} - P_g = \Delta P$$

So, a stack pressure or Pg was;

$$P_g = P_{atm} - \Delta P$$

$$P_g = 760 - 0.3687 \text{ ; mmHg}$$

$$Pg = 759.631 \text{ mmHg}$$

A stack pressure was nearly the atmospheric pressure, so the next calculation would be used a stack pressure was 760 mmHg.

Average Velocity

The average velocity from stack boiler can calculate by using Equation 8 and input the data as flow rate of dry gas, moisture in air, cross-section area of stack inside diameter, atmosphere temperature, absolute inside stack temperature, atmospheric pressure and static pressure inside stack (P_{Bar} + Pg) were 1,741.767 m^3/hr, 9.7%, 0.6 meter, 298 °K, 405 °K, 760 mmHg and 1,520 mmHg, respectively.

$$Q_{sd} = 3600(1 - B_{ws}) \times V_s \times A \times \left(\frac{T_{std}}{T_{s(avg)}}\right)\left(\frac{P_s}{P_{std}}\right)$$

$$1741.767 = 3600(1 - 0.097) \times V_s \times \frac{\Pi}{4} 0.6^2 \times \left(\frac{298}{405}\right)\left(\frac{1520}{760}\right)$$

$$Vs = 1.28 \frac{m}{s}$$

Emission Rate

The concentration of SO_2 from measurement was 263.10 ppm and used Equations 5 to 7 for calculate the emission rate in g/s. The calculations are showed in following below.

$$Cp\ (SO_2) = \frac{Cstp\ (SO_2) \times P(atm) \times T(s)}{T(atm) \times P(s)}$$

$$Cstp\ (SO_2) = \frac{263.10\ ppm \times 1520\ mmHg \times 298°K}{760mmHg \times 405°K}$$

$$Cstp\ (SO_2) = 387.085ppm$$

Convert unit to mg/m^3, by using Equation 6.

$$Cm\ (SO_2) = \frac{Cstp(SO_2) \times MW\ SO_2}{24.45}$$

$$Cm\ (SO_2) = \frac{387.085 \times 64}{24.45} = 1013.229\ \frac{mg}{m^3}$$

Used the Equation 7 for calculated the emission rate;

$$Emission\ Rate\ = Cm\ (SO_2) \times V \times A$$

$$Emission\ Rate\ = 1013.229\ \frac{mg}{m^3} \times 1.28\ \frac{m}{s} \times \frac{\Pi}{4}(0.6^2)m^2 \times \frac{1g}{1000mg}$$

$$Emission\ Rate\ = 0.366\ \frac{g}{s}$$; for used in AERMOD-PRIME

The concentration of NO_2 from measurement was 27.7 ppm and used Equations 5 to 7 for calculate the emission rate in g/s. The calculations are showed in following below.

$$Cp\ (NO_2) = \frac{Cstp\ (NO_2) \times P(atm) \times T(s)}{T(atm) \times P(s)}$$

$$Cstp\ (NO_2) = \frac{27.7\ ppm \times 1520\ mmHg \times 298°K}{760mmHg \times 405°K}$$

$$\text{Cstp (NO}_2) = 40.753 \text{ ppm}$$

Convert unit to mg/m^3, by using Equation 6.

$$\text{Cm (NO}_2) = \frac{\text{Cstp (NO}_2) \times \text{MW NO}_2}{24.45}$$

$$\text{Cm (NO}_2) = \frac{40.753 \times 46}{24.45} = 76.672 \frac{\text{mg}}{\text{m}^3}$$

Used the Equation 7 for calculated the emission rate;

$$\text{Emission Rate} = \text{Cm (NO}_2) \times \text{V} \times \text{A}$$

$$\text{Emission Rate} = 76.672 \frac{\text{mg}}{\text{m}^3} \times 1.28 \frac{\text{m}}{\text{s}} \times \frac{\Pi}{4}(0.6^2)\text{m}^2 \times \frac{1\text{g}}{1000\text{mg}}$$

$$\text{Emission Rate} = 0.0277 \frac{\text{g}}{\text{s}}$$; for used in AERMOD-PRIME

The concentration of CO from measurement was 6 ppm and used Equations 5 to 7 for calculate the emission rate in g/s. The calculations are showed in following below.

$$\text{Cp (CO)} = \frac{\text{Cstp (CO)} \times \text{P(atm)} \times \text{T(s)}}{\text{T(atm)} \times \text{P(s)}}$$

$$\text{Cstp (CO)} = \frac{6 \text{ ppm} \times 1520 \text{ mmHg} \times 298°\text{K}}{760\text{mmHg} \times 405°\text{K}}$$

$$\text{Cstp (CO)} = 8.827 \text{ ppm}$$

Convert unit to mg/m^3, by using Equation 6.

$$\text{Cm (CO)} = \frac{\text{Cstp (CO)} \times \text{MW NO}_2}{24.45}$$

$$\text{Cm (CO)} = \frac{8.827 \times 28}{24.45} = 10.12 \frac{\text{mg}}{\text{m}^3}$$

Used the Equation 7 for calculated the emission rate;

$$\text{Emission Rate} = \text{Cm (CO)} \times \text{V} \times \text{A}$$

$$\text{Emission Rate} = 10.12 \frac{\text{mg}}{\text{m}^3} \times 1.28 \frac{\text{m}}{\text{s}} \times \frac{\Pi}{4} (0.6^2)\text{m}^2 \times \frac{1\text{g}}{1000\text{mg}}$$

$$\text{Emission Rate} = 0.00365 \frac{\text{g}}{\text{s}}$$; for used in AERMOD-PRIME

2. The example for calculation of the background concentration

The emission rate for used in AERMOD program can used Equation 14, 15, emission factor in Table 7 and amount of vehicles per day. The example in this section would be showed CO emission on Arunamrin road and the calculation were expressing in below.

From counted the vehicle in Arunamarin road for motorcycle, gasoline engine, diesel engine and large diesel engine were 15,504; 37,248; 7,596; and 1,464 vehicle per day, respectively. The average velocity in arunamarin road was 30.25 km/hr.

The emission factor of CO for motorcycle, gasoline engine, diesel engine and large diesel engine at 30.25 km/hr were 17.2, 32.25, 1.40 and 8.67 g/km, respectively.

$$\text{CEF of Motorcycle} = \frac{15{,}504 \text{ vehicle}}{24 \text{ hr}} \times 17.2 \frac{\text{g}}{\text{km}} = 11{,}111.20 \frac{\text{g}}{\text{km}} \times \frac{\text{vehicle}}{\text{hr}}$$

$$\text{CEF of Gasoline Engine} = \frac{37{,}248 \text{ vehicle}}{24 \text{ hr}} \times 32.25 \frac{\text{g}}{\text{km}} = 50{,}052 \frac{\text{g}}{\text{km}} \times \frac{\text{vehicle}}{\text{hr}}$$

$$\text{CEF of Diesel Engine } = \frac{7{,}596 \text{ vehicle}}{24 \text{ hr}} \times 1.40 \frac{\text{g}}{\text{km}} = 442.40 \frac{\text{g}}{\text{km}} \times \frac{\text{vehicle}}{\text{hr}}$$

$$\text{CEF of Large Diesel Engine } = \frac{1{,}464 \text{ vehicle}}{24 \text{ hr}} \times 8.67 \frac{\text{g}}{\text{km}} = 641.58 \frac{\text{g}}{\text{km}} \times \frac{\text{vehicle}}{\text{hr}}$$

Total of vehicles per hour equal to 2,588 and solve the total of composite emission factor (CEF) follow as;

$$\text{Total(CEF)} = 62{,}247.18 \frac{\text{g}}{\text{km}} \times \frac{\text{vehicle}}{\text{hr}} \times \frac{1}{2{,}588 \frac{\text{vehicle}}{\text{hr}}}$$

$$\text{Total(CEF) CO} = 24.052 \frac{\text{g}}{\text{km}}$$

The emission rate of CO can used Equation 15 and the average velocity to calculate following as;

$$\text{Emission Rate } = 24.052 \frac{\text{g}}{\text{km}} \times 30.25 \frac{\text{km}}{\text{hr}} \times \frac{1 \text{ hr}}{3600 \text{ s}}$$

$$\text{Emission Rate } = 0.202 \frac{\text{g}}{\text{s}}$$; For used in AERMOD program.

Appendix C

The Meteorological Data Formation

Appendix Table C1 The example of hourly surface data in term of SAMSON format for input to RAMMET View program.

A	B	C	D	E	F	G	H	I	J	K	L	M
2007	1	1	0	5	25	77	1013	125	0	2000	0	0
2007	1	1	1	5	25	78	1013	122	0	2000	0	0
2007	1	1	2	5	25	77	1012	167	0	2000	0	0
2007	1	1	3	5	24	84	1012	288	1	2000	0	0
2007	1	1	4	4	23	88	1012	291	0	2000	0	0
2007	1	1	5	4	23	88	1012	155	0	2000	0	0
2007	1	1	6	6	23	87	1013	125	0	2000	0	5
2007	1	1	7	6	23	86	1013	282	0	2000	0	87
2007	1	1	8	6	25	76	1014	238	0	2000	0	224
2007	1	1	9	6	27	67	1016	267	0	-99	0	327
2007	1	1	10	6	29	61	1016	271	0	2000	0	495
2007	1	1	11	5	30	53	1014	284	0	2000	0	632
2007	1	1	12	6	32	44	1013	307	0	2000	0	644
2007	1	1	13	6	33	43	1012	287	0	2000	0	495
2007	1	1	14	5	33	45	1012	278	1	2000	0	434
2007	1	1	15	5	32	51	1010	285	1	2000	0	304
2007	1	1	16	5	31	53	1012	289	2	2000	0	135
2007	1	1	17	6	30	56	1012	289	1	2000	0	22
2007	1	1	18	5	29	58	1012	280	1	2000	0	0
2007	1	1	19	5	28	60	1013	289	1	2000	0	0
2007	1	1	20	4	28	61	1013	294	0	2000	0	0
2007	1	1	21	3	27	64	1013	126	0	2000	0	0
2007	1	1	22	3	27	68	1013	196	0	2000	0	0
2007	1	1	23	3	26	72	1013	104	0	2000	0	0

Remark : A = Year, B = Month, C = Day, D = Hour, E = Opaque Cloud Cover, F = Dry Bulb Temperature (°C), G = Relative Humidity (%), H = Station Pressure (mBar), I = Wind Direction (Degrees), J = Wind Speed (m/s), K = Ceiling Height (feet), L = Hourly Precipitation (mm/h), M = Global Horizontal Radiation (Wh/m^2).

The example of upper air data in term of FSL format for used in AERMET program.

```
   254      0      1      JAN    2007
     1  48455  72518  13.72 100.55      4      0
     2    100    220    145     35  32767      0
     3           BKK                32767     kt
     9   1012      4    220    179      0      0
     4   1000    110    228    128    180      2
     4    962    448    242    102    222      3
     5    925    790    222    112    265      4
     4    866   1357    172     92    222      1
     5    850   1515    158     68    210      0
     5    808   1942    124     -6    209      4
     5    788   2152    116   -114    208      7
     5    767   2377    124   -246    207      9
     5    700   3138    100   -390    205     17
     5    670   3500     88   -402    226     17
     5    646   3801     80   -410    243     17
     4    555   5032      0   -390    315     18
     5    548   5133     -5   -455    321     18
     5    507   5750    -31   -521    358     19
     5    500   5860    -35   -525      5     19
     5    437   6912    -95   -575    359     38
     5    400   7590   -137   -607    355     50
     5    353   8525   -197   -647    340     36
     5    334   8932   -217   -657    333     30
     5    300   9710   -275   -705    320     18
     5    287  10028   -291   -711    299     18
     5    250  11000   -365   -765    235     18
     5    200  12490   -501   -681    220     21
     4    150  14290   -667   -847    200     29
     5    143  14577   -693   -863    191     27
     4    117  15746   -791   -941    154     17
     5    112  15993   -801   -971    146     15
     5    106  16304   -809   -989    136     12
     5    101  16574   -823   -993    127      9
     5    100  16630   -823   -993    125      9
```

For the example of upper air data in term of FSL format can be explained following as below;

<u>header lines</u>

254	HOUR	DAY	MONTH	YEAR	(blank)	(blank)
1	WBAN#	WMO#	LAT D	LON D	ELEV	RTIME
2	HYDRO	MXWD	TROPL	LINES	TINDEX	SOURCE
3	(blank)	STAID	(blank)	(blank)	SONDE	WSUNITS

data lines

9	PRESSURE	HEIGHT	TEMP	DEWPT	WIND DIR	WIND SPD
4						
5						
6						
7						
8						

LEGEND

LINTYP: type of identification line

254 = indicates a new sounding in the output file

1 = station identification line

2 = sounding checks line

3 = station identifier and other indicators line

4 = mandatory level

5 = significant level

6 = wind level (PPBB) (GTS or merged data)

7 = tropopause level (GTS or merged data)

8 = maximum wind level (GTS or merged data)

9 = surface level

HOUR: The time of report in UTC

LAT: The latitude in degrees and hundredths

LON: The longitude in degrees and hundredths

D: The direction latitude ('N' or 'S') or longitude ('E' or 'W') -note this only appears in the online archive containing international observations.

ELEV: The elevation from station history in meters

RTIME: The actual release time of radiosonde from TTBB. Appears in GTS data only.

HYDRO: The pressure of the level to where the sounding passes the hydrostatic check.

MXWD: The pressure of the level having the maximum wind in the sounding. If within the body of the sounding there is no "8" level then.

MXWN: The station number.

TROPL: The pressure of the level containing the tropopause. If within the body of the sounding there is no "7" level, then TROPL is estimated.

LINES: The number of levels in the sounding, including the 4 identification lines.

TINDEX: The indicator for estimated tropopause. A "7" indicates that sufficient data was available to attempt the estimation; 11 indicates that data terminated and that tropopause is a "suspected" tropopause.

SOURCE: 0 = The National Climatic Data Center (NCDC).
1 = The Atmospheric Environment Service (AES), Canada.
2 = The National Severe Storms Forecast Center (NSSFC).
3 = GTS or FSL GTS data only
4 = merge of NCDC and GTS data (sources 2, 3 merged into sources 0,1)

SONDE: type of radiosonde code from TTBB. Only reported with GTS data.
10 = VIZ "A" type radiosonde
11 = VIZ "B" type radiosonde
12 = Space data corp.(SDC) radiosonde.

WSUNITS: The wind speed units (selected upon output)
ms = Tenths of meters per second.
kt = knots.

PRESSURE: The pressure in whole millibars (original format) in tenths of millibars (new format).

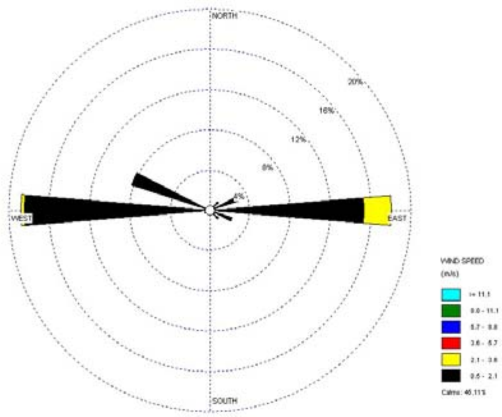
HEIGHT: The height in meters (m).

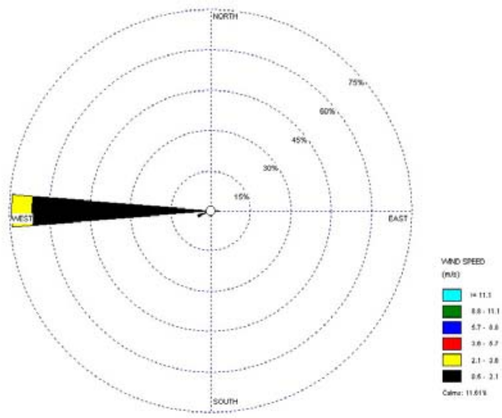
TEMP: The temperature in tenths of degrees Celsius.

DEWPT: dew point temperature in tenths of a degree Celsius.

WIND DIR: The wind direction in degrees.

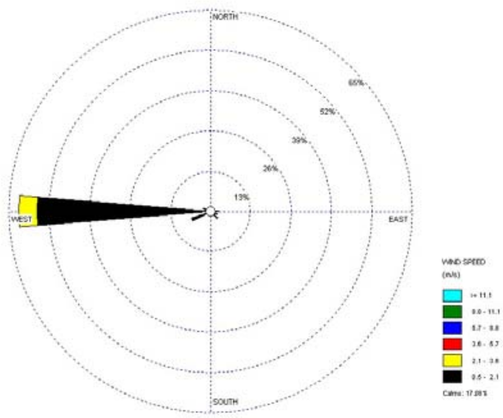
WIND SPD: The wind speed in either knots or tenths of a meter per second selected by user upon output.

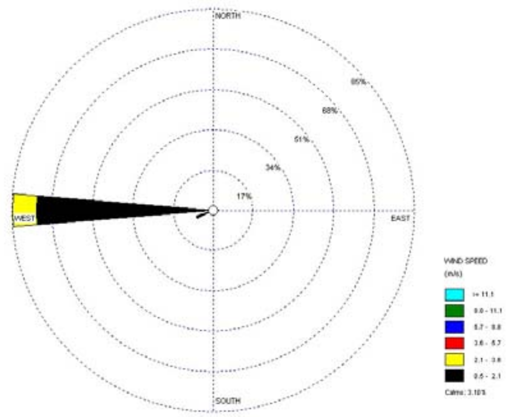




a) January 2007

b) Febuary 2007

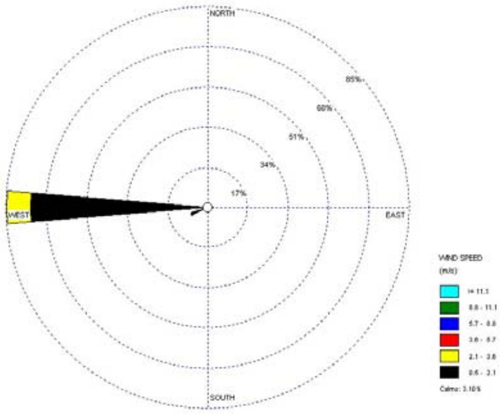




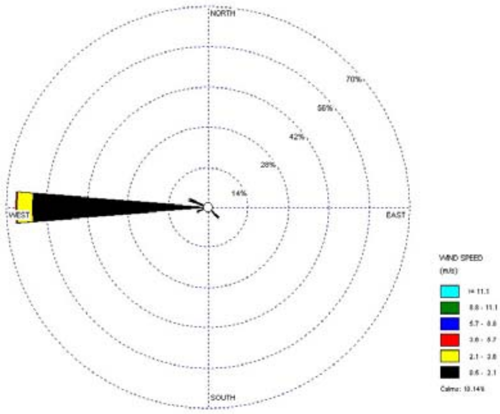
c) March 2007

d) April 2007

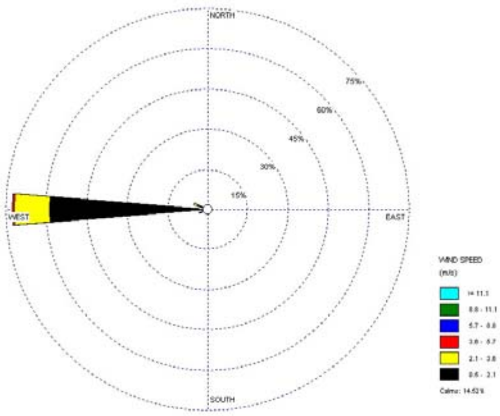
Appendix Figure C1 The frequency of wind direction in period of January to April (2007).



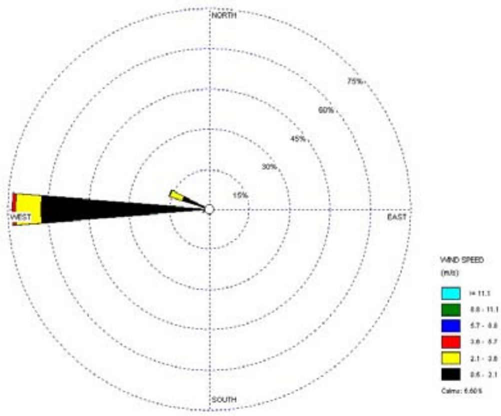
a) May 2007



b) June 2007

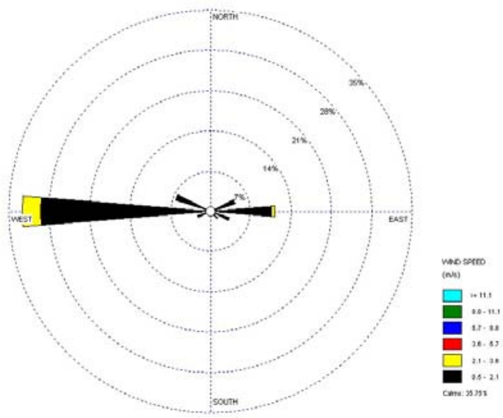


c) July 2007

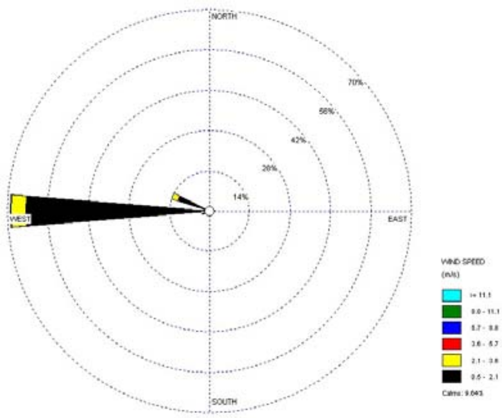


d) August 2007

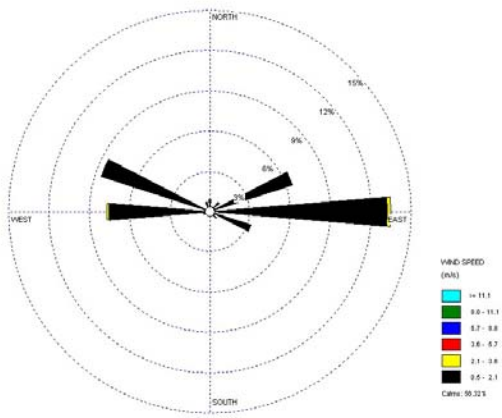
Appendix Figure C2 The frequency of wind direction in period of May to August (2007).



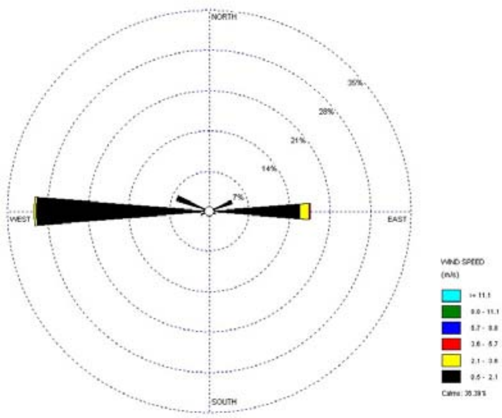
a) September 2007



b) October 2007



c) November 2007



d) December 2007

Appendix Figure C3 The frequency of wind direction in period of September to December (2007).

Appendix D

The AERMOD Data Formation

This section was showed the output file from AERMOD-PRIME. The example for this section is the concentration of SO_2, the results following expressed below.

```
                        *** THE SUMMARY OF MAXIMUM ANNUAL (   1 YRS) RESULTS ***

                        ** CONC OF SO2      IN MICROGRAMS/M**3                    **

                                                        NETWORK
GROUP ID               AVERAGE CONC          RECEPTOR   (XR, YR, ZELEV, ZHILL, ZFLAG)  OF TYPE  GRID-ID
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

SRCGP1   1ST HIGHEST VALUE IS      8.29712 AT (    300.00,     450.00,     0.00,     0.00,     0.00)  GC   UCART1
         2ND HIGHEST VALUE IS      6.68268 AT (    300.00,     475.00,     0.00,     0.00,     0.00)  GC   UCART1
         3RD HIGHEST VALUE IS      6.10811 AT (    500.00,     525.00,     0.00,     0.00,     0.00)  GC   UCART1
         4TH HIGHEST VALUE IS      6.01717 AT (    475.00,     525.00,     0.00,     0.00,     0.00)  GC   UCART1
         5TH HIGHEST VALUE IS      5.95040 AT (    525.00,     525.00,     0.00,     0.00,     0.00)  GC   UCART1
         6TH HIGHEST VALUE IS      5.85443 AT (    550.00,     525.00,     0.00,     0.00,     0.00)  GC   UCART1
         7TH HIGHEST VALUE IS      5.84206 AT (    550.00,     500.00,     0.00,     0.00,     0.00)  GC   UCART1
         8TH HIGHEST VALUE IS      5.73417 AT (    500.00,     500.00,     0.00,     0.00,     0.00)  GC   UCART1
         9TH HIGHEST VALUE IS      5.66262 AT (    475.00,     500.00,     0.00,     0.00,     0.00)  GC   UCART1
        10TH HIGHEST VALUE IS      5.64333 AT (    325.00,     450.00,     0.00,     0.00,     0.00)  GC   UCART1

ALL      1ST HIGHEST VALUE IS      8.29712 AT (    300.00,     450.00,     0.00,     0.00,     0.00)  GC   UCART1
         2ND HIGHEST VALUE IS      6.68268 AT (    300.00,     475.00,     0.00,     0.00,     0.00)  GC   UCART1
         3RD HIGHEST VALUE IS      6.10811 AT (    500.00,     525.00,     0.00,     0.00,     0.00)  GC   UCART1
         4TH HIGHEST VALUE IS      6.01717 AT (    475.00,     525.00,     0.00,     0.00,     0.00)  GC   UCART1
         5TH HIGHEST VALUE IS      5.95040 AT (    525.00,     525.00,     0.00,     0.00,     0.00)  GC   UCART1
         6TH HIGHEST VALUE IS      5.85443 AT (    550.00,     525.00,     0.00,     0.00,     0.00)  GC   UCART1
         7TH HIGHEST VALUE IS      5.84206 AT (    550.00,     500.00,     0.00,     0.00,     0.00)  GC   UCART1
         8TH HIGHEST VALUE IS      5.73417 AT (    500.00,     500.00,     0.00,     0.00,     0.00)  GC   UCART1
         9TH HIGHEST VALUE IS      5.66262 AT (    475.00,     500.00,     0.00,     0.00,     0.00)  GC   UCART1
        10TH HIGHEST VALUE IS      5.64333 AT (    325.00,     450.00,     0.00,     0.00,     0.00)  GC   UCART1


 *** RECEPTOR TYPES:  GC = GRIDCART
                      GP = GRIDPOLR
                      DC = DISCCART
                      DP = DISCPOLR
*** AERMOD - VERSION 02222 ***    *** Hospital
```

*** THE SUMMARY OF HIGHEST 1-HR RESULTS ***

** CONC OF SO2 IN MICROGRAM/M**3

DATE NETWORK
GROUP ID AVERAGE CONC (YYMMDDHH) RECEPTOR (XR, YR, ZELEV, ZHILL, ZFLAG) OF TYPE GRID-ID

SRCGP1	HIGH	1ST	HIGH	VALUE	IS	110.041	ON	07121420:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	2ND	HIGH	VALUE	IS	109.932	ON	07051205:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	3RD	HIGH	VALUE	IS	109.872	ON	07050905:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	4TH	HIGH	VALUE	IS	109.549	ON	07032107:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	5TH	HIGH	VALUE	IS	108.278	ON	07012819:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	6TH	HIGH	VALUE	IS	108.174	ON	07122820:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
ALL	HIGH	1ST	HIGH	VALUE	IS	110.041	ON	07121420:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	2ND	HIGH	VALUE	IS	109.932	ON	07051205:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	3RD	HIGH	VALUE	IS	109.872	ON	07050905:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	4TH	HIGH	VALUE	IS	109.549	ON	07032107:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	5TH	HIGH	VALUE	IS	108.278	ON	07012819:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	6TH	HIGH	VALUE	IS	108.174	ON	07122820:	AT	(	75.00,	475.00,	0.00,	0.00,	0.00)	GC	UCART1

*** RECEPTOR TYPES: GC = GRIDCART
GP = GRIDPOLR
DC = DISCCART
DP = DISCPOLR
*** AERMOD - VERSION 02222 *** *** Hospital

*** THE SUMMARY OF HIGHEST 8-HR RESULTS ***

** CONC OF SO2 IN MICROGRAM/M**3

DATE NETWORK
GROUP ID AVERAGE CONC (YYMMDDHH) RECEPTOR (XR, YR, ZELEV, ZHILL, ZFLAG) OF TYPE GRID-ID

SRCGP1	HIGH	1ST	HIGH	VALUE	IS	36.29036	ON	07020108:	AT	(	75.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	2ND	HIGH	VALUE	IS	35.50558	ON	07010608:	AT	(	75.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	3RD	HIGH	VALUE	IS	32.85660	ON	07050208:	AT	(	75.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	4TH	HIGH	VALUE	IS	30.19856	ON	07121108:	AT	(	75.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	5TH	HIGH	VALUE	IS	28.31805	ON	07121708:	AT	(	100.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	6TH	HIGH	VALUE	IS	27.00078	ON	07111224:	AT	(	75.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
ALL	HIGH	1ST	HIGH	VALUE	IS	36.29036	ON	07020108:	AT	(	75.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	2ND	HIGH	VALUE	IS	35.50558	ON	07010608:	AT	(	75.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	3RD	HIGH	VALUE	IS	32.85660	ON	07050208:	AT	(	75.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	4TH	HIGH	VALUE	IS	30.19856	ON	07121108:	AT	(	75.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	5TH	HIGH	VALUE	IS	28.31805	ON	07121708:	AT	(	100.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	6TH	HIGH	VALUE	IS	27.00078	ON	07111224:	AT	(	75.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1

*** RECEPTOR TYPES: GC = GRIDCART
GP = GRIDPOLR
DC = DISCCART
DP = DISCPOLR
*** AERMOD - VERSION 02222 *** *** Hospital

*** THE SUMMARY OF HIGHEST 24-HR RESULTS ***

** CONC OF SO2 IN MICROGRAM/M**3

DATE NETWORK
GROUP ID AVERAGE CONC (YYMMDDHH) RECEPTOR (XR, YR, ZELEV, ZHILL, ZFLAG) OF TYPE GRID-ID

SRCGP1	HIGH	1ST	HIGH	VALUE	IS	20.08500	ON	07110724:	AT	(	100.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	2ND	HIGH	VALUE	IS	18.05383	ON	07020124:	AT	(	100.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	3RD	HIGH	VALUE	IS	17.43634	ON	07110224:	AT	(	100.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	4TH	HIGH	VALUE	IS	15.19711	ON	07020124:	AT	(	125.00,	450.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	5TH	HIGH	VALUE	IS	14.95237	ON	07013124:	AT	(	125.00,	450.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	6TH	HIGH	VALUE	IS	14.27134	ON	07111224:	AT	(	125.00,	450.00,	0.00,	0.00,	0.00)	GC	UCART1
ALL	HIGH	1ST	HIGH	VALUE	IS	20.08500	ON	07110724:	AT	(	100.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	2ND	HIGH	VALUE	IS	18.05383	ON	07020124:	AT	(	100.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	3RD	HIGH	VALUE	IS	17.43634	ON	07110224:	AT	(	100.00,	425.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	4TH	HIGH	VALUE	IS	15.19711	ON	07020124:	AT	(	125.00,	450.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	5TH	HIGH	VALUE	IS	14.95237	ON	07013124:	AT	(	125.00,	450.00,	0.00,	0.00,	0.00)	GC	UCART1
	HIGH	6TH	HIGH	VALUE	IS	14.27134	ON	07111224:	AT	(	125.00,	450.00,	0.00,	0.00,	0.00)	GC	UCART1

*** RECEPTOR TYPES: GC = GRIDCART
GP = GRIDPOLR
DC = DISCCART
DP = DISCPOLR
*** AERMOD - VERSION 02222 *** *** Hospital

***	Message	Summary	:	AERMOD	Model	Execution	***			
	---------	Summary	of	Total	Messages	--------				
A	Total	of	0	Fatal	Error	Message(s)				
A	Total	of	29	Warning	Message(s)					
A	Total	of	1953	Informational	Message(s)					
A	Total	of	1932	Calm	Hours	Identified				
A	Total	of	21	Missing	Hours	Identified	(		0.24	Percent)
	********	FATAL	ERROR	MESSAGES	********					
	***	NONE	***							

Appendix E

The BPIP data Formation

Appendix Table E1 The dimension of building in Siriraj Hospital area as around the boiler stack for used in BPIP program.

Item	Building Name	Width (m)	Length (m)	Height (m)
1	Laundry Division	26	50	14
2	Sub - Electric Station	15	16	20
3	Memorial Service	12	24	12
4	Adulyadejvikrom	35	103	42
5	Syamindry	67	65	60
6	Dieteties & Nutrition	35	35	17.5
7	84th Year Aniversary	48	42	45
8	Microbiology	27	60	21
9	SiME	58	157	67.5
10		80	66.50	60
11	Chalermphrakiet	36	56	80
12	Boiler House	10	16	7.5
13	Anatomy	20	58	17.5
14	Car Park II & Gymnasiam	25	50	45.5
15	Nursing Dormitory 4	12	30	31.5
16	Nursing Dormitory 3	46	30	31.5
17	Waste Water Treatment Plant	20	48	22.5
18	Environment Conservation	25	20	10.5
19	Medical Technology	42	14	30
20	Her Majesty' s Cardiac Center	44	20	67
21	72th Year Aniversary	53	40	45
22	Female Medical Student Dormitory 1	12	60	45.5
23	Pharmacy	20	36	10.5
24	Men Medical Student Dormitory	16	42	45.5

Appendix Table E1 (Continued)

Item	Building Name	Width (m)	Length (m)	Height (m)
25	Female Medical Student Dormitory 2	12	72	20
26	Salakinbangrattaban	46	15	17.5
27	Out Patient Department (OPD)	102	76	31
28	Paob – Nop – Supatra - Rabeab	20	58	15
29	100th Year Smdet Phrasrinagarindra	35	73	67.5
30	Srisangwan	24	15	24.5
31	Asdang	30	45	45.5
32	Resident Dormitory	20	42	25
33	Car Park (OPD)	30	64	17.5
34	Anandamahidol	18	44	42
35	Chaofa Mahaghakri	51	40	42
36	Amarin School	85	45	13

Used the data in Appendix Table E1 input for BPIP program, the output file from running the BPIP program as Laundry Division stack and Syamindry Building stack are expressing below.

BPIP output is in meters.

SO	BUILDHGT	LAUNDRY	31.50	31.50	67.50	67.50	67.50	67.50
SO	BUILDHGT	LAUNDRY	67.50	67.50	67.50	60.00	60.00	60.00
SO	BUILDHGT	LAUNDRY	60.00	60.00	60.00	60.00	60.00	60.00
SO	BUILDHGT	LAUNDRY	31.50	31.50	67.50	67.50	67.50	67.50
SO	BUILDHGT	LAUNDRY	67.50	67.50	67.50	60.00	60.00	60.00
SO	BUILDHGT	LAUNDRY	80.00	80.00	80.00	67.50	67.50	67.00
SO	BUILDWID	LAUNDRY	33.02	40.21	168.54	166.17	158.74	146.50
SO	BUILDWID	LAUNDRY	129.80	109.16	85.20	191.61	207.75	216.27
SO	BUILDWID	LAUNDRY	95.38	217.29	207.19	194.87	177.84	127.27
SO	BUILDWID	LAUNDRY	147.17	140.47	168.54	166.17	158.74	146.50
SO	BUILDWID	LAUNDRY	129.80	109.16	85.20	82.62	89.34	93.78
SO	BUILDWID	LAUNDRY	56.23	59.37	60.30	83.18	82.10	120.90
SO	BUILDLEN	LAUNDRY	47.79	51.52	110.12	130.45	146.81	158.71
SO	BUILDLEN	LAUNDRY	165.79	167.83	164.77	132.95	135.16	188.15
SO	BUILDLEN	LAUNDRY	99.37	154.04	166.34	173.59	175.68	182.77
SO	BUILDLEN	LAUNDRY	135.99	150.92	110.12	130.45	146.81	158.71
SO	BUILDLEN	LAUNDRY	165.79	167.83	164.77	67.39	80.61	91.38
SO	BUILDLEN	LAUNDRY	61.35	60.27	57.36	62.94	52.67	99.67
SO	XBADJ	LAUNDRY	-144.95	-145.32	88.49	96.34	101.25	103.09
SO	XBADJ	LAUNDRY	101.80	97.42	90.07	76.04	93.60	32.49
SO	XBADJ	LAUNDRY	117.07	101.33	82.51	61.18	37.99	119.32
SO	XBADJ	LAUNDRY	23.70	1.15	-198.61	-226.78	-248.06	-261.81
SO	XBADJ	LAUNDRY	-267.59	-265.25	-254.85	-208.99	-218.13	-220.64
SO	XBADJ	LAUNDRY	-254.13	-255.37	57.36	-322.41	-317.07	-302.10
SO	YBADJ	LAUNDRY	2.61	-18.52	-116.76	-90.29	-61.07	-30.00
SO	YBADJ	LAUNDRY	1.98	33.91	64.80	-84.09	-59.28	90.48
SO	YBADJ	LAUNDRY	57.65	22.70	49.77	77.37	103.21	57.79
SO	YBADJ	LAUNDRY	54.47	66.10	116.76	90.29	61.07	30.00
SO	YBADJ	LAUNDRY	-1.98	-33.91	-64.80	29.60	0.08	-29.23
SO	YBADJ	LAUNDRY	29.92	-9.31	57.36	25.34	-25.62	-54.60

SO	BUILDHGT	SAYA	67.50	67.50	67.00	67.00	67.00	60.00
SO	BUILDHGT	SAYA	60.00	60.00	60.00	60.00	60.00	80.00
SO	BUILDHGT	SAYA	80.00	67.50	67.50	67.50	67.50	67.50
SO	BUILDHGT	SAYA	67.50	67.50	67.50	67.50	67.50	60.00
SO	BUILDHGT	SAYA	60.00	60.00	60.00	60.00	60.00	80.00
SO	BUILDHGT	SAYA	80.00	67.50	67.50	67.50	67.50	67.50
SO	BUILDWID	SAYA	77.92	81.54	147.91	150.82	149.15	96.36
SO	BUILDWID	SAYA	92.79	86.41	77.40	76.97	86.35	51.37
SO	BUILDWID	SAYA	56.23	76.31	76.31	83.18	82.10	164.77
SO	BUILDWID	SAYA	77.92	81.54	168.54	166.17	158.74	96.36
SO	BUILDWID	SAYA	92.79	86.41	77.40	76.97	86.35	51.37
SO	BUILDWID	SAYA	56.23	76.31	76.31	83.18	82.10	78.52
SO	BUILDLEN	SAYA	40.67	52.65	69.84	71.50	77.91	96.02
SO	BUILDLEN	SAYA	91.10	83.42	73.20	71.20	81.59	60.57
SO	BUILDLEN	SAYA	61.35	60.27	57.36	62.94	52.67	85.20
SO	BUILDLEN	SAYA	40.67	52.65	110.12	130.45	146.81	96.02

SO	BUILDLEN	SAYA	91.10	83.42	73.20	71.20	81.59	60.57
SO	BUILDLEN	SAYA	61.35	60.27	57.36	62.94	52.67	40.80
SO	XBADJ	SAYA	-172.50	-168.74	-159.85	-146.10	-128.03	-43.28
SO	XBADJ	SAYA	-33.70	-23.09	-11.77	-4.75	-5.54	70.14
SO	XBADJ	SAYA	66.47	60.27	57.36	121.49	130.88	-232.40
SO	XBADJ	SAYA	131.83	116.09	-276.87	-283.97	-282.45	-52.73
SO	XBADJ	SAYA	-57.40	-60.33	-61.42	-66.45	-76.05	-130.71
SO	XBADJ	SAYA	-127.82	60.27	57.36	-184.43	-183.55	-177.10
SO	YBADJ	SAYA	-43.64	-69.28	-60.19	-78.76	-94.93	-41.35
SO	YBADJ	SAYA	-39.75	-36.95	-33.02	-28.73	-23.04	10.01
SO	YBADJ	SAYA	27.27	60.27	57.36	-38.96	-11.77	112.46
SO	YBADJ	SAYA	43.64	69.28	2.30	-36.02	-73.25	41.35
SO	YBADJ	SAYA	39.75	36.95	33.02	28.73	23.04	-10.01
SO	YBADJ	SAYA	-27.27	60.27	57.36	38.96	11.77	-15.79

From the output file; SO is specifying Source information;, BUILDHGT is a building height, BUILDWID is a building width, BUILDLEN is a building length, XBADJ is an along-flow, YBADJ is an across-flow, LAUNDRY is a laundry division stack and SAYA is a Syamindry building stack.

Furthermore, the output files for each stack can separate in 5 sections as BUILDHGT, BUILDWID, BUILDLEN, XBADJ and YBADJ. The data in each section was 6 rows and 6 columns. The data in 1st row of 1st, 2nd, 3rd, 4th, 5th and 6th column were building condition 0 - 10, 11 - 20, 21 - 30, 31 – 40, 41 – 50, 51 – 60 degree around the stack, respectively. The data in 2nd, 3rd, 4th, 5th and 6th row were 70 - 120, 130 – 180, 190 – 240, 250 – 300 and 310 – 360 degree around the stack, respectively.

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