A STUDY OF IMPORTANT FACTORS RELATING TO THE EFFICIENCY OF ROOF VENTILATORS

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2008

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Thesis

Entitled

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A STUDY OF IMPORTANT FACTORS RELATING TO THE EFFICIENCY OF ROOF VENTILATORS

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ABSTRACT

The objectives of this experimental study were to find the minimum wind speed at which roof ventilators can effectively exhaust air, and to compare the exhausting power of the ventilator at different angles of installation (0, 5, 10 and 15 degrees). The study also aimed to study the relationships between the exhausting power inside the roof ventilator and the wind speed, the angles of the axle's roof ventilator and the wind directions that blow towards the roof ventilator. The study was conducted in the simulation laboratory using a model designed to comply with the regulations of Thai Industrial Standards 1408-1997, size 1.50 m x 3 m x 1.50 m. The roof ventilator used in this experiment had a duct diameter 0.36 cm (14 inches), weighed 2.8 kg, had 24 propellers and a needle axle, and was made of aluminum. The experiments were conducted at 10 different levels of wind speed.

The result showed that the minimum wind speed at which the roof ventilator can effectively exhaust air had an average value of 0.53 m/s (1.06 knots). The roof ventilator had a cycle of about 8 rpm. The factors which affect the efficiency of the ventilator were the wind speed and the axles of the roof ventilator. The exhausting power of the roof ventilator can be calculated from equation $Y = 0.146X_1 - 0.023X_2$. It was shown that the roof ventilator could be ventilated most effectively when the axles of the roof ventilator were installed perpendicularly. In case of installing the roof ventilators, the calculation could be performed using the prediction model. When comparing the exhausting power inside the roof ventilator at the axle of roof ventilator perpendicular and the angles of 5, 10 and 15 degrees at the same wind speed, it was found that the exhausting power inside the roof ventilator when installed perpendicularly was significantly different at a 95% confidence interval ($p < 0.001$).

This experimental study can be of use for designing and installing roof ventilators in future.

KEY WORDS: ROOF VENTILATOR / VENTILATOR

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การศึกษาปัจจัยสำคัญที่มีความสัมพันธ์กับประสิทธิภาพของกังหันระบายอากาศบนหลังคา
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บทคัดย่อ

วัตถุประสงค์ของการศึกษาในครั้งนี้คือ เพื่อหาความเร็วลมต่ำสุดที่ทำให้กังหันระบายอากาศบนหลังคาสามารถดูดอากาศได้จริง, เพื่อเปรียบเทียบความสามารถในการดูดอากาศของกังหันระบายอากาศบนหลังคาเมื่อแกนของกังหันระบายอากาศบนหลังคาตั้งตรงและเอียงทำมุมในแนวดิ่งที่ระดับ 5, 10 และ 15 องศา การศึกษามีจุดมุ่งหมายเพื่อศึกษาความสัมพันธ์ระหว่างแรงดูดอากาศภายในกังหันระบายอากาศบนหลังคากับ ความเร็วลม มุมเอียงของแกนกังหันระบายอากาศและและทิศทางที่ลมพัดเข้ากังหันระบายอากาศ โดยได้ทำการศึกษาภายในห้องทดลองที่สร้างขึ้นและออกแบบจำลองตามมอก.1408-2540 มีขนาดกว้าง 1.5 เมตร ยาว 3 เมตร และสูง 1.5 เมตร กังหันระบายอากาศบนหลังคาที่ใช้ในการศึกษามีขนาดเส้นผ่านศูนย์ท่อ 14 นิ้ว น้ำหนัก 2.8 กิโลกรัม มีใบพัดจำนวน 24 ใบ แกนเป็นแบบเข็ม และทำมาจากอะลูมิเนียม ทำการศึกษาที่ระดับความเร็วลมที่สร้างขึ้น 10 ระดับ

ผลการศึกษาพบว่า ความเร็วลมเฉลี่ยต่ำสุดที่ทำให้กังหันระบายอากาศสามารถดูดอากาศได้จริงมีค่าเท่ากับ 0.53 เมตร/วินาที (1.06 น็อต) กังหันระบายอากาศหมุนได้ประมาณ 8 รอบ/นาที ปัจจัยสำคัญที่มีความสัมพันธ์กับประสิทธิภาพของกังหันระบายอากาศคือ ความเร็วลมและมุมเอียงของแกนกังหันระบายอากาศ แรงดูดอากาศของกังหันระบายอากาศสามารถคำนวณได้จากสมการ $Y = 0.146X_1 - 0.023 X_2$ สมการนี้แสดงให้เห็นว่ากังหันระบายอากาศสามารถระบายอากาศได้ดีที่สุดเมื่อติดตั้งแกนของกังหันระบายอากาศทำมุม 90 องศา การติดตั้งกังหันระบายอากาศบนหลังคาสามารถคำนวณโดยใช้รูปแบบการทำนาย

ผลการเปรียบเทียบระหว่างแรงดูดอากาศภายในกังหันระบายอากาศเมื่อแกนของกังหันระบายอากาศบนหลังคาทำมุม 90 องศากับเมื่อทำมุมที่ระดับ 5, 10 และ 15 องศา ที่ระดับความเร็วลมเดียวกัน พบว่า แรงดูดอากาศภายในกังหันระบายอากาศเมื่อติดตั้งแกนกันหันระบายอากาศทำมุม 90 องศา มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ ด้วยความเชื่อมั่น 95% ($p < 0.001$)

การศึกษาทดลองในครั้งนี้คงจะเป็นตัวอย่างที่ดีและเป็นประโยชน์ต่อการออกแบบและการติดตั้งกังหันระบายอากาศบนหลังคา

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LIST OF ABBREVIATIONS

A	Area
C	Constant of proportionality
Cp	Constant of pitot tube
DEDE	Department of Alternative Energy Development and Efficiency
h	Height
Q	Flow rate
RSC	Roof Solar Chimney
T	Temperature
TIS	Thai Industrial Standards
V	Velocity
VP	Velocity pressure
$\triangle t$	Difference temperature
θ	Angle
°C	Degree Celsius
cfm	Cubic foot per minute
cm	Centimeter
ft	Foot
ft^2	square foot
fpm	Foot per min
in	Inch
inHg	Inch of mercury
km	Kilometer
m	Meter
mm	Millimeter
mmHg	Millimeters of mercury
rpm	Round per minute
sec	Second

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CHAPTER I
INTRODUCTION

1.1 Background and Rationale

Thailand located on Hot-humid weather zone, usually hot weather is still almost of the year. From study of temperature data, by Thai Meteorological department, from 1951 to 2007 (56 years) found that minimum average, maximal average temperature and average temperature of Thailand tends to increase figure 1-1 to 1-3 [1].

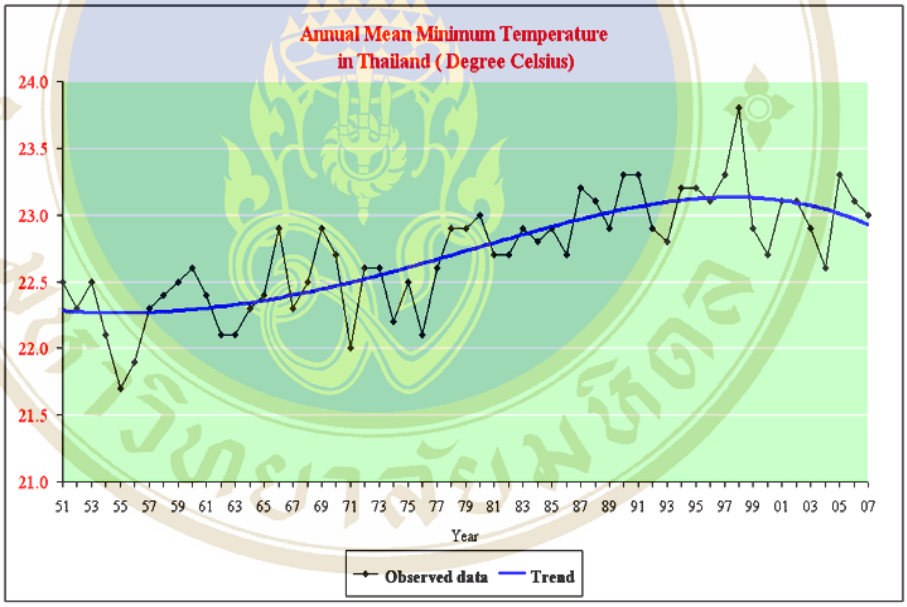

Figure 1-1 The minimum average temperature of Thailand since 1951 to 2007 (Thailand Meteorological department, 2007)

Figure 1-1 illustrated the minimum average temperature of Thailand in 1951 which equal to 22.4 degrees Celsius and in 2007 the minimum average temperature equal to 23 degrees Celsius. Thus, the average increase of temperature was 0.6 degrees Celsius.

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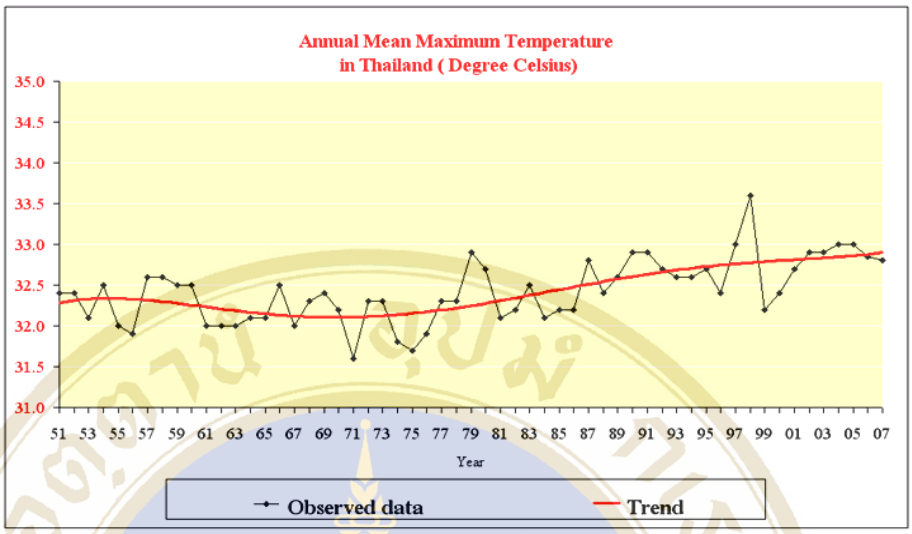

Figure 1-2 The maximum average temperature of Thailand since 1951 to 2007 **(**Thai Meteorological Department, 2007)

Figure 1-2 illustrated the maximum average temperature of Thailand in 1951 which equal to 32.4 degrees Celsius and in 2007 the maximum average temperature equal to 33 degrees Celsius. Thus, the average increase of temperature was 0.6 degrees Celsius.

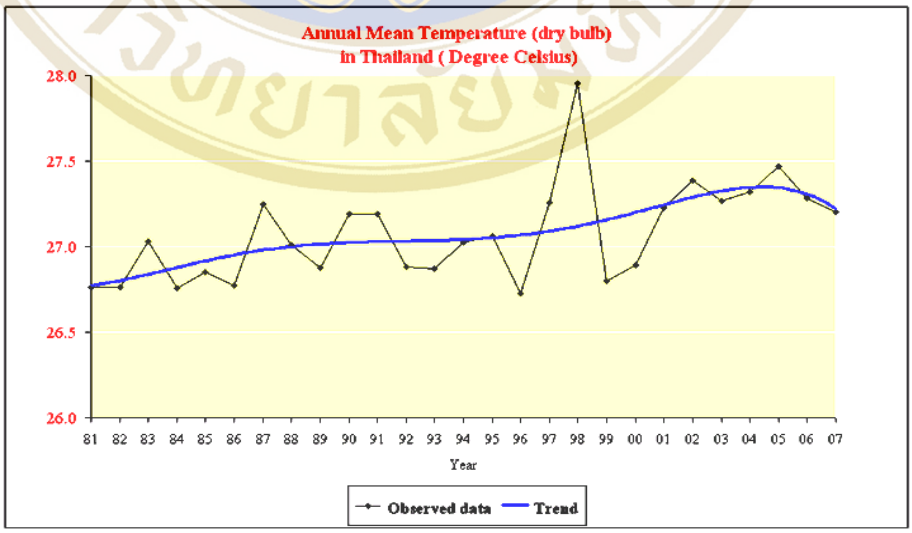

Figure 1-3 The average temperature of Thailand since 1951 to 2007 **(**Thai Meteorological Department, 2007)

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Figure 1-3 illustrated the average temperature of Thailand in 1951 which equal to 26.8 degrees Celsius and in 2007, the average temperature of Thailand equal to 27.2 degrees Celsius. Thus, the average increase of temperature was 0.4 degrees Celsius.

From the hot weather effect, the occupants feel that they are being exposed to sickness caused by the heat in the surrounding environment. If the residential area or working area has the high temperature, it may increase the likelihood of sickness. Hence, the popular remedy is to use air-conditioner, which affect the usage growth rate approximately 10 percents each year and consume more than 60 percents of electricity consumption in the building [2].

There are 2 major environmental heat sources, heat from the sun and heat from the industrial factories. When the sun heat enters the building, it will amplify the heat produced by the machines on the production line. This high temperature work environment will have a direct impact on workers, and the common dangers from the heat are heat exhaustion, fainting, heat stroke, etc. Thus, this leads to the ongoing studies to protect and control dangers from the heat, such as using solar chimney, roof ventilator, and insulator.

The most popular solution for both factories and home is to use roof ventilator because of its ease of installation, strong, durable, quiet, and reduce electricity consumption. Although, there had been no research to confirm the wind strength needed for the roof ventilator to effectively circulate the heat.

The survey results by using questionnaires showed that the popular roof ventilator is the aluminum roof ventilator and sizes are ranged from 19-28 inches. Many of installed roof ventilators do not have standard guaranteed certificate and only 30.77% conduct an efficiency test. There had been a fault belief that, when roof ventilator rotates, it will produce 100% ventilation.

From the doubt that, 1) How much is the wind power quantity that the roof ventilator can effectively exhaust air? 2) In installation roof ventilator, when the axles of roof ventilator slanted in the different vertical angles level, will the efficiency of exhausting air different? and 3) How is the exhausting power and the exhausting distances of the roof ventilator at the different levels of wind velocity? The researcher interests and conducts this study.

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1.2 Objectives

1.2.1 To study the minimum wind speed which the roof ventilator can effectively exhaust air.

1.2.2 To compare the exhausting power inside the roof ventilator, when the axle of roof ventilator was installed perpendicularly and the angles of 5, 10 and 15 degrees.

1.2.3 To study the relationships between the exhausting power inside the roof ventilator and the influencing factors (i.e. the wind speed, the angles of the axle's roof ventilator and the wind direction that blow towards the roof ventilator).

1.2.4 To study the exhausting power and the exhausting distances of the roof ventilator at the different levels of wind speed.

1.3 Hypothesis

1.3.1 With the constant level of wind speed, the exhausting power inside the roof ventilator between when the axle of roof ventilator was perpendicularly and the angles of 5, 10 and 15 degrees, were no significant different.

1.3.2 With the different levels of wind speed, the exhausting power inside the roof ventilator when the axle's roof ventilator slanted in the same vertical angles were no significant different

1.3.3 The exhausting power inside the roof ventilator had relationships with the wind speed and the angles of the axle's roof ventilator.

1.4 Variables

1.4.1 Independent variables

1) Wind speed

2) The angles of the axle's roof ventilator

1.4.2 Dependent variables

1) The efficiency of exhausting air of roof ventilator

2) The exhausting air distances of roof ventilator

1.4.3 Extraneous variables

1) The size of roof ventilator

2) Direction of slant the axle's roof ventilator

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3) Wind flow of direction

4) Position measure of wind speed

5) Duration of sampling

6) Type of the axle's roof ventilator

1.5 Scope and Limitation

1.5.1 This research study was conducted in the simulation laboratory in order to comply with the regulations Thai Industrial Standards 1408-1997.

1.5.2 The roof ventilator in this study was made of aluminum. It had a body diameter 48.26 centimeters (19 inches), duct diameter 35.56 centimeters (14 inches), had 24 propellers and weighed 2.8 kilogram, selected from company that made Thai Industrial Standards 1408-1997 or had the standard in built.

1.5.3 The scope of this study was to focused on the efficiency of exhausting air and the cycle of roof ventilator when the axle's roof ventilator was perpendicularly and the angles of 5, 10 and 15 degrees.

1.5.4 The type of the axle's roof ventilator in this study was needle axle.

1.5.5 The study will be limited on the distances of the roof ventilator when the axle's roof ventilator was perpendicularly.

1.5.6 The air flow direction in this study will limit only one direction.

1.6 Expected Outcomes and Benefit

1.6.1 To know the minimum wind speed, which the roof ventilator can effectively exhaust air.

1.6.2 To know the efficiency of exhausting air of roof ventilator when the axle's roof ventilator made the angles of 5, 10 and 15 degrees in the vertical.

1.6.3 To know the exhausting distances of the roof ventilator at the different levels of wind speed.

1.6.4 The advantages of this experimental study will be the guideline for installation and designs the roof ventilator for enhance the efficiency of exhausting air of roof ventilator.

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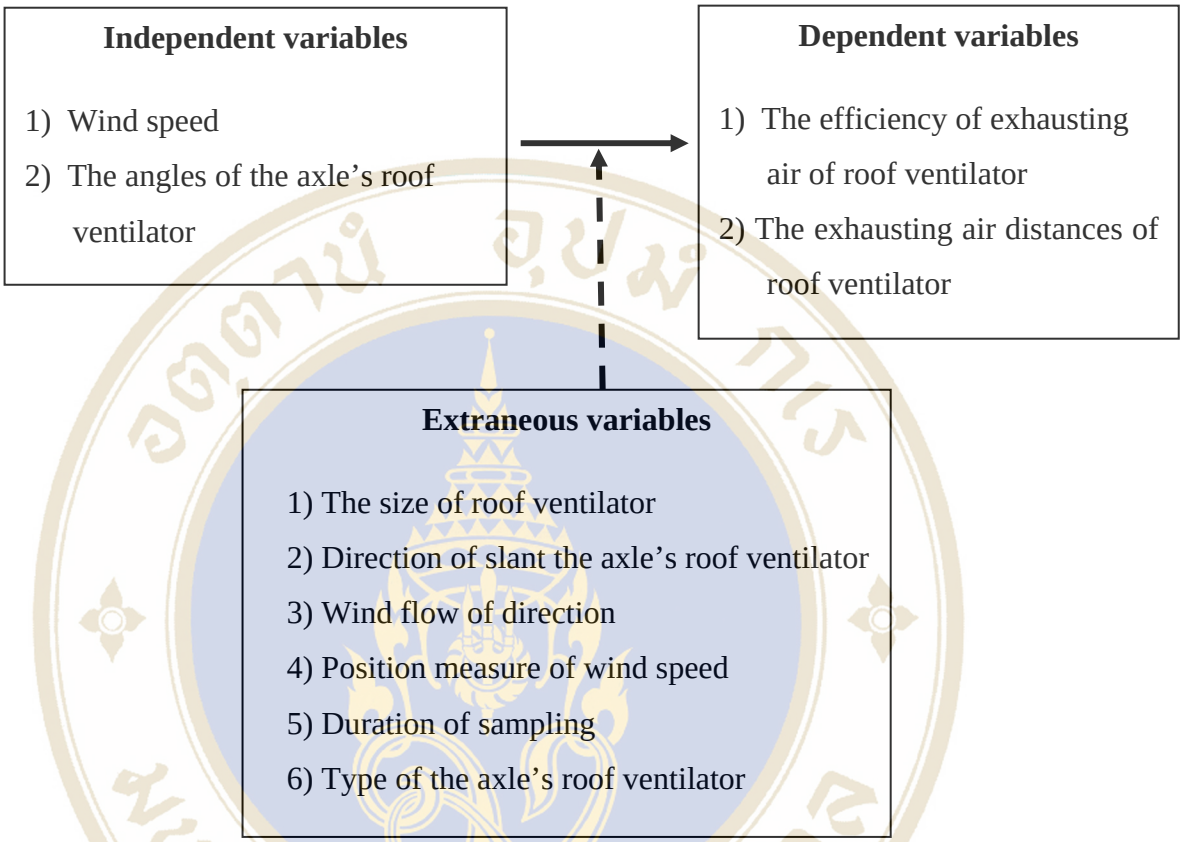
1.7 Conceptual Framework



1.8 Glossary of Terms and Definitions

Roof ventilator (Thai Industrial Standards, TIS 1408-1997) means a heat extractor on roof has normal curve figure, its work base on the rotation of the propeller [3].

The wind speed inside the roof ventilator (TIS 1408-1997) or wind speed on base. It represents the measurement of wind velocity in roof ventilator follow TIS 1408-1997.

The important factor means the factor have affect to the efficiency of exhausting air of roof ventilator. The important factors in this study include the wind speed, the angles of the axle's roof ventilator and the wind direction that blow towards in the roof ventilator.

The efficiency of roof ventilator means the efficiency of exhausting air of roof ventilator in each wind speed.

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The cycle of roof ventilator means the number of rounds at the roof ventilator can rotate one minute.

The exhausting distances of roof ventilator means the distance that is roof ventilation can effectively exhaust air. The measuring point will be at the end of duct which installs the flange. While measuring the axis of the roof ventilation must install perpendicularly. The test of the exhausting air will be done by using smoke tube.

Thermal comfort or the comfortable condition means the conditions that balance temperature between the temperature in the body and the temperature in the environment or without any exposure to heat source [4].

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CHAPTER II
LITERATURE REVIEW

2.1 Climate in Thailand [5]

2.1.1 Location and Size Thailand is in tropical southeast of Asia, between latitudes 5° 37′ north with 20° 27′ north and between longitudes 97° 22′ east, with 105° 37′ east, there is the all area about 513, 115 a square kilometers**.**

2.1.2 Monsoon Thailand stays beneath the influence of two kinds cresses be southwest monsoon and northeast monsoon**.**

2.1.2.1 Southwest monsoon will blow to cover Thailand during the middle of May to the middle of October. The source come from high-pressure area in South hemisphere of Indian Ocean, which will blow from the center and become the southeast monsoon and when blow crosses the equator will become south west wind. This monsoon will take the mass of damp air from Indian Ocean to Thailand, which make cloudy and rainy**.**

2.1.2.2 Northeast monsoon will blow to cover Thailand during the middle of October. The source comes from high-pressure area in Northeast hemisphere of Mongolia and Chinese. This monsoon will take the mass of cold air and dry air from Mongolia and Chinese to Thailand, which make clod and dry**.**

Position of intertropical convergence zone show in Figure 2-1

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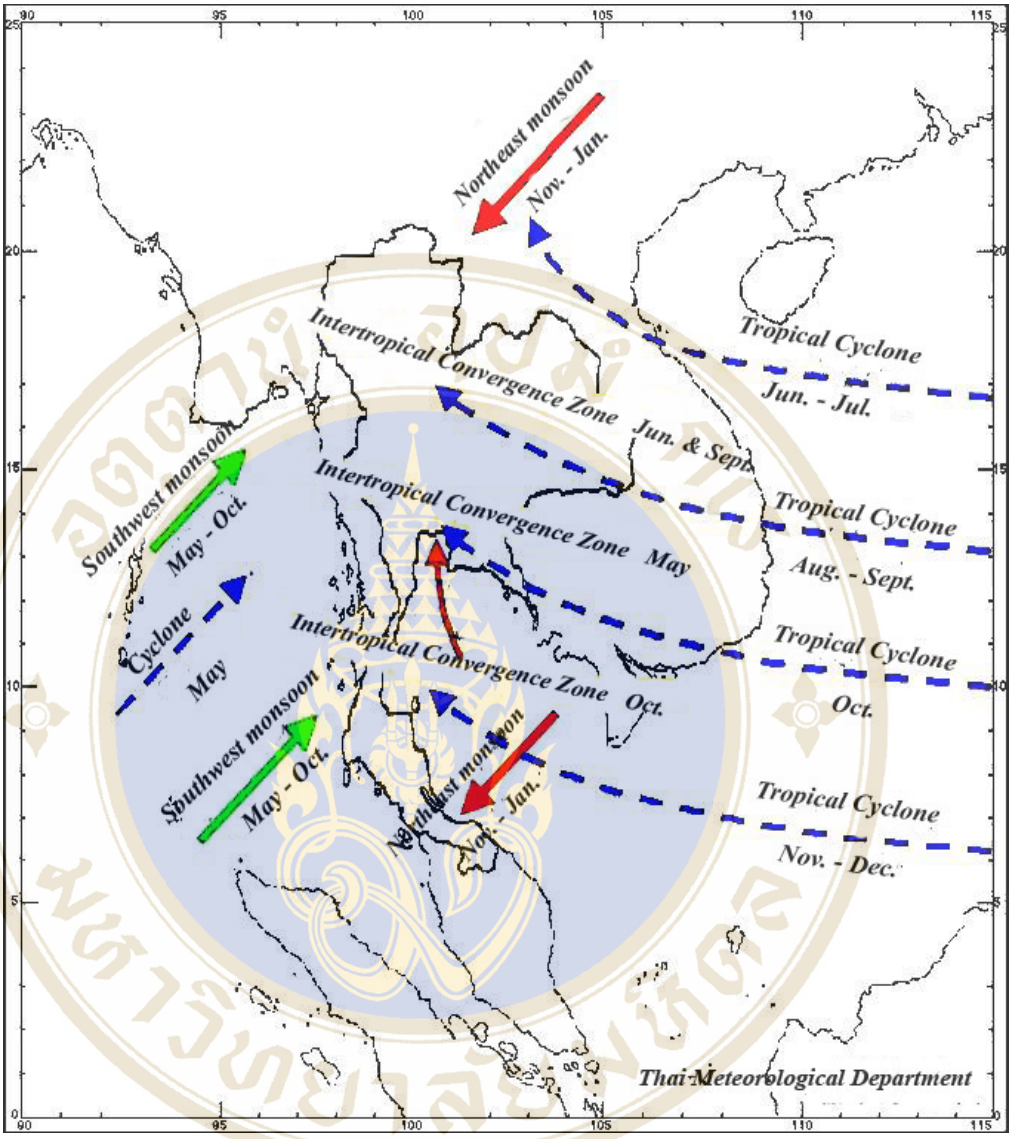

Figure 2-1 Position of intertropical convergence zone.

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2.1.3 The wind speed of Thailand [6] classify according to region since 2002 - 2007 Thai Meteorological Department is summarize in table 2 – 1 (Source: from Thai Meteorological Department)

Table 2 – 1 The Maximum wind speed according to the month and region

Region	Year	Maximum wind speed, (knots)			
		Min	Month	Max	Month
North	2002	1	Jun., Oct.	55	Mar.
	2003	6	Jan., Jun., Jul., Oct.- Dec.	54	Apr.
	2004	5	Sept.- Nov.	56	Apr.
	2005	6	Jan., Jul., Aug.,Sept., Nov., Dec.	53	Apr.
	2006	0	Jan.- Mar., May - Nov.	180	Sept.
	2007	0	Feb.- Jul.	210	Jul.
Northeast	2002	8	Aug.	45	Apr.
	2003	9	Jul., Sept.	47	Apr.
	2004	8	Aug.	45	Apr.
	2005	7	Feb.	90	Mar.
	2006	3	Feb.	45	Mar.
	2007	4	Sept.	190	Jul.
Central	2002	8	Feb.	45	Apr.
	2003	10	Jan.	56	Apr.
	2004	8	Jan.	40	Jul.
	2005	7	Jan.	45	Sept.
	2006	0	Jan.- Apr., Oct., Nov.	162	Oct.
	2007	7	May, Sept., Dec.	230	Mar.
East	2002	3	Jan.	45	Aug.
	2003	8	Jul.	40	Mar., May, Jul.
	2004	8	Feb., Jul.	50	May, Jun.
	2005	6	Feb.	45	Mar.

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Table 2 – 1 The Maximum wind speed according to the month and region (continued)

Region	Year	Maximum wind velocity, (knots)			
		Min	Month	Max	Month
East	2006	6	Sept.	40	Jun.
	2007	6	Sept.	75	Sept.
South					
- East shore	2002	6	Sept.	48	Apr.
	2003	8	Mar., Apr.	38	Jul.
	2004	10	Jan. – May, Jul.,Oct. – Dec.	40	Mar.
	2005	8	Feb., Nov. , Dec.	40	Apr.
	2006	5	Jan., Feb.	43	Aug.
	2007	7	Nov.	270	Aug.
- West shore	2002	9	Feb.	46	May
	2003	8	Jun., Jul., Nov.	41	Jul.
	2004	8	May	30	Jul.
	2005	10	Nov.	32	Jun.
	2006	4	Jan.	70	Mar.
	2007	10	Nov.	270	Sept.

2.1.4 The level of wind power in Thailand [7] show in Figure 2-2 (Source: from Department of Energy Development and Promotion**)**

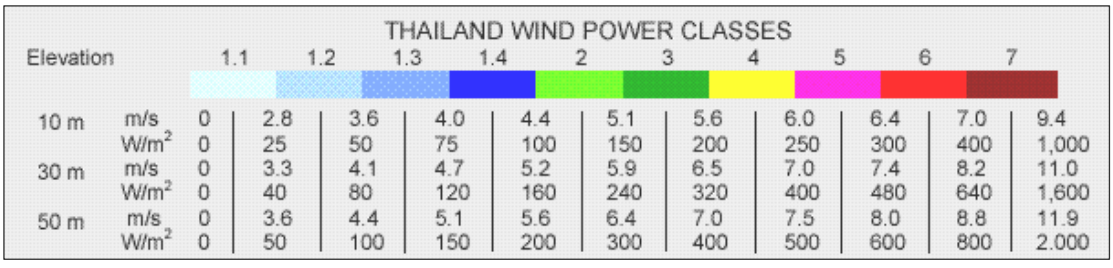

Figure 2-2 The level of wind power in Thailand

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2.1.5 The average maximum and minimum temperatures of Thailand classify according to the region since 2002 to 2007 [8] (Source: from Thai Meteorological Department)

Tables 2-2 The average maximum and minimum temperatures of Thailand since 2002 – 2007

Region	Year	Average maximum temperature (°C)	Month	Average minimum temperature (°C)	Month
North	2002	37.5	Apr.	15.7	Jan.
	2003	36.8	Apr.	15	Dec.
	2004	37.5	Apr.	13.9	Dec.
	2005	36.5	Apr.	15.7	Jan.
	2006	36.1	Mar.	15.2	Jan.
	2007	36.6	Apr.	15	Jan.
Northeast	2002	36.2	Apr.	16.4	Jan.
	2003	36.3	Apr.	15.9	Jan.
	2004	36.1	Apr.	15.7	Dec.
	2005	36.1	Apr.	16.8	Jan.
	2006	35	Mar., Apr.	16.7	Jan.
	2007	35.9	Apr.	16.6	Jan.
Central	2002	36.8	Apr.	22	Dec.
	2003	36.4	Apr.	19.6	Dec.
	2004	37.2	Apr.	12	Dec.
	2005	36	Apr.	20.6	Jan.
	2006	35.6	Apr.	20.5	Jan.
	2007	36.1	Mar., Apr.	21	Jan.
East	2002	34.9	Apr.	21.1	Jan.
	2003	33.9	Mar.	20.2	Dec.
	2004	35.5	Apr.	20.2	Dec.
	2005	34.6	Apr.	21.1	Jan.
	2006	34.4	Apr.	21.6	Jan., Dec.
	2007	34.4	Mar.	21.9	Jan., Nov., Dec.
South	2002	34.5	Apr.	22.1	Feb.
	2003	34.6	Apr.	22.4	Jan.
	2004	33.8	March	22.2	Dec.
	2005	35.1	Apr.	22	Jan.
	2006	33.6	Apr.	22.2	Jan.
	2007	33.9	Apr.	22.1	Feb.

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2.1.6 Pressure value that all altitude [9]

Table 2-3 The pressure value according to the height of sea level

The height from sea level (km)	Pressure Value (mmHg)
0	760
1	675
2	600
3	530
4	470
5	410
6	360
7	320
8	280
9	245
10	210
11	185
12	160
13	140

From table 2-3 When the high from sea level increase the pressure value will decrease and change according to the height of sea level. The pressure value can used to identify the height of sea level (using the barometric pressure: mercury type). The formula for calculating the height of sea level calculated as the following equation:

$$\text{The height from sea level} = (760 - \text{the pressure}) \times 11 \quad (2.1)$$

2.2 The principle of air movement [10, 11]

The air movement had two causes.

2.2.1 Difference of the temperature. When the air has different temperature, the air movement from the area where has low temperature to high temperature.

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In the high temperature, the air has less density with high temperature will rise up on the top while the low air temperature will replace then cause the movement of air.

2.2.2. Difference of the pressure. The air movement from the area where has high pressure to low pressure.

2.3 Kinds of airflow [10]

Airflow has existed four kinds:

1. Laminar Flow.
2. Separate Flow.
3. Turbulent Flow
4. Eddy Currents Flow.

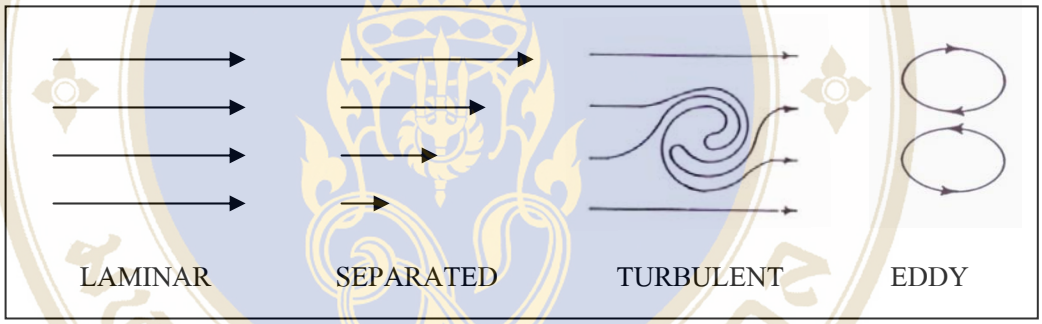

Figure 2-3 The Characteristics of Airflow

The property of airflow as follows [12]:

1. Inertia of Air. Usually, the air movement in straight line but, if outside power makes the air movement, it is a curve and it does not move in a corner of reflection.

2. High and Low Pressure Areas, when there is the wind comes to impact with the material. It will cause the power pressure at the wall of the material and make the positive pressure area. In opposite, the backside of material will be negative and natural pressures when the air blows beside of the material. This phenomenon can course the air circulation.

3. Stability of air occurs because of there is no gain and loss of the amount of air. Then the air in coming to the building will be equal to the air exhaust.

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2.4 The principle of Stack Effect [10, 13, 14, 15, 16, 17]

The Stack Effect might sometimes know in the other name such as Stack action, Chimney effect, etc [18]. The Stack Effect is the movement of air into and out of buildings chimneys, flue gas stacks or other containers, and is driven by buoyancy, Buoyancy occurs due to a difference in indoor-to-outdoor air density resulting from temperature and moisture differences. The result is either a positive or negative buoyancy force. The greater the thermal difference and the height of the structure, the greater the buoyancy force, and thus the stack effect. The stack effect is also referred to as the "chimney effect", and it helps drive natural ventilation and infiltration.

Factor of the movement in Stack Effect as follows:

1. Difference of temperature. If the temperature has difference extremely, it will have more float only.

2. The height of the entrance and the exit the air follow the vertical, if very height extremely, the movement of the air is very extremely.

3. The area infront cut of the entrance and the exit in the air, by see the area infront cut that most tiny that is standard. Consider follow equation of algebraic rate like Natural ventilation as follows:

$$Q = 9.4A\sqrt{h\,(\Delta t)} \qquad (2.2)$$

When, Q = The rate of flow of air for natural ventilation (cfm).

A = The area of the inlet or outlet, assuming that each is the same (ft^2).

h = The difference in height between inlet and outlet areas (ft).

△t, = Difference of outside and inside temperature (F).

2.5 The principle of Heat Transfer [19, 20, 21, 22, 23] There is three ways

2.5.1 Heat conduction or thermal conduction is the spontaneous transfer of thermal energy through matter, from a region of higher temperature to a region of lower temperature, and acts to equalize temperature differences. The same coulomb forces that act to support the structure of matter so can be said to move by physical contact between the particles transfer thermal energy, in the form of continuous

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random motion of the particles of the matter. Heat can also be transferred by radiation and/or convection, and often more than one of these processes occur in a given situation. Heat Conduction has the algebraic equation in the calculation as follows

$$Q = U * A * (Ti - To) \quad (2.3)$$

When, Q = Thermal energy transfer, (Btu/h).
U = Heat transfer coefficient, (U-Value) (Btu/h * ft^2 * F).
A = Surface area of the heat being transferred, (ft^2).
Ti = The indoor temperature (F).
To = The outdoor temperature (F).

2.5.2 Convective heat transfer is a mechanism of heat transfer occurring because of bulk motion (observable movement) of fluids. This can be contrasted with conductive heat transfer, which is the transfer of energy by vibrations at a molecular level through a solid or fluid, and radiative heat transfer, the transfer of energy through electromagnetic waves. As convection is dependent on the bulk movement of a fluid, it can only occur in liquids, gases and multiphase mixtures. Convective heat transfer is split into two categories: natural (or free) convection and forced (or advective) convection, also known as heat advection has the algebraic equation in the calculation as follows:

$$Q = h * A * (Ta - Ts) \quad (2.4)$$

When, Q = Thermal energy transfer (Btu/h).
h = Heat transfer coefficient (Btu/h * ft^2 * F)
A = Surface area of the heat being transferred (ft^2).
Ta = Temperature of the environment (F).
Ts = Temperature of the object's surface (F).

2.5.3 Heat radiation is the transfer of heat through electromagnetic radiation. Hot or cold, all objects radiate energy at a rate equal to their emissivity times the rate at which energy would radiate from them if they were a black body. No medium is

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necessary for radiation to occur; radiation works even in and through a perfect vacuum. The energy from the Sun travels through the vacuum of space before warming the earth. Also, the only way that energy can leave earth is by being radiated to space. Heat radiation has the algebraic equation in the calculation as follows:

$$Q = \delta * \varepsilon * A * (T_1 - T_2) \qquad (2.5)$$

When, Q = Thermal energy transfer (Btu/h).

δ = the constant of Stefan-Boitzmann = 1.7135×10^{-9} (Btu/h * ft^2 * F),

ε = spitting infrared rays value of inventory skin.

A = Surface area of the heat being transferred that radiate, (ft^2).

T1 = Temperature of the object's surface that radiate (F).

T2 = Temperature of the environment that has to radiate (F).

2.6 The way is Air pocket ventilation

The way is Air pocket ventilation can separate four ways [24], as follows:

2.6.1 Scups ventilation. This ventilation use the voltage of pressure by designing air reaches in one line with wind direction. Designing turn opens in the direction follows the wind. The wind is will crash, it cause self-glorification of way wind air reaches because of way area reaches positive pressure make the wind from the channel opens in the direction opposite with wind line will can move to change wind way has go out again the one way convenient, the ventilation with this way will depend on wind speed, the size of the channel opens and the difference of air outside building temperature and area temperature under a roof.

2.6.2 Burnury effect. This ventilation is difference pillar of the air pressure, which cause going back in the air within a duct and can apply with a building.

2.6.3 The ventilation with the chimney. It is difference pillar of the air pressure in the vertical; mostly will the chimney then to call that the ventilation with the chimney or the movement in the air will go up in the air within the chimney. While below will the air that has tall density air part that the chimney that has the a little density and more temperature. Thus, hot airflows are departing to the chimney cold air

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that the density comes instead. The stack effect can calculate get from the algebraic equation as follows [4].

$$Q = CA\sqrt{\frac{h\,(t_i - t_o)}{t_i}} \qquad (2.6)$$

When, Q = Stack effect draft / draught flow rate (cfm).

C = Constant (Constant of Proportionality) = 313, (be the value that assume circulating state of topmost air in 65 % theoretical but, if state circulating of not good air use the value, C = 240).

A = Flow area (ft^2).

H = Height or distance (ft).

T_i = Average inside temperature, (F).

T_O = Outside air temperature, (F).

2.6.4 Turbine ventilator, this way is wind speed and the difference in the temperature. Wind mill child sphere causes power efficiency exhaust the air within comes out to the outside, which be air lead that have height temperature within the channel under a roof has come out then liberate to give the air that has the low temperature to flow enter instead of .

2.7 The meaning of the Roof Ventilators

The Roof Ventilators: The Thai Industrial Standards Institutes, TIS 1408- 1997 had defined the measuring of roof ventilator which is the ventilator that set up on a roof with the Figure resemble normal curve. The mechanism of the ventilator is the whirling of propeller. (See Figure 2-4)

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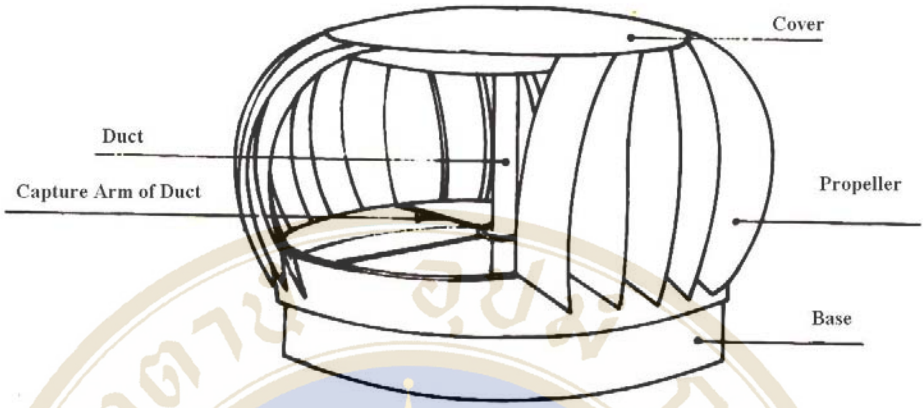

Figure 2-4 The components of roof ventilator from the Thai Industrial Standards Institute 1408 – 1997.

The roof ventilators sometimes are defined as the turbine ventilators or the ventilators on a roof [24] or turns to ventilate on a roof.

Speed test of that the base of roof ventilator according to the Thai Industrial Standards Institutes 1408-1997 will perform at wind tunnel with the surface area of M > 2.8D and L > M. The test will be using wind velocity 16 ± 2 m/s for 2 min. Then the measurement can be performed.

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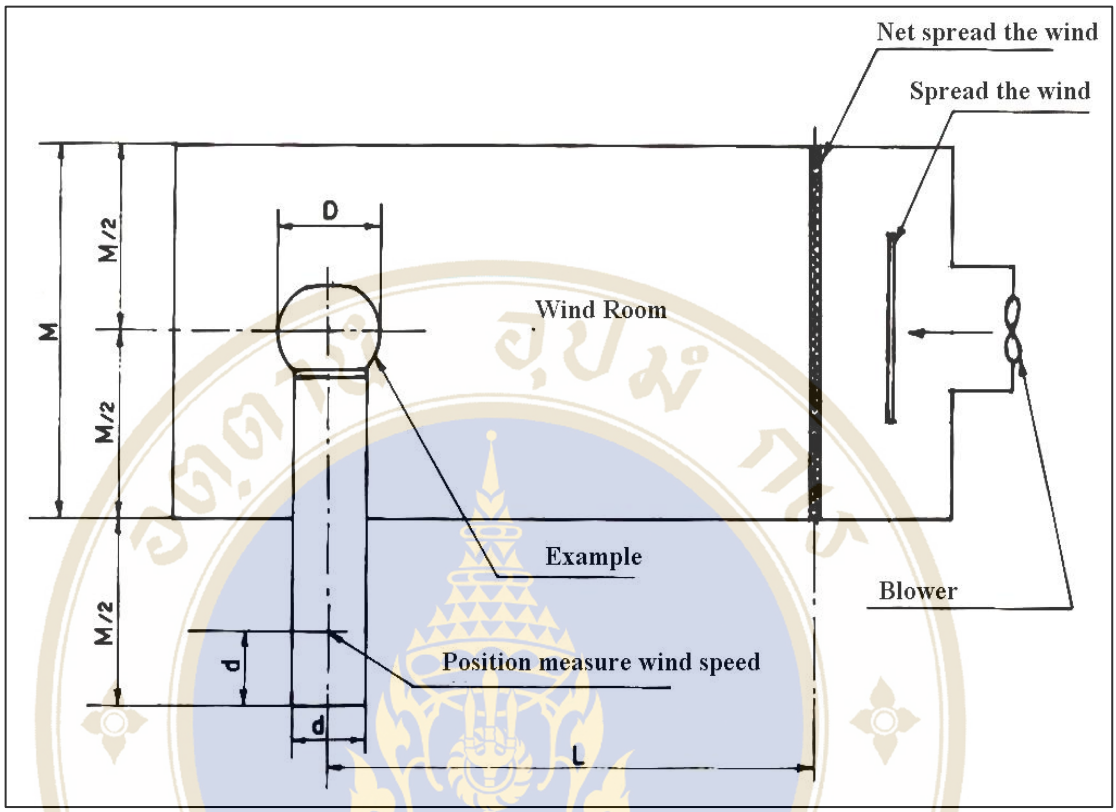

Figure 2-5 Test velocity that the base of the roof ventilator
(Thai Industrial Standards Institute, TIS 1408-1997)

2.8 The ventilation by the roof ventilator

The roof ventilator will ventilate air on the roof by difference of temperature and wind velocity [24]. The wind blows pass the part of the propeller and cause the ventilation.

2.8.1 The principles of the roof ventilator, as the following:

a) Two mechanism occurs when the wind source power blow to the propeller and fin the air.

b) When the fin traps the wind of the roof ventilator was turned. It move air of the inside go to outside (show in Figure 2-6).

c) In case of still air, there is no power to build the fin traps the roof ventilator will act as the chimney (show in Figure 2-7).

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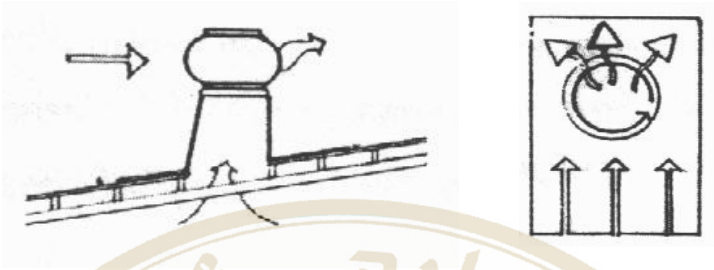

Figure 2-6 Illustrated the work of the electric fan in character transfer to Turbine Ventilator

Figure 2-7 Illustrated the work of the electric fan in character chimney

2.8.2 At the present time, there are two kinds of the axles used in the roof ventilator.

2.8.2.1 The need axle [25], which has character resembles a needle, install on the base and shaft. Part of top was connected with the top plate of ventilator (show in Figure 2 – 8).

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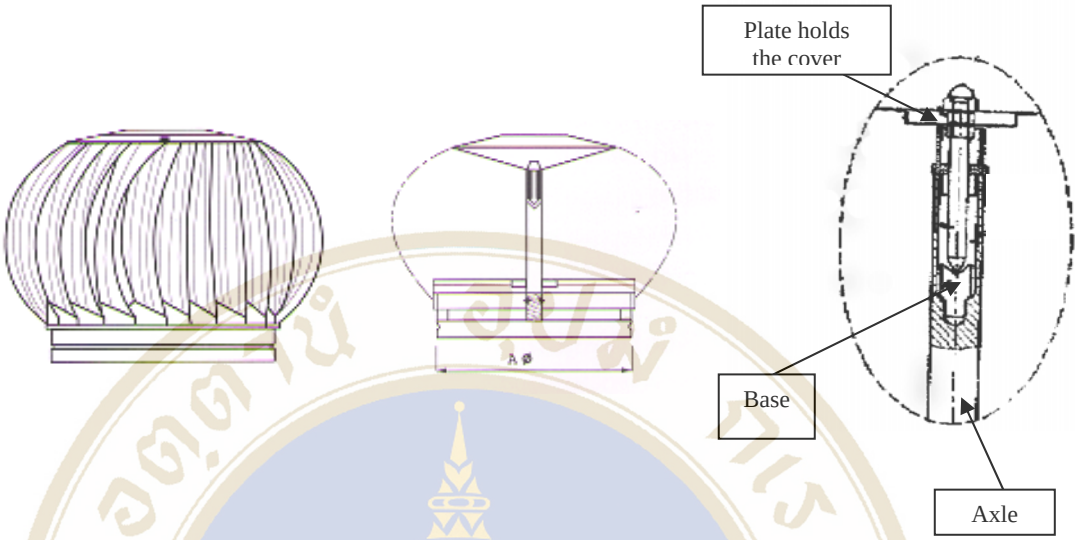

Figure 2-8 The Roof Ventilator is a kind of needle

2.8.2.2 The bullet axle [26], the character of this kind makes from the stainless or the galvanized iron and the upper bullet and the lower are connected with the axle of the roof ventilator (show in Figure 2 – 9).

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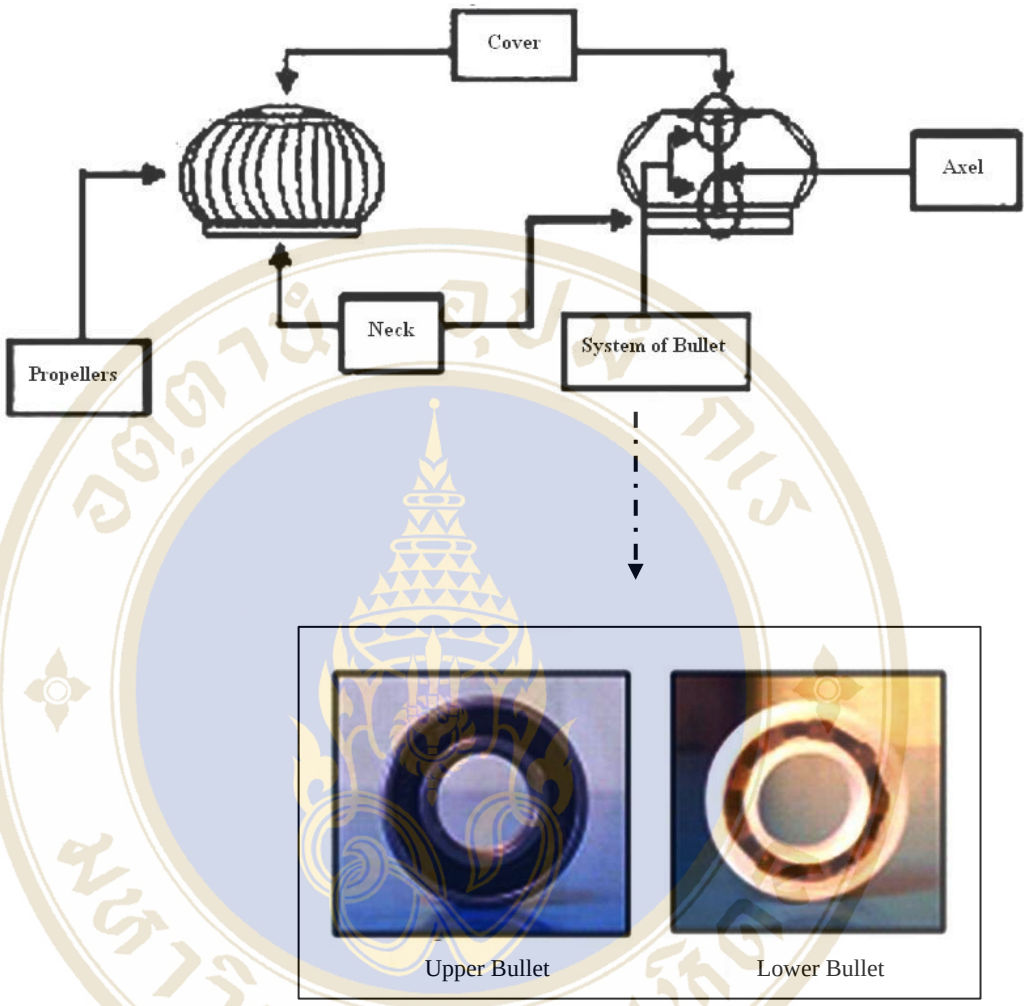

Figure 2-9 The axle of the roof ventilator use a bullet

2.8.3 Roof ventilator installation [24], is as follows:

a) Single unit installation is to install on the roof's top most area to ventilate the heat in the attic. Installation of this character should spaced out no less than 2 times the height, so the wind can collided with full velocity and work at full capacity.

b) Multiple units' installation is to install multiple rows on the roof to ventilate the whole area beneath the roof, suitable for buildings with extensive roofs or have slightly incline roofs.

c) Installation of air ventilation mill with chimney (Lift motor room), the chimney will allow the mill to collide with the wind at a specific height.

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2.8.4 Factors that effect roof ventilation mill are wind velocity, temperature difference, height of the ventilator, and propeller size or the wind trap fin. [24, 27]

2.8.5 The advantages of air ventilation mill installation are improving ventilation, easy to install, light weight, strong, durable, always on, and protect rain water to seep through the ceiling. There is give choosing both of the aluminum and the hornet does not produce loud noise, decrease electricity consumption and environmental friendly [27].

2.9 Measuring speed instruments in the air movement have various kinds for example [28, 29]:

2.9.1 Deflecting vane velometer measures capture velocity, face velocity and slot velocity. It provides an average measurement range from 0 to 10,000 fpm.

2.9.2 Vane anemometer functions by the airflow stream hitting the vane, making it rotate. The most common vane diameter is four inches. It provides an average measurement range from 2 to 4 fpm.

2.9.3 Heated wire anemometers operate on the principle of heat transfer. It provides an average measurement range from 0.5 to 100 fpm.

2.9.4 Swinging Vane Anemometer is the equipment measures wind velocity, which there is moderate velocity and low, moderately well. Usual will use at not exceed 50 foot per minute (fpm).

2.9.5 Rotating Vane Anemometer, like to use wind velocity temple outside a mostly building. In a building where have wind height velocity, it can use.

2.10 Measurement of Wind speed in Duct

2.10.1 Pitot tube is wind velocity meter in a pipe. The specifications of the Pitot tube in use which the Standard Pitot Tube. Use a coefficient of 0.99±0.01 and must have especial other quality, as follows [30, 31]:

a) Hemispherical (shown in Figure 2-10), ellipsoidal, or conical tip.

b) A minimum of six diameters straight run (based upon D, the external diameter of the tube) between the tip and the static pressure holes.

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c) A minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube, following the 90 degrees bend.

d) Static pressure holes of equal size (approximately 0.1 D), equally spaced in a piezometer ring configuration.

e) Ninety degrees bend, with curved or mitered junction.

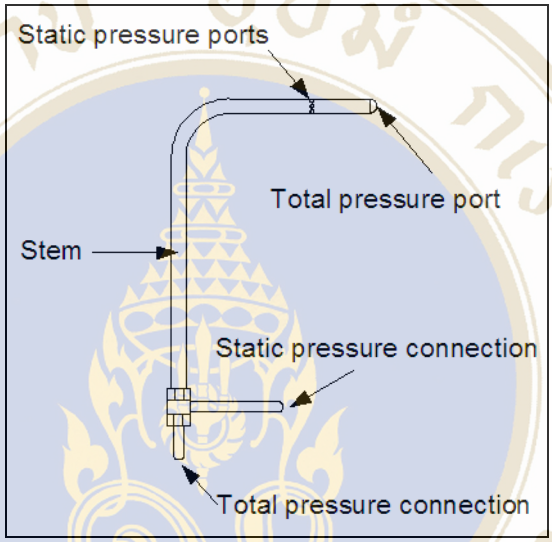

Figure 2-10 Standard Pitot Tube

Type S Pitot Tube Assemblies. During sample and velocity traverses, the isolated Type S Pitot tube is not always used; in many instances, the pitot tube is used in combination with other source-sampling components (e.g., thermocouple, sampling probe, and nozzle) as part of an "assembly." The presence of other sampling components can sometimes affect the baseline value of the Type S Pitot tube coefficient; therefore, an assigned (or otherwise known) baseline coefficient value may or may not be valid for a given assembly. The baseline and assembly coefficient values will be identical only when the relative placement of the components in the assembly is such 226 that aerodynamic interference effects are eliminated. Interference-free component arrangements for Type S pitot tubes having external tubing diameters between 0.48 and 0.95 cm (3/16 and 3/8 in.). Type S Pitot tube assemblies that fail to meet any or all of the specifications should be calibrated according to the procedure outlined, and prior to calibration, the values of

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the intercomponent spacing (pitot-nozzle, pitot-thermocouple, and pitot-probe sheath) shall be measured and recorded.

When any of the traverse points as located fall within 2.5 cm (1.0 in.) of the stack walls, relocate them away from the stack walls to: (1) a distance of 2.5 cm (1.0 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger. These relocated traverse points (on each end of a diameter) shall be the "adjusted" traverse points. Stacks with Diameters Equal to or Less Than 0.61 m (24 in.). Follow the procedure noting only that any "adjusted" points should be relocated away from the stack walls to: (1) a distance of 1.3 cm (0.50 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger.

2.10.2 Bearings filtration will measure when the eight- and two-diameter criterion cannot be met, the minimum number of traverse points is determined. Before referring to the figure, however, determine the distances from the measurement site to the nearest upstream and downstream disturbances, and divide each distance by the stack diameter or equivalent diameter, to determine the distance in terms of the number of duct diameters. The minimum number of traverse points that corresponds: (1) to the number of duct diameters upstream; and (2) to the number of diameters downstream. Select the higher of the two minimum numbers of traverse points, or a greater value, so that for circular stacks the number is a multiple of 4, and for rectangular stacks, the number is one of those. But if a pipe dares to cut is a quadrilateral seek diameter size is equal to loud the algebraic equation this time [31, 33, 34].

$$\text{A diameter is equal to} \quad \frac{2\,(\text{length} \times \text{wideness})}{(\text{length} + \text{wideness})} \qquad (2.7)$$

2.10.3 Amount dot specification will to measure (Traverse point) have as follows [31, 34, 35]:

Round pipe with diameters greater than 0.61 m (24 in.). Measuring must more than 12 points.

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a) Round pipe with diameters between 0.30 - 0.61 m (12 - 24 in.). Measuring must more than 8 points.

b) Square pipe with diameters between 0.30 - 0.61 m (12 - 24 inches). Measuring must more than 9 points.

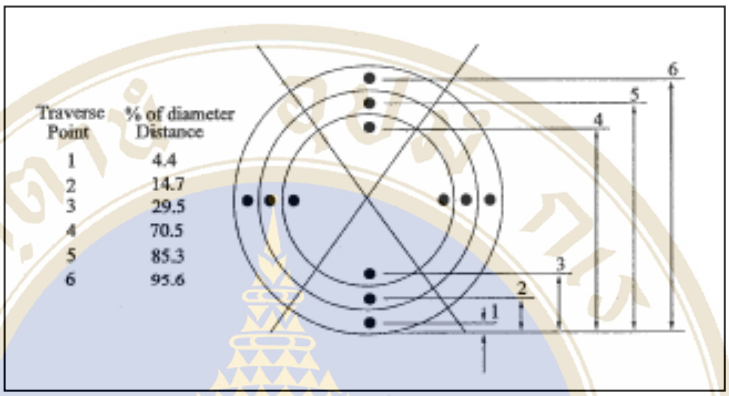

Figure 2 - 11 Traverse points of round duct

Figure 2 – 12 Traverse points of rectangular duct

2.10.4 The way of measures wind speed in a pipe has as follows [35, 36]

a) Assemble the pitot tube suit Inclined manometer or manometer by have trace test leaks before the measure.

b) Fine level of liquid level in Manometer give in the middle give read the value has zero.

c) Insert the pitot tube go inside straight bearings pipe notes, temperature measurement and different pressure, key in each the point.

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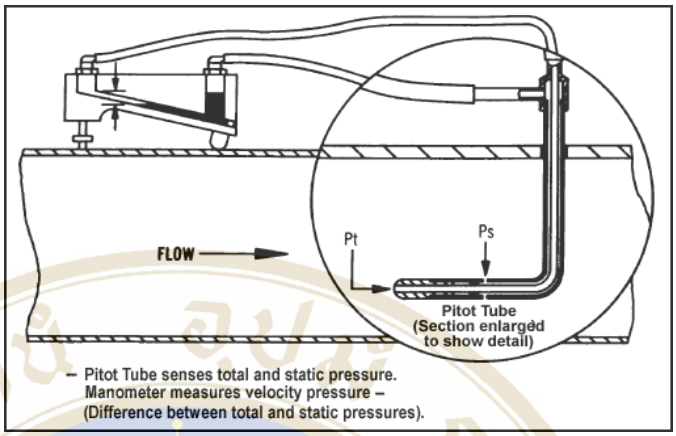

Figure 2 - 13 Measure wind speed, it uses pitot tube with Inclined Manometer

d) Pressure value of wind speed (Speed pressure) at get come to calculate seek wind speed value by use the algebraic equation this time.

$$V_{avg.} = (2.90)(C_p)[(29.92/P_s)(28.95/M_s)(T_s)]^{\frac{1}{2}}\sqrt{VP_{avg.}} \qquad (2.8)$$

When, Vavg. = Average velocity through the area infront cut of the chimney (fpm).

Cp = Coefficient of Correction factor for pitot tube.

Ps = Completed pressure in the chimney (inHg).

Ms = Average of Molecule weight lies of exhaust gas in the chimney.

Ts = Completed temperature in the chimney (°R).

VPavg. = Average of square roots of velocity pressure.

In case of the air is in Standard condition be the density in the air is valuable with 1 or at standard condition at 70 °F. Pressure atmosphere value 29.92 inHg, air density temperatures in 0.075 Pb/ft^3 (pound / foot gram) and the value equal to 32.2 m/sec^2 will can calculate seek wind velocity has from the algebraic this equation.

$$V = 4005\sqrt{VP} \qquad (2.9)$$

when, V = wind speed (fpm).

VP = the pressure of the velocity (inH_2O).

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2.11 Other related literatures

Pibool Sutipun (1994) [39] had studied the heat in the hall by using the model. The study found that the variable affect to the behaviors of the heat in the hall were temperature, channel size opens to ventilate and height.

Kanit Hutanuwat (1994) [12] had studied the factor that effect ventilation rate of solar chimney. The results showed that using tile translucent have the ventilation better using CPAC monier and carved pair.

Supavadee Boontanom (1998) [40] had studied about the promotion of conduction heat loss through maximum stratification, by using the two identical test units. The result sure that heat remove using conduction heat loss through maximum stratification will be more effective when ceiling height is 2 meters higher than typical height.

J-ray Suwanachart (2001) [24] had studied about roof efficiency development to decrease thermal transfer value. Case study: Carrefour superstore ramindra Branch. The study determined the problem solving alternative by focusing at insulation system together with air pocket system. The cellulose insulation is suitable for reducing both conduction and convection; aluminum foil insulation reduces the solar radiation, further more on gypsum board as the ceiling construction. The air pocket system is design for ventilate the air by natural way and make insulation system more completely. As conclusion, the recommendation can reduce the thermal transfer value more than 2 times and better the cooling load by 30 ton/hour after roof system.

Apituch Pomsirisang (2001) [41] had developed of roof design and air circulation system to reduce temperature in building. The result showed that a roof design can reduce thermal during the daytime and reduce temperature night day radiation. Recommendations of roof design are as follow: 1) Use a low mass material roof and use to cooperate the insulator. 2) Insulation system should still be low mass. 3) Roof material should have a long-wave radiation. 4) Roof ventilation system should be employed daytime and 5) Roof cavity and duct system should have less friction loss.

Promsit Sroyraya (2002) [42] had developed a prototype of tropical roof system to reduce heat gain. The objective of this study for analyzes and search for the model roof that can be developed to stop heat gain in the tropical climate. The result showed

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that generally the roof at 60 degrees is better at preventing heat gain when compared with the 15 degrees roof. The heat transferring under the cavity of the black roof can reduce the heat loss at 18.33% rate and in use together with 6 inches thick horizontal insulation would be able to reduce the heat gain 90.28% compared to the metal sheet roof without insulation.

Rachata Sumanon (2002) [43] had studied about the slant angle of roof with in Thai house style. The result showed that daytime period, the temperature within the roof model made the angle of 60 degree, there is topmost temperature lowers the roof model made the angle of 30 degree about 25 degree Celsius and nighttime period, the angle of roof, that 30 degree, will have the temperature lowers 60 roof degree angle.

Orot Sriruang (2002) [27] had experimental comparative analysis of thermal performance between roof solar collector and roof wind turbine. The roof solar collector is composed of CPAC monier tile on the outside, air gap and gypsum board. Roof solar collector and roof wind turbine were installing using small house of 3.92 m^3 during the day of volume. The result showed that the average indoor temperature roof wind turbine was less than roof solar collector was. The difference between the ceiling heat flux is also small about 0.2 W/m^2.

Awbi H.B. (1994) [45] had studied about the natural convection of the solar chimney for use calculate ventilation rate. The result showed that the natural ventilation had related with the height and the float power of solar chimney, in positive.

Boonsri (1998) [46] had studied about the channel opens that affect room temperature and air change per hour by using solar chimney that and roof solar collector. The result showed that using solar chimney can decreased indoor temperature about 2-4 °C and has air change per hour about 15 times of house capacity.

Lai, CM. (2003) [47] had studied the efficiency of roof ventilator that use in the ventilation within a building and a factory in the Taiwan, by use low speed tunnel in test. The result showed that it was indeed helpful to increase ventilation with the installation of ventilators. The bigger the ventilator was with inner vanes, the better ventilation was guaranteed.

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Lai, CM. (2005) [48] had studied the necessity of installation roof ventilator for ventilate within the bathroom which the location in a dormitory of first-class university in Taiwan, by use low speed tunnel in test. The result showed that the bathroom had enough ventilation and now, the ventilation has applied to the quality of air within the bathroom.

Lai, CM. (2006) [49] had developed a prototype's ventilation performance. This study showed installing an inner fan at a high outdoor wind speed (0 and 5 m/s) increased the ventilation rate. A rated rotation speed close to 1500 rpm is highly recommended when installing the inner fan. The experiment showed in Figure 2-14.

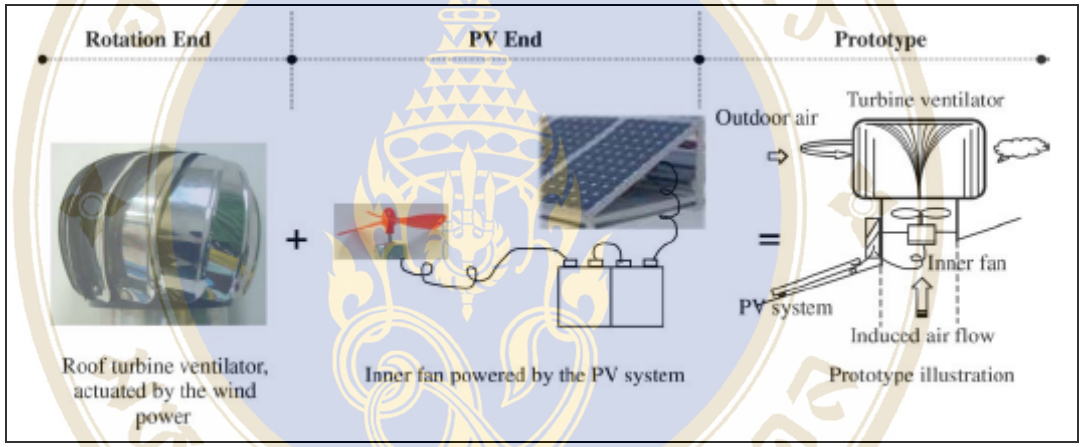

Figure 2-14 Experiment roof turbine ventilator of Lai

Mathur J., et al (2006) [50] had studied effect of inclination of absorber on the airflow rate has been investigated in a solar induced ventilation system using Roof Solar Chimney (RSC) concept. Results of the developed solution show that optimum absorber inclination varies from 40 to 60 degrees depending upon the latitude of place. At Jaipur (India) 45 degrees was found to be optimum for obtaining maximum rate of ventilation. At this inclination, the rate of ventilation is about 10% higher as compared to 60 and 30 degrees inclinations. Experimental investigations show good agreement with the theoretical results. Roof Solar chimney of this size can easily be mounted on residential buildings for enhancing natural ventilation.

Khan N, et al. (2008) [51] had studied the flow rates of four ventilators against wind speed are shown in Figure 2-15. The measurement was carried out on four turbine ventilators: one 300 mm straight vane ventilator and one 300 mm curved vane

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ventilator, both of which are made of steel and aluminum, and two 250 mm straight vane ventilators made of polycarbonate, one of which is transparent to facilitate day lighting. The experiment within special laboratory at establishes (shown in Figure 2-16). This study presents measurement of flow rates of four commercial turbine ventilators on a specifically designed experimental system. The ventilation flow rates and rotational speeds are taken at different wind speeds and compared with a simple open column and two standard vent hats. Use of a DC motor to power the ventilators in the absence of wind is described and power consumption against flow rate is given.

Figure 2 - 15 Four ventilators under test

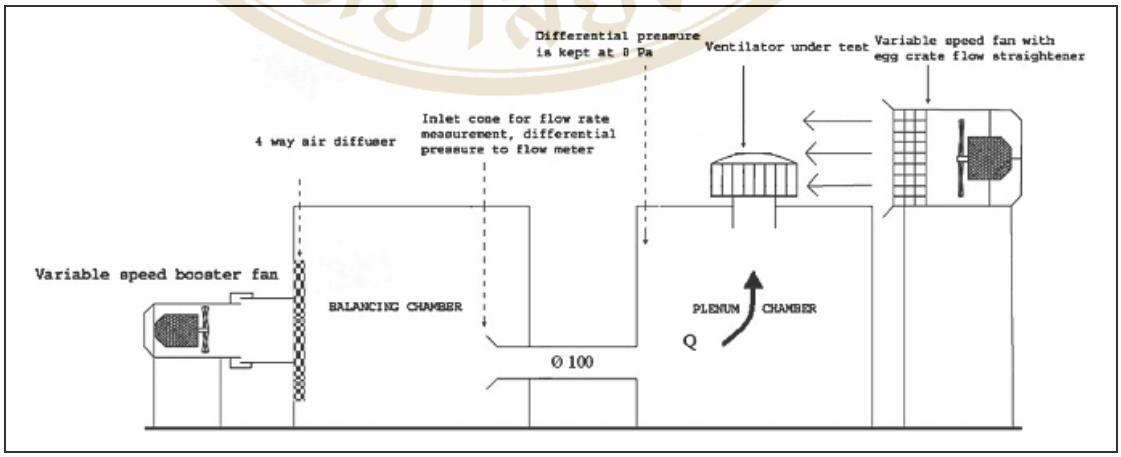

Figure 2 – 16 Schematic view of test rig.

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CHAPTER III
MATERIALS AND METHODS

3.1 Study Design

The study design is the experimental research. The objective is to study the factors that effect exhaust air of the roof ventilator. These factors include wind speed, deviation of axel and distance of exhausting air. This experimental study was conducted in the simulation laboratory in order to follow Thai Industrial Standards Institute number 1408-1997.

3.2 Materials and Equipment

3.2.1 The roof ventilator used in this experiment made from aluminum. The diameter of the roof ventilator (Body diameter) was 48.26 centimeters (19 inches) and the diameter of roof ventilator duct was 35.56 centimeters (14 inches). The amount of propellers in this experiment was 24.

3.2.2 The equipment generated wind speed was consisted of a blower, a driver of pulley (Pulley was attached with the motor.) and the diameters were 6 inches and 8 inches. The diameters of pulley follower (Pulley was attached with the blower) were 6 inches, 12 inches, 14 inches, 16 inches and 18 inches. The conveyor belts were B68, B74, B80, B86 and B90.

3.2.3 The speed meter was PocketTach™ Mini Photo Tachometer Model 461700.

3.2.4 The wind speed meter was VelociCalc plus Air Velocity Meter, Model: 8386 A-M-GB, Serial No.: 03120366 and used a program LOGDAT to transferring data.

3.2.5 The standard pitot tube was 8 millimeters in diameter and 61 centimeters in length. The size of type S pitot tube was 3/8 inches with the length was 1.5 meters.

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3.2.6 The inclined Manometer was U tube with read the maximum value of 1 inch water and the scale was divided into 0.01 inch water. The U-tube Manometer with the maximum value of 10 inches water and the scale was divided into 0.01 inch water. The equipment was supplied from company Dwyer Instrument, Inc. USA.

3.2.7 Smoke tube

3.2.8 Thermometer which was used to measure the temperature of the air.

3.2.9 Barometer which was used to measure the pressure of atmosphere.

3.2.10 Meter.

3.2.11 Stopwatch

3.3 Methodology

In this study, the methodology was divided into 2 parts, were**:**

3.3.1 Simulation Laboratory, the steps of construction are as follows**:**

3.3.1.1 We designed and determined the size of the simulation laboratory according to regulations of Thai Industrial Standards Institutes 1408 – 1997. The dimension of simulation laboratory was 1.5 m × 3 m × 1.5 m (width × length × height). Cross section was in a square shape. We drilled a hole on both side of the laboratories wall. The duct of the wall duct was connected to the roof ventilator at the distance of 35.56 centimeters (14 inches) from the end of the duct. The size of the holes was big enough so that the probe of wind speed meter could enter.

3.3.1.2 Selection of the tool used to the simulation laboratory;

a) We used box iron steels with the length and thickness of 1.5 inches, and 2 millimeters, respectively as the structure of the simulation laboratory. We used square plates with the dimension of 4 inches x 4 inches x 1/4 millimeters to build the base part, which endured weight**.**

b) We used clear acrylic plates with the dimension of 1.5 meters, 1.5 meters and 5 millimeters in width, length and thickness, respectively to build the simulation laboratory wall.

c) The plate used for spreading the wind was made from iron rods with 0.5 meters, 0.5 meters, and 1 millimeters in width, length and thickness, respectively. We used round-iron rod to attach the wind spreaders with the simulation laboratory room.

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d) The wind spreading nets used in this study were iron seize with the dimension of 0.5 meters in width and 0.5 meters in length. The inner part of the nets were drilled a hole drilling, which the sizes of the diameters were 5 millimeters and 10 millimeters. The distances of pith were 5 and 10 millimeters, respectively.

e) Iron plates with 1 inch and 1.5 millimeters in length and thickness, respectively were used to made gutters for moving and holding the seize.

f) The tinplates were used to construct the ducts for connecting the roof ventilator with laboratory and the laboratory with Blower. In addition, we also used slanted duct and flanged in this experiments.

3.3.1.3 The simulation laboratory was constructed and set up. All equipment was installed, following with drilling holes drilling as designed in Figure 3-1 and 3-2. The details and the specifications of the simulation laboratory showed in Appendix D Figure D-1.

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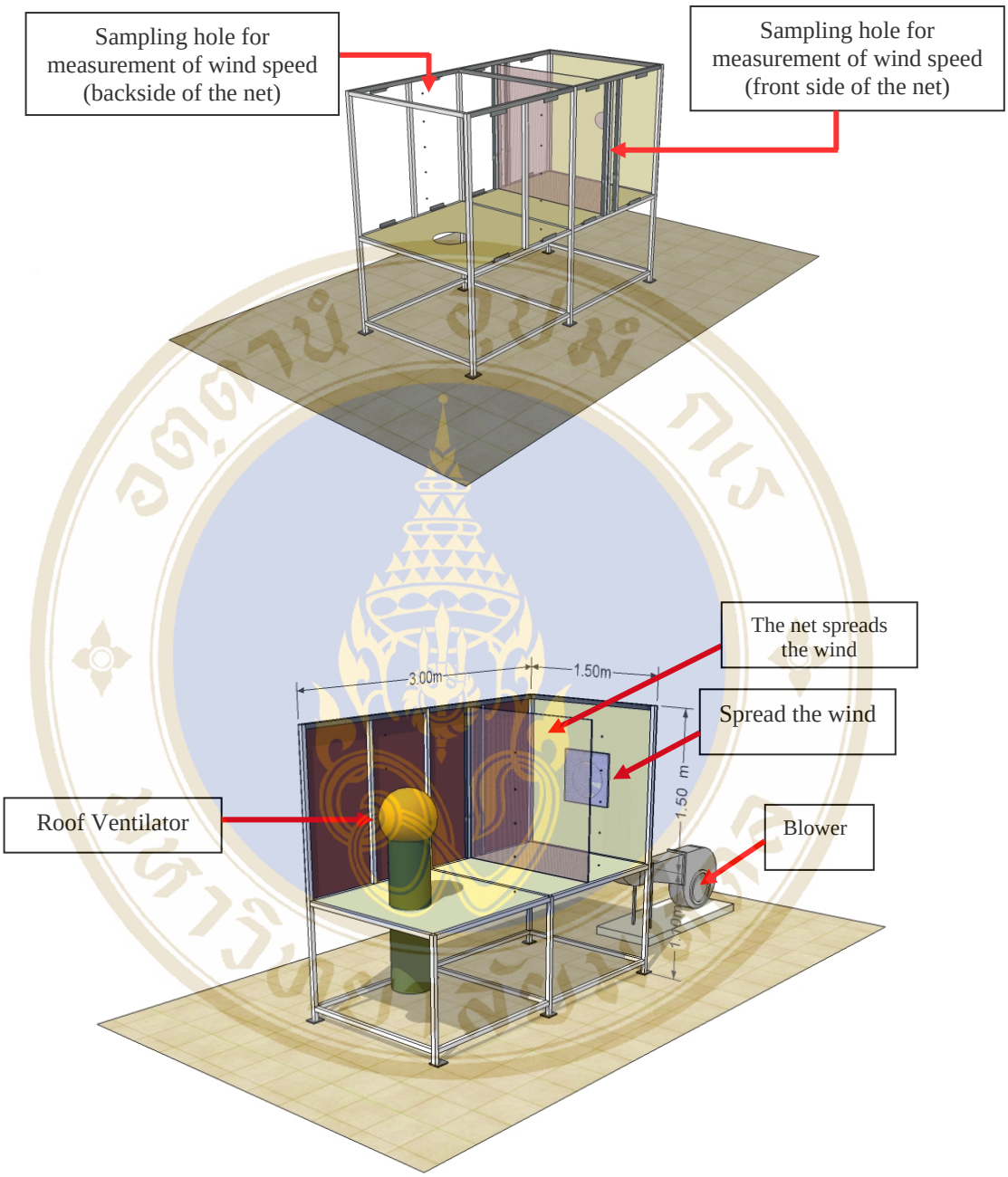

Figure 3-1 The simulation laboratory model and installation tool in this research

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Figure 3-2 Laboratory equipment and installation tool used in this research

3.3.2 The experimental procedure

The experimental design include of 10 wind speeds. Each step the experiment was divided into 4 parts.

Part I the experiment for finding average wind speeds in the simulation laboratory.

Part II the experiment for finding the minimum wind speed which the roof ventilator can effectively exhaust air.

Part III the experiment for finding the efficiency in exhausting air and the speed of roof ventilator when the axles of the roof ventilator were perpendicularly and when the vertical angles were 5, 10 and 15 degrees, respectively.

Part IV the experiment for finding distances in exhaust of roof ventilator at different wind speeds.

Thus, Experiment 1 was to study wind speeds at first step, as follow:

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Experiment 1 was to study wind speeds at first step.

Part I the experiment for finding average wind speeds in the simulation laboratory. Follow below steps:

1.1 Prepare the tools for ready to used.

1.2 Operate the wind speed. It turns on switch of the motor and operates at least 5 minutes. After that, begin measure in the next step.

1.3 Measure the speed in a driver of pulley (Pulley was attached with the motor) and pulley follower (Pulley was attached with the blower). It measure before and after in this experiment. Follow below steps**:**

1.3.1 Cut the marker tapes, the marker tapes was 1/4 inches. Then, marker tapes were attached driver of pulley and pulley follower show in Figure 3-3.

Figure 3-3 Marker tape was attached driver of pulley and pulley follower for measure the speed

1.3.2 Turn on the Mini Photo Tachometer, Model 461700

1.3.3 Turn head of the speed meter perpendicularly with the marker tapes was attached pulley follower; the space should not exceed 30 centimeters show in Figure 3-4.

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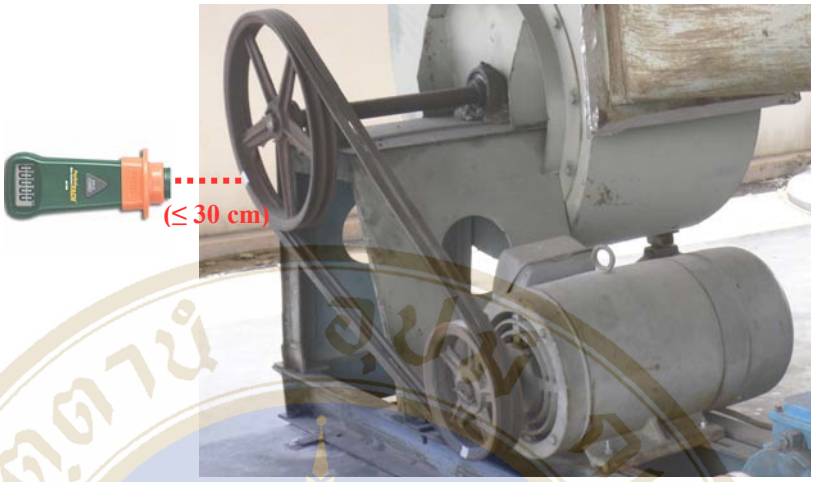

Figure 3-4 A driver of pulley and pulley follower for measurement of the speed by use Mini Photo Tachometer.

1.3.4 Reading and recording the speed value on the LCD monitor.

1.3.5 Repeated measure at least 4 times, thus will get the speed 25 values and calculate the average speed at pulley follower.

1.3.6 Measure the speed at driver of pulley in follow step 1.3.2 to 1.3.5.

1.4 Measure wind speed in duct, Follow below steps:

1.4.1 We determined the point to measures the wind speed in duct amount 8 points, the duct size of diameters was 0.38 centimeters in U.S. EPA Method 2 standardized. It determined the Chimney size of diameters was 0.30 – 0.61 meters (12 - 24 inches).

1.4.2 Connect the rubber tube between Type S Pitot tube with inclined manometer or U-tube Manometer. Type S Pitot tube in this experiment was to calibrate already. The coefficient was 0.83.

1.4.3 Adjust the liquid level of Manometer was zero.

1.4.4 Insert Pitot tube inside straight duct. Reading and recording the value different pressure (△P).

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1.4.5 Measuring the temperatures within a duct and in the air use the thermometer. Measuring and Recording the pressure use the barometer.

1.4.6 Calculate wind speed in a duct.

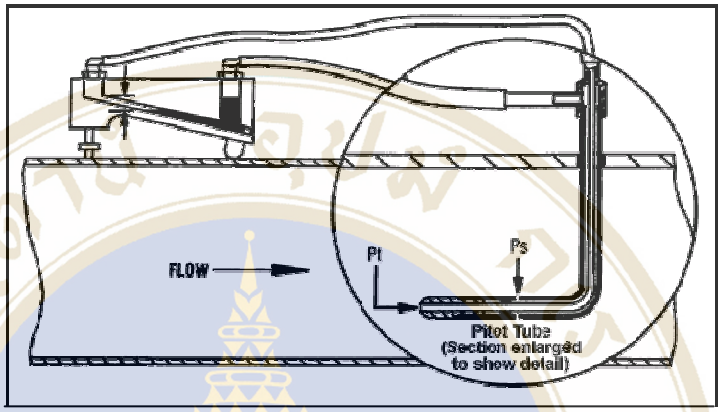

Figure 3-5 Speed measure in a duct use Pitot tube with Manometer

1.5 Measuring the wind speed within laboratory that measuring was divided to 2 parts. Part 1 and Part 2 was measure experiment. Measurement of wind speed (backside and front side of the net). In this study will measure in Part 1; measure wind speed (backside of the net). Follow below steps:

1.5.1 Set zero, open and close probe of wind speed meter. Reading the wind speed values on the monitor, it was zero.

1.5.2 Opening the sampling hole to measure wind speed. In this experiment was measured wind speed at first row (First row was below row, it was attached with the ground of laboratory). Measuring the wind speed to five rows. The measure area was dividing to 5 x 5 of cross section and samplings were 25 points. It showed in Figure 3-6. Sampling hole for measurement of wind speed (backside and front side of the net), Show in Figure 3-7.

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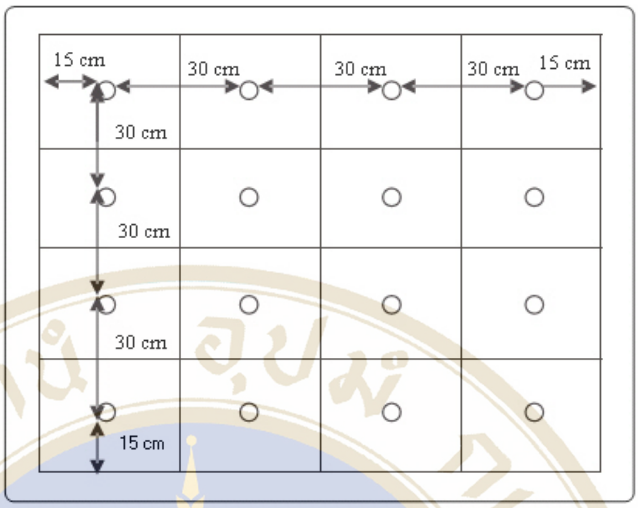

Figure 3-6 The position of wind speed was 25 points

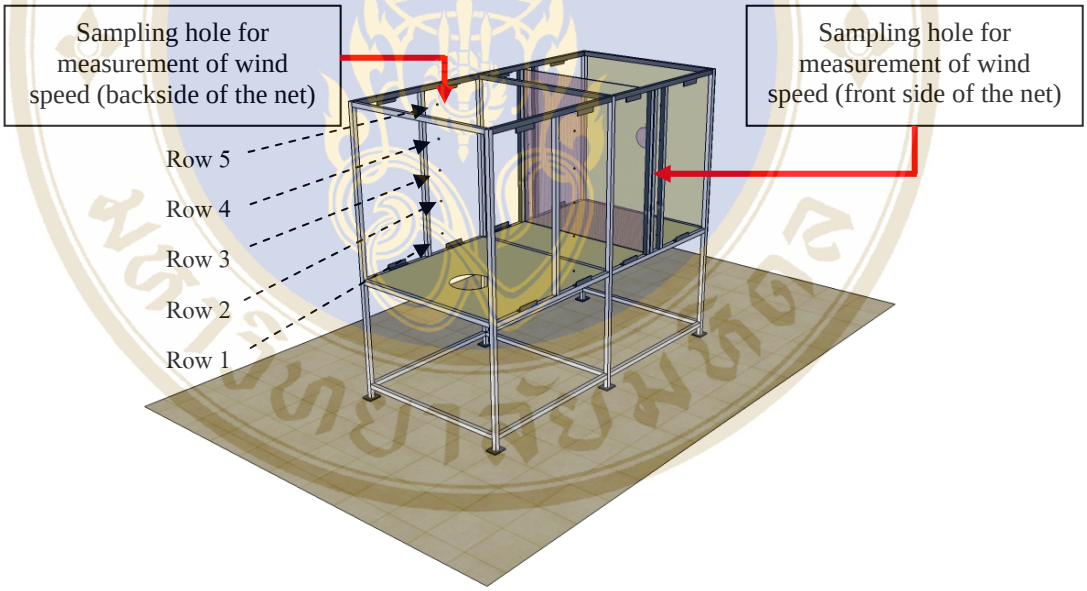

Figure 3-7 The position of wind speed measurement at front and back nets

1.5.3 Measuring the wind speed by take probe into the hole. Show in Figure 3-8. Then, recording the wind speed values in to wind speed meter.

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Figure 3-8 Measurement of wind speed (backside of the net) by use VelociCalc Plus Air Velocity Meter

1.5.4 Use a program LOGDAT transfer the data from wind speed meter (VelociCalc Plus Air Velocity Meter) downloads to the computer. After that checking maximum wind speed value to net, that exceeds 1.5 times of average wind speed. If maximum wind speed value not exceeds 1.5 times of average wind speed, then accept. Because of it was regulation of Thai Industrial Standards Institutes is 1408-1997 and can experiment in next step. However, the maximum wind speed value exceeds 1.5 times of average wind speed must edit state of laboratory according to regulations of Thai Industrial Standards Institutes is 1408-1997. It can experiment in next step.

1.5.5 Repeat measure follows 1.5.1 – 1.5.4 that was 4 times, which wind speed values will get 125. The values have to calculate and record.

1.5.6 Measurement of wind speed (front side of the net). Follow that 1.5.1-1.5.5.

1.5.7 Finish experiment, Measurement of wind speed in laboratory again. Follow that 1.5.1-1.5.6.

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<u>Part II</u> the experiment for finding minimum wind speeds which the roof ventilator can effectively exhaust air. Follow below steps:

2.1 The experiment for finding minimum wind speeds which generated the exhaust air of roof ventilator. In this step axle of roof ventilator upright, measure step as follows**:**

2.1.1 Set zero the wind speed meter

2.1.2 A position measures was measure the end duct go up 35.56 centimeters (14 inches), show in Figure 3-9. Determining and Marking the point to measures the wind speed both x and y axis.

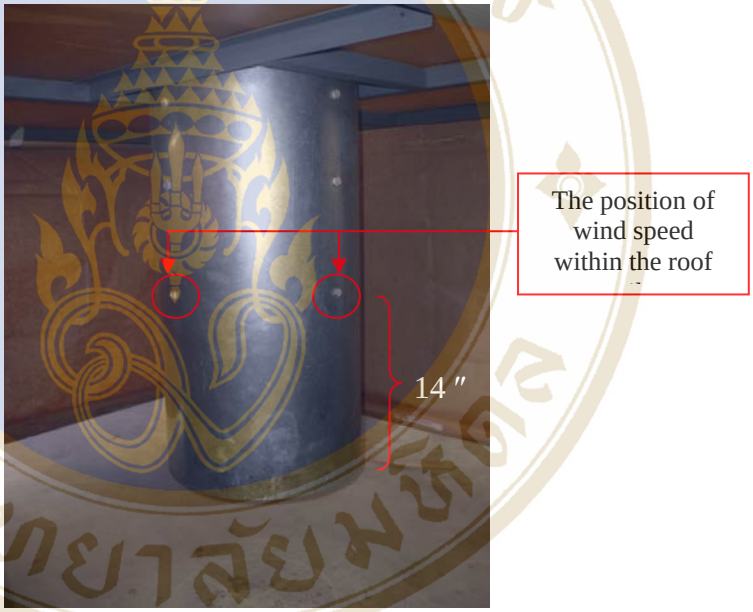

Figure 3-9 Measuring the position of wind speed within the roof ventilator

2.1.3 Opening the sampling hole to measure wind speed.

2.1.4 Measuring the wind speed in axle line x; it was 8 points. And recording the wind speed values in to wind speed meter.

2.1.5 Measuring the wind speed in axle line y; it was 8 points. And recording the wind speed values in to wind speed meter.

2.1.6 Repeat measuring the wind speed in axle line x and y follows 2.1.3 - 2.1.5 that was 7 times

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2.1.7 Use a program LOGDAT transfer the data from VelociCalc Plus Air Velocity Meter downloads to the computer. . Measuring the wind speed in the axle was calculated wind speed values.

2.1.8 Check sucking air use a Smoke tube.

<u>Part III</u> the experiment for finding the efficiency in exhausting air and the speed of roof ventilator when the axles of the roof ventilator installed perpendicularly and when the vertical angles were 5, 10 and 15 degrees, respectively. Follow below steps:

3.1 The case finding the efficiency in exhausting air and the cycle of roof ventilator when the axles of the roof ventilator installed perpendicularly; the experiments step as follows:

3.1.1 Measuring the wind speed of roof ventilator. The way measures also with 1.3 but marker tape was attached with side edge of roof ventilator show in Figure 3-10. In this part finding the efficiency in exhausting air the axles of the roof ventilator was upright in the experimental part 2.

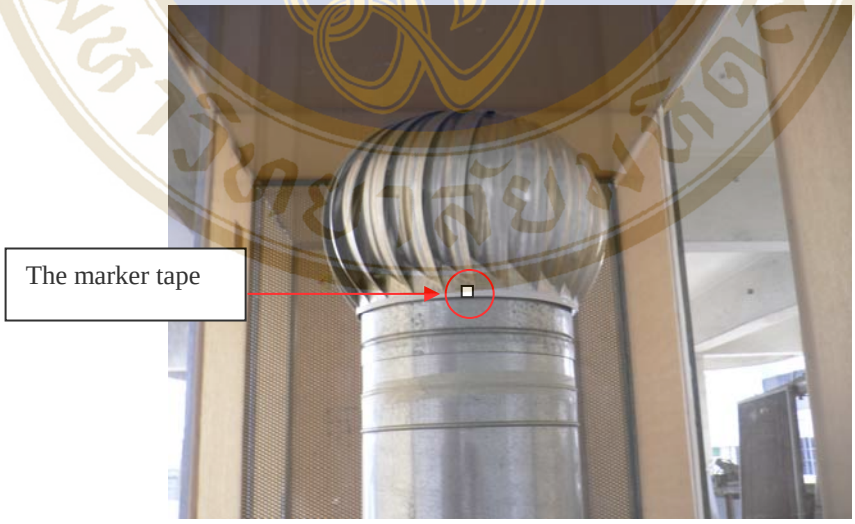

Figure 3-10 The marker tape was used on the roof ventilator for wind speed measure

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3.2 The case finding the efficiency in exhausting air and the cycle of roof ventilator when the axle of the roof ventilator were vertical that angles have 5, 10 and 15 degrees; the experiment step as follows:

3.2.1 Construction the duct slant in the vertical that angles were 5, 10 and 15 degrees. Duct sizes of diameter were 14 inches. Show in Figure 3 – 11

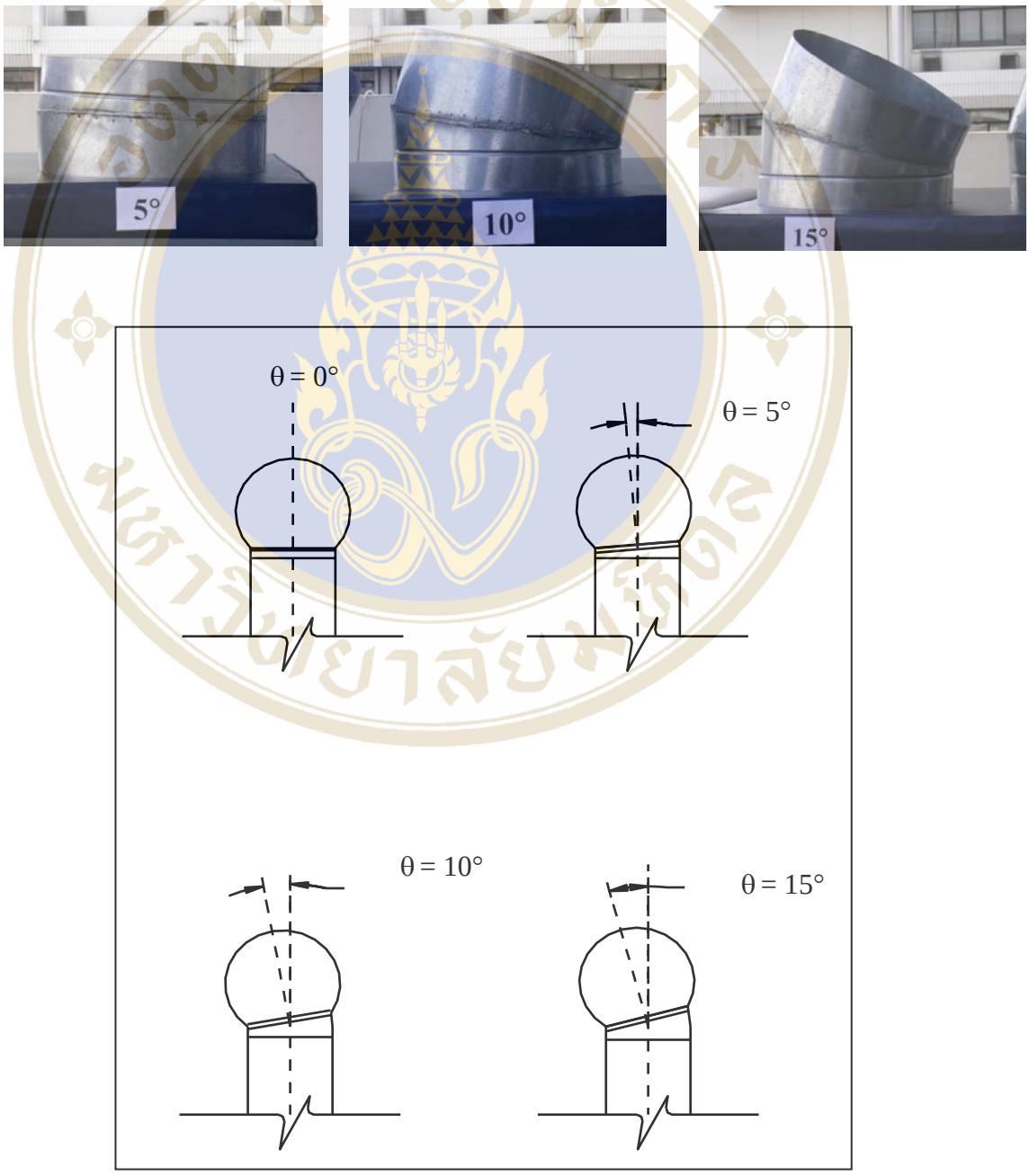

Figure 3-11 Installation of the axle's roof ventilators were 0, 5, 10 and 15 degrees

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3.2.2 Determining the wind direction of roof ventilator turn right, left, front and back, when the roof ventilator incline in the vertical were 5, 10 and 15 degrees. Show in figure 3-12.

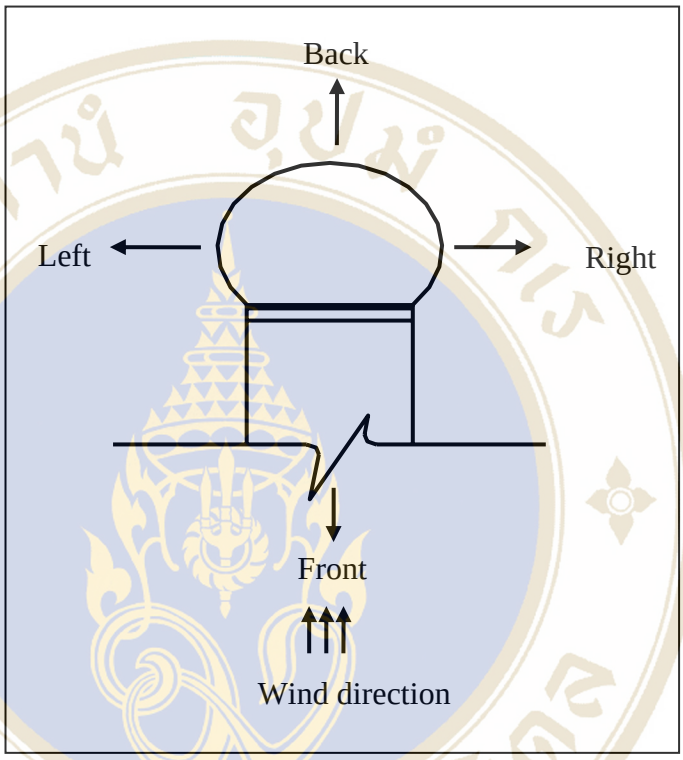

Figure 3-12 Illustrated the wind direction that blows to roof ventilator

3.2.3 Wear the duct of roof ventilator; it incline in the vertical that angle has 5 degrees.

3.2.4 Roof ventilator was turned right. Show in Figure 3-13. Measuring the wind speed and the efficiency in exhausting air of roof ventilator. Follow steps in 2.1.1-2.1.8; and measure the speed follow steps in 3.1.1.

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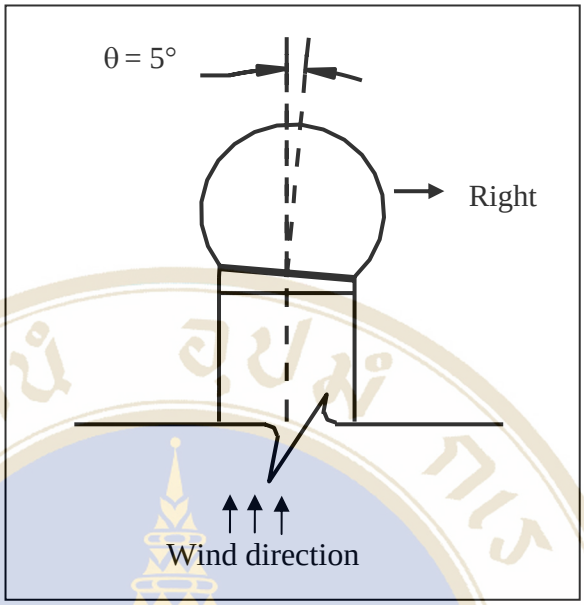

Figure 3-13 Roof ventilator is turn right when the roof ventilator incline in the vertical was 5 degrees

3.2.5 Roof ventilator is turn left. Show in Figure 3-14. Measuring the wind speed and the efficiency in exhausting air of roof ventilator. Follow steps in 2.1.1-2.1.8; and measure the speed follow steps in 3.1.1.

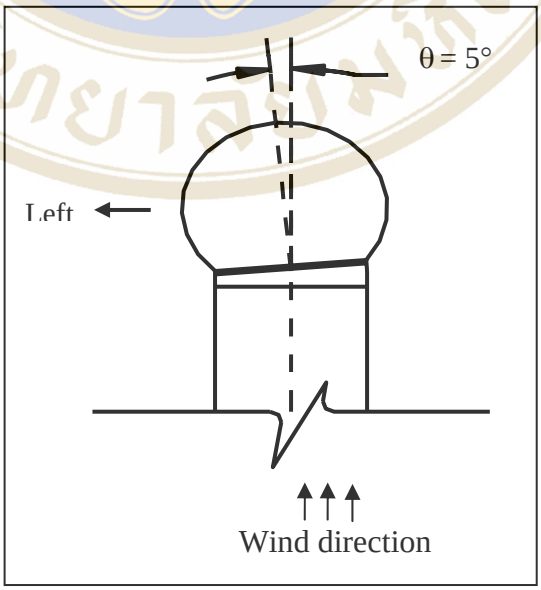

Figure 3-14 Roof ventilator is turn left when the roof ventilator incline in the vertical that angle has 5 degrees.

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3.2.6 Roof ventilator is turn to front. Show in Figure 3-14. Measuring the wind speed and the efficiency in exhausting air of roof ventilator. Follow steps in 2.1.1-2.1.8; and measure the speed follow steps in 3.1.1.

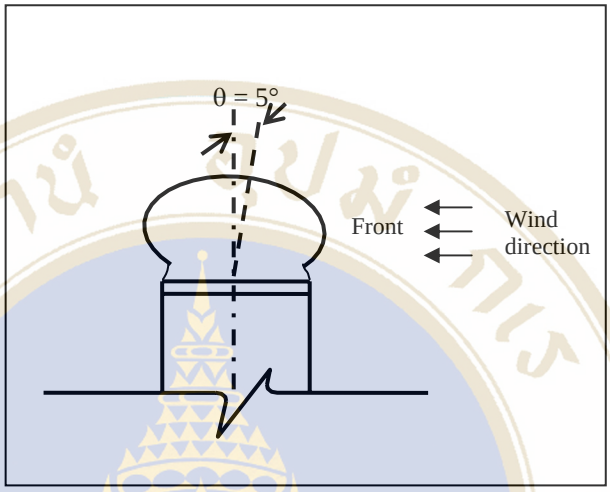

Figure 3-15 Roof ventilator turn to front when the roof ventilator slant in the vertical that angle has 5 degrees.

3.2.7 Roof ventilator is turn back. Show in Figure 3-14. Measuring the wind speed and the efficiency in exhausting air of roof ventilator. Follow steps in 2.1.1-2.1.8; and measure the speed follow steps in 3.1.1.

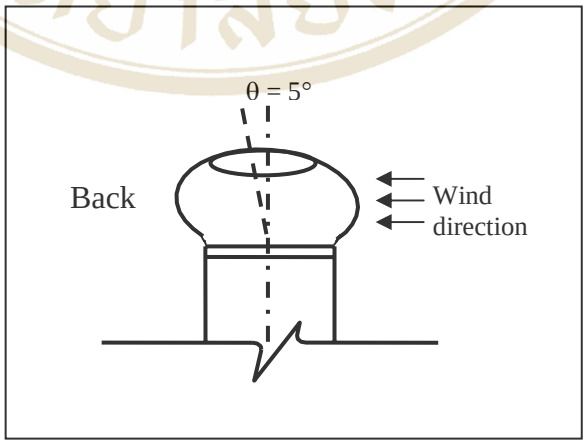

Figure 3-16 Roof ventilator is turn back when the roof ventilator incline in the vertical was 5 degrees.

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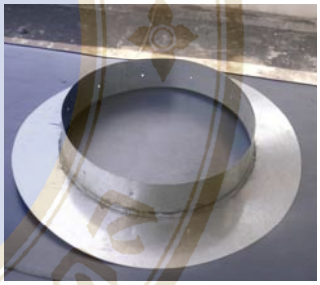
3.2.8 Changing the inclined duct that wears a duct of roof ventilator incline in the vertical were 5 degrees to 10 degrees. The experiment follow step in 3.2.1 – 3.2.7.

3.2.9 Changing the inclined duct that wears a duct of roof ventilator incline in the vertical were 10 degrees to 15 degrees. The experiment follow step in 3.2.1 – 3.2.7.

Part IV the experiment for finding the exhausting power and the exhausting distances of the roof ventilator at the different levels of wind speeds. Follow below steps:

4.1 Wearing flange at the end duct, show in Figure 3-17. These steps will the axis of roof ventilator do not be inclining.

(a) Pipe end that must wear Flange



(b) Flange

(c) Wear flange the end duct

Figure 3-17 Wear flange the end duct for measure distance of exhausting air

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4.2 Using smoke tube to test exhausting air of roof ventilator, show in Figure 3-18.

Figure 3 - 18 Using smoke tube to test exhausting air of roof ventilator

4.3 Exhausting air test use smoke tube until to occur no suck position then measures a maximum distance that the roof ventilator can farthest suck air for record distance and position with meter tap.

4.4 Measuring the wind speed by take probe into hole. Measuring wind speed of roof ventilator was efficiency of exhausting air turn front of VelociCalc Plus Air Velocity Meter. Data was received from 1.9.3; the measuring was divided to five parts as follow: 1) Middle point of duct 2) Half radius of duct 3) End of duct 4) Half radius of flange 5) End of flange. Each of parts was measured wind speed at same level that was showed in figure 3-19. It used time 10 seconds when measured times up that record the data in VelociCalc Plus Air Velocity Meter.

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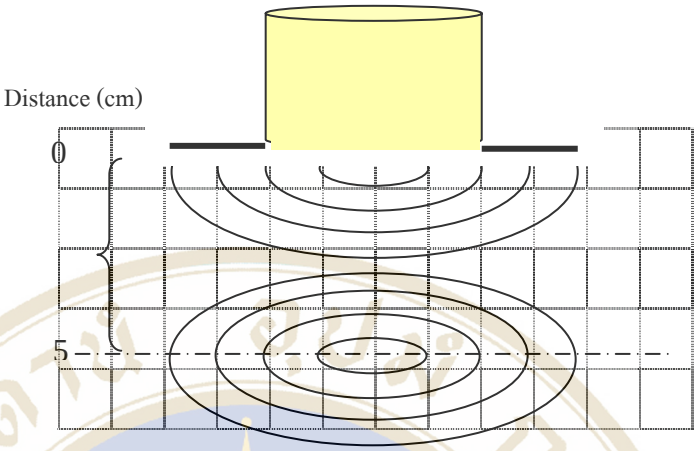

Figure 3-19 Testing the radius line used in exhausting air

4.5 Use a program LOGDAT transfer the data from wind speed meter (VelociCalc Plus Air Velocity Meter) downloads to the computer.

4.6 Bring the wind speed value and the distance of roof ventilator was efficiency in exhausting air. Drawing the velocity contour.

4.7 Measuring the temperature and pressure.

Experiment 2-10 Next experiments had experiment 2 until 10, Studying by change driver of pulley and pulley follower up part 1 to 4 in First experiments.

3.4 Statistical Analysis

The data were analyzed by using statistic as follows:

3.4.1 Descriptive statistic: the mean and standard deviation was applied.

3.4.2 Inferential statistic

3.4.2.1 The comparison results of the exhausting power inside the roof ventilator by using General Linear Model: Repeated Measures ANOVA

3.4.2.2 The comparison results of the exhausting power inside the roof ventilator when the axle of the roof ventilator slanted in the same vertical angles by using General Linear Model: Repeated Measures ANOVA

3.4.2.3 The comparison of pairs by using Multiple Comparisons: LSD.

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3.4.2.4 The results of relationships between the exhausting power inside the roof ventilator and the influencing factors by using Stepwise Regression

3.4.2.5 Significant at the 0.5 level.

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CHAPTER IV
RESULTS

Based on conducting our research, to achieve study objectives, this studied roof ventilator in the simulation laboratory. This chapter presented the study and analysis results, which were divided into 7 parts as below.

4.1 The test results of wind speed in the simulation laboratory.

4.2 The testing results of finding the minimum wind speed which the roof ventilator can effectively exhaust air.

4.3 The testing results of the exhausting efficiency of the air and the cycle of roof ventilator, when the axle of the roof ventilator installed perpendicularly and when they made the angles of 5, 10 and 15 degrees.

4.4 The comparison results of the exhausting power inside the roof ventilator between when the axle of the roof ventilator installed perpendicularly and when they made the angles of 5, 10 and 15 degrees.

4.5 The comparison results of the exhausting power inside the roof ventilator when the axle of the roof ventilator slanted in the same vertical angles.

4.6 The results of the relationships between the exhausting power inside the roof ventilator and the influencing factors (i.e. the wind speed, the angles of the axle of roof ventilator and the wind direction that blow towards the roof ventilator).

4.7 The measure results of the exhausting power and the exhausting distances of the roof ventilator at the different levels of wind velocity.

4.1 The testing results of wind speed in the simulation laboratory.

Before starting the wind speed test in the roof ventilator, the wind speed in the simulation laboratory had to be tested, in order to comply with the regulations of Thai Industrial Standards 1408-1997, the maximum wind speed passing through the nets should not exceed 1.5 times of the average wind speed. The test results of wind speed in the simulation laboratory were showed in table 4-1.

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Table 4-1 The test results of wind speed in the simulation laboratory

Number of experiment	Average wind speed (m/s)		Maximum wind speed through the back of the net	Maximum wind speed passed through the net must not exceed (m/s)	The test results of wind speed in the simulation laboratory
	In front of the net	At the back of the net			
1	0.94	0.37	0.55	0.56	passed
2	1.07	0.42	0.62	0.63	passed
3	1.29	0.49	0.74	0.74	passed
4	1.35	0.53	0.77	0.80	passed
5	1.74	0.59	0.87	0.89	passed
6	1.82	0.60	0.86	0.90	passed
7	1.92	0.68	1.01	1.02	passed
8	2.18	0.77	1.14	1.16	passed
9	2.50	0.85	1.25	1.28	passed
10	2.38	0.90	1.28	1.35	passed

From table 4-1, the maximum wind speed went through the net of 10 experiments were equal to 0.55-1.28 m/s, which did not exceed 1.5 times of the average wind speed through the net. This complied with the regulations of Thai Industrial Standards 1408-1997. Then we started conducting the next steps of our research.

4.2 The testing results of finding the minimum wind speed which the roof ventilator can effectively exhaust the air.

The test of the efficiency of roof ventilator with the diameter size of 19 inches (48.26 centimeters), made from aluminum. The testing at the levels of average wind speed from 0.37 m/s to 0.9 m/s, totally 10 levels. The results of the test were showed in table 4-2.

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Table 4-2 The exhausting efficiency of the air of roof ventilator were conducted at 10 levels of wind speed

Average wind speed in the duct (m/s)	Average speed of the roof ventilator (rpm)	Average wind speed (m/s)		The exhausting air
		The simulation laboratory	Inside the roof ventilator	
6.64	0	0.37	0.010	did not exhaust
7.02	0	0.42	0.010	did not exhaust
8.38	0	0.49	0.010	did not exhaust
9.51	7.9489	0.53	0.045	exhausted
11.24	9.3135	0.59	0.085	exhausted
11.51	14.357	0.60	0.085	exhausted
13.18	19.025	0.68	0.100	exhausted
14.26	19.935	0.77	0.110	exhausted
14.86	21.009	0.85	0.145	exhausted
17.19	23.758	0.90	0.220	exhausted

Note: Average wind speed in the duct is the wind speed measured in the duct that connected with the simulation laboratory and the measurement follows US EPA Method**.**

Average wind speed in the simulation laboratory is the average wind speed measured at the back of the net both before and after the experiment.

Average wind speed inside the roof ventilator is the average wind speed measured inside the roof ventilator. The measuring point will be at 14 inches from the end of duct which installs the flange.

The exhausting efficiency of the air was checked by use smoke tube.

Table 4-2 showed that the minimum average wind speed which the roof ventilator can effectively exhaust air at 0.53 m/s. The roof ventilator had the cycle about 8 rpm. The average wind speed inside the roof ventilator was equal to 0.045 m/s. At the average wind speed in the simulation laboratory from 0.37 m/s to 0.49 m/s, the roof ventilator did not have the exhausting efficiency of the air.

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4.3 The testing results of the exhausting efficiency of the air and the cycle of roof ventilator, when the axle of the roof ventilator installed perpendicularly and when they made the angles of 5, 10 and 15 degrees.

The testing results of the exhausting efficiency of the air and the cycle of roof ventilator, when the axle of the roof ventilator installed perpendicularly and when they made the angles of 5, 10 and 15 degrees. The results of the test were showed in table 4-3 and 4-4.

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Table 4-3 The testing result of the exhausting efficiency of the air

Average wind speed (m/s) / Experiment	The simulation laboratory	Inside the roof ventilator	5^{o} Right	10^{o} Right	15^{o} Right	5^{o} Left	10^{o} Left	15^{o} Left	5^{o} Front	10^{o} Front	15^{o} Front	5^{o} Back	10^{o} Back	15^{o} Back
1	0.37	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.42	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.49	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.53	0.045	0	0	0	0	0	0	0	0	0	0	0	0
5	0.59	0.070	0	0	0	0	0	0	0	0	0	0	0	0
6	0.60	0.085	0.060	0	0	0.060	0	0	0.050	0	0	0.045	0	0
7	0.68	0.100	0.080	0	0	0.080	0	0	0.055	0	0	0.050	0	0
8	0.77	0.110	0.085	0	0	0.085	0	0	0.060	0	0	0.055	0	0
9	0.85	0.145	0.130	0	0	0.125	0	0	0.085	0	0	0.080	0	0
10	0.90	0.220	0.210	0.065	0	0.205	0.065	0	0.170	0.055	0	0.160	0.050	0

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Note: Average wind speed in the simulation laboratory is the average wind speed measured at the back of the net both before and after the experiment.

Average wind speed inside the roof ventilator is the average wind speed measured inside the roof ventilator. The position of the measurement is at 14 inches from the end of duct.

5, 10 and 15 degrees are the angles of 5, 10 and 15 degrees when the axle of the roof ventilator made angles to each other in the vertical.

Right, left, front and back are the direction of the roof ventilator, going to the right, left, front and back, when the axle of the roof ventilator made the angles of 5, 10 and 15 degrees.

The exhausting efficiency of the air was checked by use smoke tube.

Wind velocity value 0 m/s means there is not exhaust the air.

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Table 4-4 The testing results of the cycle of roof ventilator

Average wind speed in the simulation laboratory (m/s)	The cycle of roof ventilator (rpm)												
	0°	**5^{O} Right**	**10^{O} Right**	**15^{O} Right**	**5^{O} Left**	**10^{O} Left**	**15^{O} Left**	**5^{O} Front**	**10^{O} Front**	**15^{O} Front**	**5^{O} Back**	**10^{O} Back**	**15^{O} Back**
0.37	0	0	0	0	0	0	0	0	0	0	0	0	0
0.42	0	0	0	0	0	0	0	0	0	0	0	0	0
0.49	0	0	0	0	0	0	0	0	0	0	0	0	0
0.53	7.9489	0	0	0	0	0	0	0	0	0	0	0	0
0.59	10.039	0	0	0	0	0	0	0	0	0	0	0	0
0.60	12.443	9.2282	0	0	9.2250	0	0	8.1644	0	0	7.8176	0	0
0.68	16.678	11.295	0	0	11.281	0	0	8.7652	0	0	8.1665	0	0
0.77	17.638	12.136	0	0	12.242	0	0	9.1714	0	0	8.7392	0	0
0.85	20.789	19.745	0	0	18.911	0	0	12.196	0	0	11.114	0	0
0.90	23.821	23.180	9.6843	0	22.019	9.6988	0	21.470	8.7809	0	20.847	8.0323	0

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Note: Average wind speed in the simulation laboratory is the average wind speed measured at the back of the net both before and after the experiment.

Average wind speed inside the roof ventilator is the average wind speed measured inside the roof ventilator. The position of the measurement is at 14 inches from the end of duct.

5, 10 and 15 degrees are the angles of 5, 10 and 15 degrees when the axles of the roof ventilator made angles to each other in the vertical.

Right, left, front and back are the direction of the roof ventilator, going to the right, left, front and back, when the axle of the roof ventilator made the angles of 5, 10 and 15 degrees, respectively.

The exhausting efficiency of the air was checked by use smoke tube.

Wind velocity value 0 m/s means there is not exhaust air.

4.4 The comparison results of the exhausting power inside the roof ventilator between when the axle of the roof ventilator installed perpendicularly and when they made the angles of 5, 10 and 15 degrees.

At the same levels of wind speed, when the axle of the roof ventilator installed perpendicularly and when they made the angles of 5, 10 and 15 degrees, the comparison results of the exhausting power inside the roof ventilator were showed in table 4-5.

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Table 4-5 The comparison results of the exhausting power inside the roof ventilator by using General Linear Model: Repeated Measures ANOVA

Average wind speed (m/s)	Angle	n	Mean	SD	df	F-test	p-value
0.60	0°	16	0.088	0.004	3, 204	265.565	< 0.001
	5°	64	0.055	0.002			[0° ≠ 5°, 10°, 15°]
	10°	64	0.004	0.002			
	15°	64	0.005	0.002			
0.68	0°	16	0.100	0.003	3, 204	438.395	< 0.001
	5°	64	0.066	0.002			[0° ≠ 5°, 10°, 15°]
	10°	64	0.005	0.002			
	15°	64	0.005	0.002			
0.77	0°	16	0.112	0.005	3, 204	222.947	< 0.001
	5°	64	0.071	0.003			[0° ≠ 5°, 10°, 15°]
	10°	64	0.004	0.003			
	15°	64	0.005	0.003			
0.85	0°	16	0.144	0.004	3, 204	749.287	< 0.001
	5°	64	0.104	0.002			[0° ≠ 5°, 10°, 15°]
	10°	64	0.005	0.002			
	15°	64	0.005	0.002			
0.90	0°	16	0.220	0.008	3, 204	495.146	< 0.001
	5°	64	0.185	0.004			[0° ≠ 5°, 10°, 15°]
	10°	64	0.059	0.004			
	15°	64	0.005	0.004			

Note: Compared with different pairs by using Multiple Comparisons: LSD

Tables 4-5 showed that the average wind speeds in the simulation laboratory were 0.60, 0.68, 0.77, 0.85 and 0.90 m/s respectively, the exhausting efficiency of the air when the axle of the roof ventilator installed perpendicularly and when they made the angles of 5, 10 and 15 degrees in the vertical were significantly different ($p < 0.001$).

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4.5 The comparison results of the exhausting power inside the roof ventilator when the axle of the roof slanted in the same vertical angles.

At the same level of wind speed, when the axle of the roof ventilator slanted in the same vertical angles, but different directions, the right, left, front, and back, respectively, the comparison results of the exhausting power inside the roof ventilator were showed in table 4-6.

Table 4-6 The comparison results of the exhausting power inside the roof ventilator when the axle of the roof ventilator slanted in the same vertical angles by using General Linear Model: Repeated Measures ANOVA

Average wind speed (m/s)	Angle	n	Mean	SD	df	F-test	p-value
0.60	5° Right	16	0.059	0.005	3, 60	1.584	0.203
	5° Left	16	0.059	0.005			
	5° Front	16	0.053	0.005			
	5° Back	16	0.048	0.005			
	10° Right	16	0.004	0.001	3, 60	0.392	0.759
	10° Left	16	0.004	0.001			
	10° Front	16	0.005	0.001			
	10° Back	16	0.004	0.001			
	15° Right	16	0.004	0.001	3, 60	0.149	0.930
	15° Left	16	0.005	0.001			
	15° Front	16	0.005	0.001			
	15° Back	16	0.005	0.001			
0.68	5° Right	16	0.077	0.004	3, 60	11.793	< 0.001
	5° Left	16	0.080	0.004			5° Right ≠ 5° Front 5° Right ≠ 5° Back 5° Left ≠ 5° Front 5° Left ≠ 5° Back
	5° Front	16	0.053	0.004			
	5° Back	16	0.055	0.004			
	10° Right	16	0.005	0.001	3, 60	0.035	0.991
	10° Left	16	0.005	0.001			
	10° Front	16	0.005	0.001			
	10° Back	16	0.005	0.001			
	15° Right	16	0.005	0.001	3, 60	0.055	0.983
	15° Left	16	0.005	0.001			
	15° Front	16	0.005	0.001			
	15° Back	16	0.004	0.001			

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Table 4-6 The comparison results of the exhausting power inside the roof ventilator when the axle of the roof ventilator slanted in the same vertical angles by using General Linear Model: Repeated Measures ANOVA (continued)

Average wind speed (m/s)	Angle	n	Mean	SD	df	F-test	p-value
0.77	5° Right	16	0.084	0.007	3, 60	3.803	0.015
	5° Left	16	0.083	0.007			5° Right ≠ 5° Back
	5° Front	16	0.064	0.007			5° Left ≠ 5° Back
	5° Back	16	0.054	0.007			
	10° Right	16	0.005	0.001	3, 60	0.154	0.927
	10° Left	16	0.004	0.001			
	10° Front	16	0.004	0.001			
	10° Back	16	0.004	0.001			
	15° Right	16	0.005	0.001	3, 60	0.387	0.763
	15° Left	16	0.004	0.001			
	15° Front	16	0.005	0.001			
	15° Back	16	0.005	0.001			
0.85	5° Right	16	0.127	0.004	3, 60	38.070	< 0.001
	5° Left	16	0.125	0.004			5° Right ≠ 5° Front
	5° Front	16	0.085	0.004			5° Right ≠ 5° Back
	5° Back	16	0.080	0.004			5° Left ≠ 5° Front
							5° Left ≠ 5° Back
	10° Right	16	0.005	0.001	3, 60	0.260	0.854
	10° Left	16	0.004	0.001			
	10° Front	16	0.005	0.001			
	10° Back	16	0.005	0.001			
	15° Right	16	0.005	0.001	3, 60	0.048	0.986
	15° Left	16	0.005	0.001			
	15° Front	16	0.005	0.001			
	15° Back	16	0.005	0.001			
0.90	5° Right	16	0.210	0.009	3, 60	6.602	0.001
	5° Left	16	0.202	0.009			5° Right ≠ 5° Front
	5° Front	16	0.167	0.009			5° Right ≠ 5° Back
	5° Back	16	0.162	0.009			5° Left ≠ 5° Front
							5° Left ≠ 5° Back
	10° Right	16	0.065	0.004	3, 60	2.545	0.064
	10° Left	16	0.064	0.004			
	10° Front	16	0.055	0.004			
	10° Back	16	0.051	0.004			

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Table 4-6 The comparison results of the exhausting power inside the roof ventilator when the axle of the roof ventilator slanted in the same vertical angles by using General Linear Model: Repeated Measures ANOVA (continued)

Average wind speed (m/s)	Angle	n	Mean	SD	df	F-test	p-value
0.90	15° Right	16	0.005	0.001	3, 60	0.142	0.934
	15° Left	16	0.005	0.001			
	15° Front	16	0.004	0.001			
	15° Back	16	0.005	0.001			

Note: compared with different pairs by using Multiple Comparisons: LSD

Table 4-6 showed that the average wind speed in the simulation laboratory was 0.60 m/s. The exhausting efficiency of the air when the axle of the roof ventilator made the angles of 5 degrees in the vertical, with different directions, right, left, front and back, were not significantly different at the 95% confidence interval ($p = 0.203$). At the average wind speeds in the simulation laboratory were 0.68, 0.77, 0.85 and 0.90 m/s, respectively, the exhausting efficiency of the air inside the roof ventilator were significantly different ($p < 0.05$). The different pairs were 5° right with 5° front, 5° right with 5° back, 5° left with 5° front, and 5° with 5° back. But at the average wind speed in the simulation laboratory was 0.77 m/s, the different pair were 5° right with 5° back, and 5° with 5° back.

We also found that at the average wind speed in the simulation laboratory were 0.60, 0.68, 0.77, 0.85 and 0.90 m/s, the exhausting efficiency of the air when the axle of the roof ventilator made the angles of 10 and 15 degrees in the vertical, went to the right, left, front and back, were no significantly different at the 95% confidence interval ($p > 0.05$).

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4.6 The results of the relationships between exhausting power inside the roof ventilator and the influencing factors (i.e. the wind speed, the angles of the axle of roof ventilator and the wind direction that blow towards the roof ventilator).

The results of relationships between the exhausting power inside the roof ventilator and the influencing factors were showed in table 4-7.

Table 4-7 The results of relationships between the exhausting power inside the roof ventilator and the influencing factors by using Stepwise Regression

Factor	B	SD	Beta	t	p - value
Wind speed	0.146	0.006	0.520	24.580	< 0.001
Angle	-0.023	0.001	-0.468	-18.382	< 0.001
Direction	1.386E-06	0.000	0.077	3.018	0.003
Adjusted R Square = 0.534, Constant = 0.00					

Table 4-7 showed that the exhausting power inside the roof ventilator was positively related to the average wind velocity speed in the simulation laboratory and was negatively related to the angles of the axle's roof ventilator ($p < 0.001$). But the exhausting powers inside the roof ventilator were slightly related to the wind directions that blow towards the roof ventilator. The regression of equation was

$$Y = 0.146X_1 - 0.023\ X_2 + (1.386 \times 10^{-6})\ X_3$$

When, Y = The exhausting power inside the roof ventilator.

X_1 = The average wind speed in the simulation laboratory, (m/s).

X_2 = The angles of the axle's roof ventilator, (degree).

X_3 = The wind direction that blow towards the roof ventilator.

4.7 The measure results of the exhausting power and the exhausting distances of the roof ventilator at the different levels of wind velocity.

The results of the exhausting power and the exhausting distances of the roof ventilator at the wind speed from 0.53 to 0.90 m/s, showed in table 4-8 and figure 4-1.

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Table 4-8 The results of the exhausting power and the exhausting distances of the roof ventilator at the wind speed from 0.53 to 0.90 m/s

Average wind speed in the simulation laboratory (m/s)	The exhausting power inside the roof ventilator (m/s) at distance (cm)				
	0	5	10	15	20
0.53	0.04	0.03	-	-	-
0.59	0.07	0.05	-	-	-
0.60	0.08	0.06	-	-	-
0.68	0.10	0.08	0.05	-	-
0.77	0.11	0.10	0.06	-	-
0.85	0.13	0.11	0.07	0.06	-
0.90	0.20	0.14	0.10	0.09	0.05

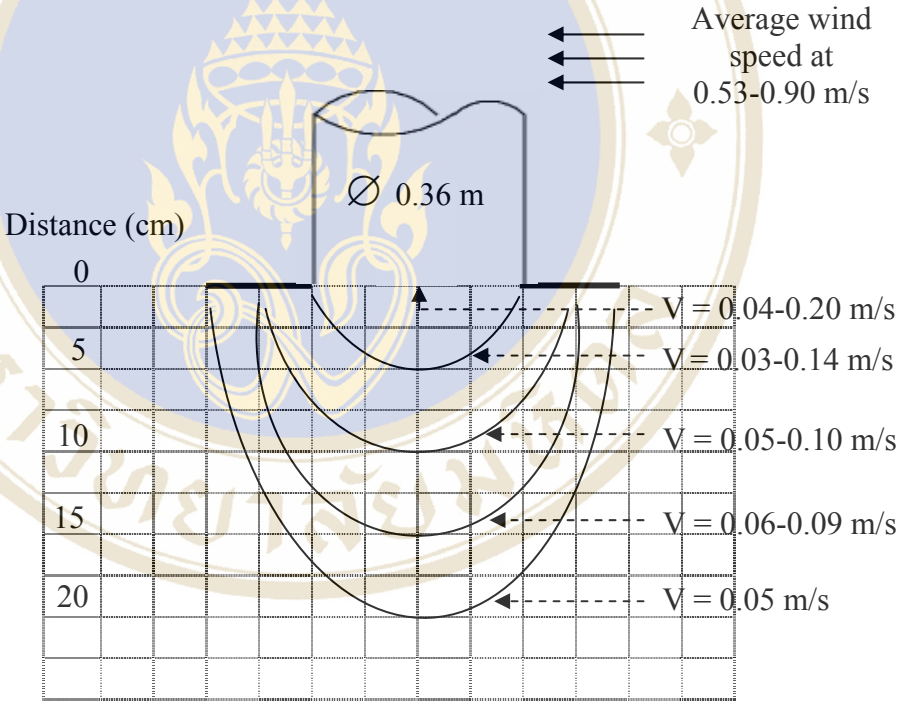

Figure 4-1 The exhausting power and the exhausting distances of the roof ventilator at the wind speed from 0.53 to 0.90 m/s.

From table 4-8 and figure 4-1 showed that when the average wind speeds in the simulation laboratory were 0.53 m/s to 0.90 m/s. At distance 0 cm, the exhausting power of the roof ventilator was from 0.04 m/s to 0.20 m/s. But at distance 5, 10, 15 and 20 cm, the exhausting power of the roof ventilator decreased.

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CHAPTER V
DISCUSSION

5.1 Discussion of Study Design

This study was a designed experimental research, which was conducted in the simulation laboratory at the Office of Public Health and Environmental Technology Services, Faculty of Public Health, Mahidol University.

5.1.1 The simulation laboratory

In Thai Industrial Standards 1408-1997 did not define the laboratory-building and materials as a wind spread plate, wind spread nets, characteristics of materials, distance between wind spread plate and nets, the height from ground to end of duct that connected to a roof ventilator and a distance from edge room to roof ventilator. If we choose different both material and distance in the laboratory then it may cause resistance of the wind flow and decrease in wind velocity in laboratory. Then, the result of wind velocity will decrease. In order to solve problem, the researcher prepared:

a) Acrylic plate for build laboratory, which its thick was 5 millimeters. The characteristic of acrylic plate was both transparent and smooth surface. This could make experiment very convenient; the smooth surface also did not have resistance on the wind flow.

b) Using the Iron plate, which its thick was 1 millimeters, to build the wind spread plate and the wind spread net due to durability, easy installation, and did not blend when the wind attack

c) The distance from ground to the end of duct that connected to the roof ventilator had value of 30 centimeters which was convenient. If it had over 30 centimeters then it was difficult to measure wind velocity within laboratory and possible danger. In the case of setting up the distance from the edge to roof ventilator distance of wind spread plate and wind spread nets were in the same consideration.

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5.1.2 Roof ventilator

When the data was inquired from producer, distributors, and using questionnaire in the group who install roof ventilator. It was found that popular roof ventilator which sizes of diameter pipe 14, 18, 22 and 25 inches, the pin made of aluminum due to no rust, easy to installation, no electric power, and not effect to environment. This research chose the roof ventilator that had body diameter 48.26 centimeters (19 inches), duct diameter 35.56 centimeters (14 inches) and 24 propellers made of aluminum. All of the equipments were supplied from company that has TIS standard and company that had the standard construction in order to reduce error. If we study the roof ventilator that had the different number of propellers, design, building, choosing material, and type of axis then the results would be different.

5.2 Discussion of Study Results

5.2.1 The results of average wind speed test in the simulation laboratory.

In the study we can not adjust stable wind velocity level throughout the period of experiment because the set of equipment for generating of wind velocity had no control for wind velocity level (inverter). Also the experiment must operate continuously for long time then it could cause the heat at conveyer and make less drive wind velocity level. The wind speed was measured once in a room before conducting the experiment and did not repeat this could make wind velocity value within the room did not incorrect. Thus, for measurement of correct wind velocity within the simulation laboratory, we should measures both wind velocity level at start and finish of experiments by repetitive time measure meet. The value of both wind velocity before and after and make the average of wide inside the simulation laboratory room, which might have more accurate values.

5.2.2 The minimum wind speed which the roof ventilator can effectively exhaust air.

The minimum average wind speed which the roof ventilator can effectively exhaust air was 0.53 m/s, the roof ventilator had the cycle about 8 rpm. The average wind speed inside the roof ventilator was equal to 0.045 m/s.

From table 4-2 showed that at wind speed that was from experiment 3 and 4 were equal to 0.49 m/s and 0.53 m/s, respectively, this values had the difference of

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0.04 m/s which may due to the wind velocity that had a little different value. Thus, its can summarize from this experiment that the wind velocity during 0.50-0.52 m/s might be the minimum wind velocity level that the roof ventilator could blow out effectively. Thus, the study in the future should be considerate.

5.2.3 The testing results of the exhausting efficiency of the air and the cycle of roof ventilator, when the axle of roof ventilator installed perpendicularly and when they made the angles of 5, 10 and 15 degrees.

While measure the cycle of roof ventilator and the wind speed inside the roof ventilator, the outside wind might cause to obstruct, this will make the value error. Thus, then partition should be installed in order to resist the wind and measure the wind when calm.

From table 4-3 and 4-4 showed the same wind speed, the exhausting efficiency of the air and the speed of roof ventilator better than when the axle's roof ventilator installed perpendicularly when they made the angles of 5, 10 and 15 degrees, respectively. This may due to the axle's roof ventilator slanted in the vertical angles increased, the friction force between the needle and the axle's roof ventilator increased, the speed of roof ventilator decreased and the exhausting efficiency of the air of roof ventilator also decreased.

5.2.4 The comparison results of the exhausting power inside the roof ventilator between when the axle of roof ventilator installed perpendicularly and when they made the angles of 5, 10 and 15 degrees.

When comparison the exhausting power inside the roof ventilator that wind speed were equal to 0.60 - 0.90 m/s and when the axle's roof ventilator slanted in the vertical angles. The comparison results showed that the same wind speed when the axle's roof ventilator installed perpendicularly (0 degree) and when they made the angles of 5°, 10° and 15 degrees were different. This was because of the friction force between a needle with the axle's roof ventilator and the wind direction that blows into the roof ventilator. When the axle's roof ventilator installed perpendicularly (0 degree), it did not have the friction force between a needle with the axle's roof ventilator and the wind direction of the roof ventilator of one direction. When the roof ventilator slanted in the vertical angles 5°, 10° and 15 degrees, it had the problems as the same as mentioned above.

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5.2.5 The comparison results of the exhausting power inside the roof ventilator when the axle of the roof ventilator slanted in the same vertical angles.

At the wind speeds were equal to 0.68, 0.85 and 0.90 m/s, the axle's roof ventilator slanted in the vertical angles of 5° right, left, front and back, the air-exhausting power in the roof ventilator between when axle's roof ventilator of 5° right with 5° front, 5° right with 5° back, 5° left with 5° front and 5° left with 5° back were different. This was because of the wind directions that blow in the roof ventilator between 5° right, 5° left with 5° front and 5° back were different. The comparison result the air-exhausting powers inside the roof ventilator between the angles of 5° right with 5° left and 5° front with 5° back were not different. This may due to the wind direction that blows in the roof ventilator was in the same direction.

At the average wind speed of 0.77 m/s and the air-exhausting power inside the roof ventilator when they made the angles of 5° right with 5° back, and 5° left with 5° back were different.

At the wind speed of 0.60 m/s and the axle's roof ventilator slanted in the vertical angles of 5° right, left, front and back, the air- exhausting power in the roof ventilator were not different. This may due to the air- exhausting power in the roof ventilator were a little different.

At the wind speed of 0.60, 0.68, 0.77, 0.85 and 0.90 m/s and the axle's roof ventilator slanted in the vertical angles of 10° and 15° right, left, front and back, the air- exhausting power in the roof ventilator were not different. This may due to the roof ventilator had not exhausted the air.

5.2.6 The results of the relationships between the exhausting power inside the roof ventilator and the influencing factors (i.e. the wind speed, the angles of the axle of roof ventilator and the wind direction that blow towards the roof ventilator).

The air-exhausting power inside the roof ventilator was related with the wind speed in the positive direction and had small relation with the wind direction that blown into the roof ventilator but they related with the angles of the axle's roof ventilator in the negative direction. Thus, in this study, the equation for prediction of the air-exhausting power inside the roof ventilator should be as follows:

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$$Y = 0.146X_1 - 0.023\ X_2 + (1.386 \times 10^{-6})\ X_3 \qquad (5.1)$$

When, Y = The air-exhausting power within the roof ventilator.

X_1 = The average wind speed in the simulation laboratory, (m/s).

X_2 = The angles of the axle's roof ventilator, (degree).

X_3 = The wind direction that blows into the roof ventilator.

This equation can predict in 53.4 percent the air- exhausting power inside the roof ventilator. It showed that the air- exhausting power inside the roof ventilator had small relation with the wind direction that blown into the roof ventilator. Thus the important factors which had relation to the air- exhausting power inside the roof ventilator was the wind speed and the angles of the axle's roof ventilator. The new equation for prediction of the air- exhausting power inside the roof ventilator should be as follows:

$$Y = 0.146X_1 - 0.023\ X_2 \qquad (5.2)$$

When, Y = The air- exhausting power inside the roof ventilator.

X_1 = The average wind speed in the simulation laboratory, (m/s).

X_2 = The angles of the axle's roof ventilator, (degree).

Should use 5.2 equation for calculated the air- exhausting power inside the roof ventilator when the axle's roof ventilator slanted in the vertical angles did not exceed 15 degrees and roof ventilator should has the same type in this study.

5.2.7 The measure results of the exhausting power and the exhausting distances of the roof ventilator at the different levels of wind velocity.

Because the outside wind of the simulation laboratory could interfere between the partition was used for resistant wind and measured the velocity when calm. The results of study showed that the exhausting efficiency of the air of roof ventilator increased when the wind direction blown into the roof ventilator increased.

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CHAPTER VI
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This experiment of studies could be concluded as the following:

6.1.1 All of the experiments, the maximum wind speed passing through the nets did not exceed 1.5 times of the average wind speed passing through the nets, which comply with the TIS 1408-1997 regulations.

6.1.2 The minimum wind speed which the roof ventilator can effectively exhaust the air had an average value of 0.53 m/s (1.06 knots). The roof ventilator had the cycle about 8 rpm and the average wind speed inside the roof ventilator was equal to 0.045 m/s. This could be summarized that when wind speed level was below 0.5 m/s (1 knot), the roof ventilator could not generate the exhausting power.

6.1.3 The comparison between the exhausting power inside the roof ventilator when the axle of roof ventilator was perpendicularly and the angles of 5, 10 and 15 degrees at the same wind speed. It was found that the exhausting power inside the roof ventilator was significant difference with 95% confidence interval ($p < 0.001$).

6.1.4 The comparison between the exhausting powers inside the roof ventilator when the axle of roof ventilator was the angles of 5, 10 and 15 degrees and the direction of roof ventilator slanted. This could be summarized that when the axle of the roof ventilator slanted in left and right direction and in front and back direction, the exhausting power inside the roof ventilator was not different. The differences were occurred when the axle slanted in right and front, right and back, left and front, and left and back direction only.

6.1.5 The relationships between the exhausting power inside the roof ventilator and the wind speed and the angles of the axle's roof ventilator. It was found that the wind speed had positive variant ($p < 0.001$) on the exhausting power of roof ventilator. The angles of the axle's roof ventilator had negative variant on the exhausting power of axle's roof ventilator.

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The formula for calculating the exhausting power inside the axle's roof ventilator was calculated as the following equation:

$$Y = 0.146X_1 - 0.023\ X_2 \qquad (6.1)$$

Where: Y = The air- exhausting power inside the roof ventilator

X_1 = The average wind speed in the laboratory (m/s)

X_2 = The angle of the axle's roof ventilator (degree)

6.1.6 When the wind blows towards the roof ventilator increased, the roof ventilator will increase the exhausting power. Then, the exhausting distance will also increase.

6.1.7 The application from this experimental study could be summarized that:

When setup the axle's roof ventilator, it should be set upright because it will yield the best exhausting power. Wind speed should be considered before installing the roof ventilator.

The exhausting power could be calculated from the formulae in section 6.1.5

That air change rate, and number of roof ventilator could be calculated from the wind speed, the exhausting power, the angle of the axles, the air flow rate, and the volume of the building.

For example, when you want to set up the roof ventilator with the diameter of 0.36 m (14 inches) on the roof of a 500 m^3 building, and also require 5 air changes per hour, how many roof ventilators are needed? (Assume that the roof ventilator had size and type the same as the one use in the study, the axle is set upright, and wind speed is 10 knots).

Method: ❶ Wind speed 1 knot = 0.5 m/s

Wind speed 10 knots = 5 m/s

❷ Calculate the exhausting power from the formulae.

$$Y = 0.146X_1 - 0.023\ X_2 \qquad (1)$$

Where: Y = The air- exhausting power the roof ventilator

X_1 = The average wind speed in the laboratory (m/s)

X_2 = The angle of the axle's roof ventilator (degree)

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Substitute X_1= 5 m/s, X_2 = 0 degrees in (1), you will get

$$Y = 0.146\ (5) - 0.023\ (0) = 0.73 \text{ m/s}$$

Hence, the roof ventilator's exhausting power was 0.73 m/s

❸ Calculate air change rate for a 0.36 cm (14 inches) roof ventilator with the following formulae.

$$Q = AV \times 3600 \qquad (2)$$

Where: Q = Air change rate (m^3/hr)

A = Area (m^2)

V = Wind speed (m/s)

Substitute A = 0.102 m^2, V = 0.73 m/s in formula (2) you will get

$$Q = 0.102 \times 0.73 \times 3600 = 268.06 \text{ } m^3/hr$$

Hence, the air change rate is 268.06 m^3/hr

❹ Building that has 500 m^3 volumes.

Number of roof ventilator = 500 ÷ 268.06 = 1.87 or approximately 2 units

Hence, when setup 2 roof ventilators the air change rate is equal to air change per hour

Therefore, air change rate of 5 air change per hour will require 10 units of ventilation mills.

6.2 Recommendations for further study

6.2.1 In the next study should change wind speed level by using inverter because it is able to control wind speed.

6.2.2 The study should be intervene in the field which has real situations.

6.2.3 Further study should concentrate on the exhausting power efficiency of the roof ventilator during 0.50 - 0.52 m/s wind speed to compare the results with this study.

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6.2.4 The study should aim to study the maximum velocity level of the roof ventilator which has ability to maintain stable exhausting power. When maximum velocity is reached, the exhausting power will not increase any further even if the wind speed increases.

6.2.5 The study should focus on the roof ventilator different sizes and characteristics which differ from this study.

6.2.6 The study should include design new propeller of the roof ventilator for enhance the exhausting air efficiency from the roof ventilator.

6.2.7 The study should include other factors that affect the exhausting air efficiency of the roof ventilator such as the size of a propeller and the characteristics of a propeller (such as be like straight, curve) etc.

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REFERENCES

1. กรมอุตุนิยมวิทยา. แผนภูมิข้อมูลอากาศ; [cited 2007 July 5]. Available from: http://www.tmd.go.th/climate/climate.php?FileID=7.

2. สำนักส่งเสริมการอนุรักษ์พลังงาน. กรมพัฒนาพลังงานทดแทนและอนุรักษ์พลังงาน. กระทรวงพลังงาน. เครื่องปรับอากาศ; [cited 2007 July 5]. Available from: http://www.aqnis.pcd.go.th.

3. กระทรวงอุตสาหกรรม สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม มาตรฐานผลิตภัณฑ์อุตสาหกรรมมอก. 1408-2540 กังหันระบายอากาศบนหลังคา (Roof Ventilators). กรุงเทพมหานคร, 2540.

4. Stein, B., and Reynolds, J.S., Mechanical and Electrical equipment for buildings. 8th ed. New York: John Willy & Sons, Inc., 1992.

5. กรมอุตุนิยมวิทยา. ความรู้อุตุนิยมวิทยา: ฤดูกาล; [cited 2007 July 7]. Available from: http://www.tmd.go.th/ climate/climate.php?FileID=23.

6. กลุ่มภูมิอากาศ. ความเร็วลมของประเทศไทยแบ่งตามภูมิภาค ตั้งแต่ปี พ.ศ. 2545 ถึง พ.ศ. 2550. สำนักพัฒนาอุตุนิยมวิทยา กรมอุตุนิยมวิทยา, 2550.

7. กรมพัฒนาและส่งเสริมพลังงาน. แผนที่ศักยภาพพลังงานลมของประเทศไทย. [cited 2007 July 7]. Available from: http://www2.dede.go.th/dede/renew/Twm/main.htm

8. กลุ่มภูมิอากาศ. อุณหภูมิเฉลี่ยสูงสุดและต่ำสุดของประเทศไทยแบ่งตามภูมิภาค ตั้งแต่ปี พ.ศ. 2545 ถึง พ.ศ. 2550. สำนักพัฒนาอุตุนิยมวิทยา กรมอุตุนิยมวิทยา, 2550.

9. วิทยาศาสตร์การศึกษา. บทเรียนเรื่องบรรยากาศ. [cited 2007 July 8]. Available from: http://www.geocities.com/scied2002/atm/015.html

Copyright by Mahidol University

10. Lechner, N. Heating Cooling Lighting Design Method for Architects. New York: John Willy & Sons, Inc., 1991.

11. เจริญพร เลิศสถิตธนกร. ศึกษาความเป็นไปได้ของการใช้ผนัง Trombe Wall แบบดัดแปลงเพื่อการระบายอากาศตามธรรมชาติภายในบ้านพักอาศัย [วิทยานิพนธ์ปริญญาวิศวกรรมศาสตร์มหาบัณฑิต สาขาเทคโนโลยีการจัดการพลังงาน]. กรุงเทพมหานคร: บัณฑิตวิทยาลัย มหาวิทยาลัยพระจอมเกล้าธนบุรี, 2540.

12. คณิต หุตานุวัตร. ปัจจัยที่มีผลต่ออัตราการระบายอากาศของหลังคาปล่องรังสีอาทิตย์ [วิทยานิพนธ์ปริญญาสถาปัตยกรรมศาสตร์มหาบัณฑิต สาขาวิชาสถาปัตยกรรมภายใน]. กรุงเทพมหานคร: บัณฑิตวิทยาลัย สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง, 2545.

13. American Industrial Hygiene Association, Chapter 4, “Type of Ventilation Systems”, Heating and Cooling for Man in Industry. 2nd ed. AIHA. U.S.A., 1975.

14. Abrams, D.W., Low-Energy Cooling a Guide to the Practical Application of Passive Cooling and Cooling Energy Conservation Measures. New York : Nostrand Reinhold, 1986.

15. John T. Talty, P.E., Section 2 Industrial ventilation, Chapter 16, “Thermal ventilation effect”, Chapter 17, “Testing Procedures in the plant”, Industrial Hygiene Engineering. 2nd ed. U.S.A.: Noyes Data Corporation, 1988: 298-299,307.

16. กาญจนา ริเริ่มสุนทร. การศึกษาการถ่ายเทมวลอากาศโดยธรรมชาติผ่านท่อที่มีพลังงานความร้อนตกบนผิวนอก [วิทยานิพนธ์ปริญญามหาบัณฑิต สาขาวิศวกรรมเครื่องกล]. กรุงเทพมหานคร: บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย, 2538.

Copyright by Mahidol University

17. อวิรุทธ์ ศรีสุธาพรรณ. การปรับปรุงหลังคาเพื่อลดปริมาณการถ่ายเทความร้อน [วิทยานิพนธ์ปริญญาสถาปัตยกรรมศาสตร์มหาบัณฑิต สาขาวิชาเทคโนโลยีอาคาร]. กรุงเทพมหานคร: บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย, 2541.

18. กำแหง จิตต์โสภักตร์. การพัฒนาโปรแกรมคอมพิวเตอร์เพื่อการวิเคราะห์การไหลของอากาศภายในอาคาร [วิทยานิพนธ์ปริญญาวิศวกรรมศาสตรมหาบัณฑิต สาขาวิชาวิศวกรรมเครื่องกล]. กรุงเทพมหานคร: บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย, 2542.

19. American Society of Heating Refrigeration and Air-Conditioning Engineers. ASHRAE Handbook of Fundamentals 1989. Atlanta: American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc., 1989.

20. Bradshaw, V. Building control systems. 2nd ed . New York: John Willy & Sons, Inc., 1993.

21. William T. Meyer. Energy Economics and Building Design. New York: McGraw-Hill Book Company, 1979.

22. สมโภชน์ อิ่มเอิบ. เทคโนโลยีความร้อน. กรุงเทพฯ : ฟิสิกส์เซ็นเตอร์; 2531: 218.

23. สำนักงานพัฒนาวิทยาศาสตร์และเทคโนโลยีแห่งชาติ. ระบบความเย็นแบบธรรมชาติ (Passive Cooling). กรุงเทพฯ; 2544: 11-13.

24. จเร สุวรรณชาต. การปรับปรุงประสิทธิภาพหลังคาเพื่อลดค่าการส่งผ่านความร้อน กรณีศึกษาคือ ศูนย์รวมสินค้า คาร์ฟูร์ สาขารามอินทรา [วิทยานิพนธ์ปริญญาสถาปัตยกรรมศาสตร์มหาบัณฑิต สาขาวิชาสถาปัตยกรรมเขตร้อน]. กรุงเทพมหานคร: สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง, 2544.

25. artith.com. [homepage on the Internet]. Thailand: Artith Ventilators Ltd.; [cited 2007 August 8]. Products, Ventilator. Available from: http://www.artith.com/product_ventilation_details.php?cate_id=4&sec_id=16.

Copyright by Mahidol University

26. bp-product.co.th. [homepage on the Internet]. Thailand: B.P. Products & Supply Co., Ltd.; [cited 2007 August 8]. Specification, Ventilator. Available from: http://www.bp-products.co.th/ th_spec1.html.

27. Thomas Bedford, Chapter XI, “Natural ventilator”, Basic principles of ventilation and heating. 2nd ed. London : Lewis, c1964: 204.

27. โอรส ศรีเรือง. การวิเคราะห์เปรียบเทียบผลการทดลองสมรรถนะทางความร้อนระหว่างการใช้หลังคารังสีอาทิตย์และกังหันระบายอากาศ [วิทยานิพนธ์ปริญญาวิศวกรรมศาสตรมหาบัณฑิต สาขาวิชาเทคโนโลยีอุณหภาพ]. กรุงเทพมหานคร: มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี, 2545.

28. วิทยา อยู่สุข. เอกสารประกอบการบรรยายวิชา หลักการระบายอากาศ. ภาควิชาอาชีวอนามัยและความปลอดภัย คณะสาธารณสุขศาสตร์ มหาวิทยาลัยมหิดล.

29. วันทนี พันธุ์ประสิทธิ์. การระบายอากาศในโรงงานอุตสากรรมสำหรับนักสุขศาสตร์อุตสาหกรรม. กรุงเทพฯ: โรงพิมพ์ธรรมสาร; 2549: 275-296.

30. Epa.gov. [homepage on the Internet]. United States: Environmental Protection Agency; [updated 2007 April 26; cited 2007 July 7]. Method 2C Determination of Stack Gas Velocity and Volumetric Flow Rate (Standard Pitot Tube). Available from: http://www.epa.gov/ttn/ emc/promgate.html

31. วิชัย พฤกษ์ธาราธิกูล. เอกสารประกอบการบรรยายวิชา การเก็บและวิเคราะห์ตัวอย่าง. ภาควิชาอาชีวอนามัยและความปลอดภัย คณะสาธารณสุขศาสตร์ มหาวิทยาลัยมหิดล.

32. Flowkinetics.com. [homepage on the Internet]. U.S.A.; [cited 2007 July 3]. Using a Pitot Static tube. Available from: http://www.flowkinetics.com/ measurement.htm

Copyright by Mahidol University

33. ขรรชัย เกรียงไกรอุดม. ประมวลสาระวิชาการจัดการและควบคุมมลพิษทางอากาศจากอุตสาหกรรม สาขาวิชาวิทยาศาสตร์สุขภาพ มหาวิทยาลัยสุโขทัยธรรมาธิราช: หน่วยที่ 7 การติดตามตรวจสอบมลพิษทางอากาศจากแหล่งกำเนิด. พิมพ์ครั้งที่ 1. กรุงเทพฯ: มหาวิทยาลัยสุโขทัยธรรมาธิราช; 2544: 127, 113.

34. Epa.gov. [homepage on the Internet]. United States: Environmental Protection Agency; [updated 2007 April 26; cited 2007 July 7]. Method 1- Sample and velocity traverse for stationary sources (Traverse Points). Available from: http://www.epa.gov/ttn/emc/promgate/m-01.pdf

35. ยงยุทธ์ พฤกษชาติ. การศึกษาประสิทธิภาพ ไทพ์ เอส พิตอททูบ ที่สร้างขึ้นด้วยวัสดุที่จัดหาได้ภายในประเทศ [วิทยานิพนธ์วิทยาศาสตรมหาบัณฑิต สาขาสุขศาสตร์อุตสาหกรรมและความปลอดภัย]. กรุงเทพมหานคร: บัณฑิตวิทยาลัย มหาวิทยาลัยมหิดล, 2535.

36. American Society for Testing and Material (ASME). Standard test method for average velocity in a duct (Pitot tube method). D 3154-74. 1990.

37. สำนักจัดการคุณภาพอากาศและเสียง กรมควบคุมมลพิษ.คู่มือการตรวจวัดมลพิษทางอากาศจากปล่องปล่อยทิ้งอากาศเสีย ฉบับที่ 1. กรุงเทพฯ; 2549: 40.

38. Dwyer-inst.com. [homepage on the Internet]. U.S.A: Dwyer Instruments, Inc.; [cited 2007 July 7]. Air Velocity Measurement. Available from: http://www.dwyer-inst.com/htdocs/airvelocity/AirVelocity Introduction.cfm.

39. ไพบูลย์ สุทธิพันธ์. การศึกษาผลของชั้นความร้อนในโถงที่มีความสูงโดยให้หุ่นจำลอง. [วิทยานิพนธ์ปริญญาสถาปัตยกรรมศาสตร์มหาบัณฑิต ภาควิชาสถาปัตยกรรม]. กรุงเทพมหานคร: บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย, 2537.

Copyright by Mahidol University

40. สุภาวดี บุญถนอม. แนวทางการเพิ่มการนำความร้อนออกที่ชั้นอากาศร้อนสูงสุด [วิทยานิพนธ์ปริญญาสถาปัตยกรรมศาสตร์มหาบัณฑิต สาขาวิชาเทคโนโลยีอาคาร]. กรุงเทพมหานคร: บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย, 2541.

41. อภิธัช พรหมศิริแสง. การพัฒนารูปแบบและระบบการไหลเวียนอากาศของหลังคา เพื่อลดอุณหภูมิภายในอาคาร [วิทยานิพนธ์ปริญญาสถาปัตยกรรมศาสตร์มหาบัณฑิต สาขาวิชาสถาปัตยกรรม]. กรุงเทพมหานคร: บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย, 2544.

42. พรหมสิทธิ์ สร้อยระย้า. การศึกษาเพื่อหาแนวทางในการสร้างต้นแบบหลังคาเพื่อลดการถ่ายเทความร้อนเข้าสู่อาคารในเขตร้อนชื้น [วิทยานิพนธ์ปริญญาสถาปัตยกรรมศาสตรมหาบัณฑิต ภาควิชาสถาปัตยกรรมศาสตร์ สาขาวิชาสถาปัตยกรรม]. กรุงเทพมหานคร:บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย, 2545.

43. รชฎ สุมานนท์. ลักษณะเฉพาะของมุมเอียงหลังคา ที่มีต่อความรู้สึกร้อนหนาวภายในเรือนไทย [วิทยานิพนธ์ปริญญามหาบัณฑิต ภาควิชาสถาปัตยกรรมศาสตร์ สาขาวิชาสถาปัตยกรรม]. กรุงเทพมหานคร: บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย, 2545.

44. โอรส ศรีเรือง. การวิเคราะห์เปรียบเทียบผลการทดลองสมรรถนะทางความร้อนระหว่างการใช้หลังคารังสีอาทิตย์และกังหันระบายอากาศ [วิทยานิพนธ์ปริญญาวิศวกรรมศาสตรมหาบัณฑิต สาขาวิชาเทคโนโลยีอุณหภาพ]. กรุงเทพมหานคร: มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี, 2545.

45. Awbi, H.B., Design Consideration for Naturally Ventilated Building. Renewable Energy, 1994, 5 (2): 1081-1090.

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46. Boonsri, B., Study of Effect of Opening on Indoor Temperature and Air Chang of Room Naturally Ventilated by Solar Chimney, Master of Engineering Thesis, Energy Management Technology Program, King Mongkut' s University of Technology Thonburi, 1998.

47. Lai, CM. Experiments on the ventilation efficiency of turbine ventilators used for building and factory ventilation. Energy and Buildings, 2003, 35: 927–932.

48. Lai CM, Kuo IS. Assessment of the potent of roof turbine ventilators for bathroom ventilation. Technical note 26.2, Building Services Engineers, Taiwan, 2005. 173-179.

49. Lai, CM. Prototype development of the rooftop turbine ventilator powered by hybrid wind and photovoltaic energy. Energy and Buildings, 2006, 38:174-180.

50. Mathur J., Mathur S., Anupma. Summer-performance of inclined roof solar chimney for natural ventilation. Energy and Buildings, 2006, 38: 1156-1163.

51. Khan N, Yuehong S, Colin B, et al. Performance testing and comparison of turbine ventilators. Renewable Energy, 2008, doi:10.1016/j.renene.2008.01.016

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APPENDIX

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APPENDIX A
ROOF VENTILATOR USE IN THIS STUDY

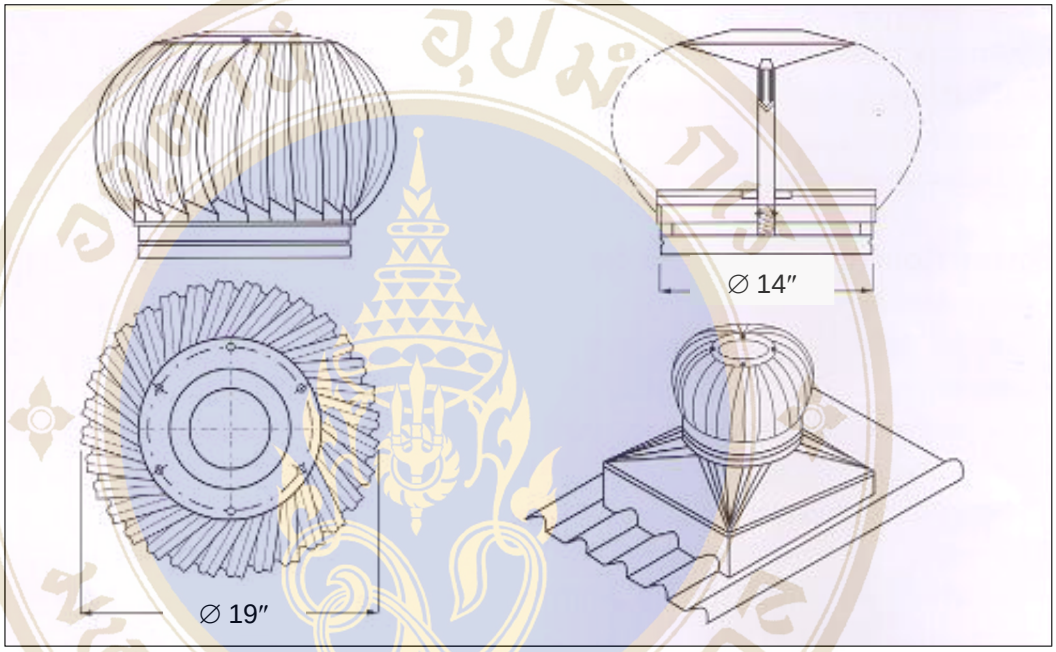

Figure A-1 Roof ventilator

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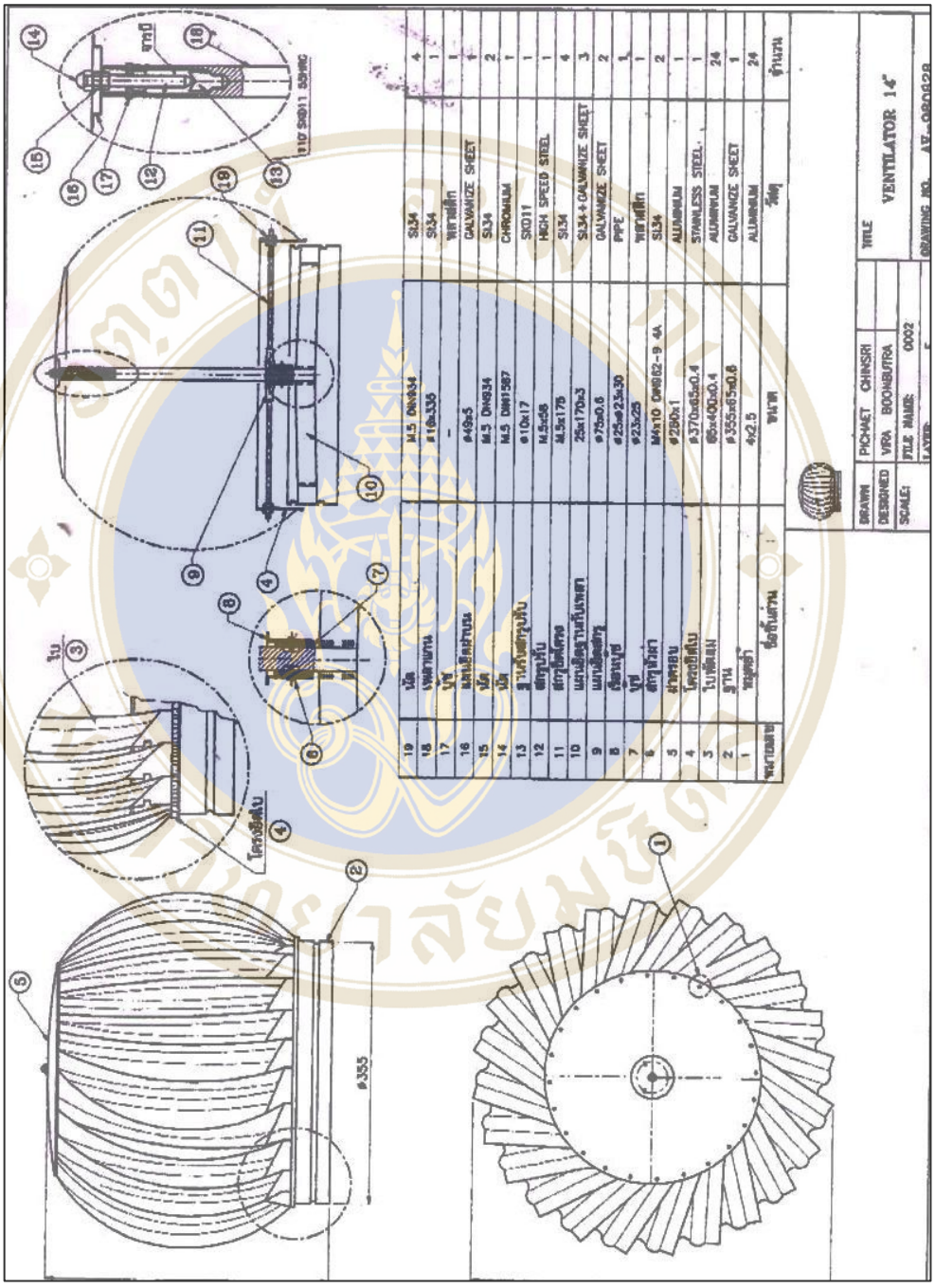

Figure A-2 The characteristics of roof ventilator

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APPENDIX B
METERIAL AND EQUIPMENT IN THIS STUDY

Figure B-1 PocketTach™ Mini Photo Tachometer

Figure B-2 VelociCalc Plus Air Velocity Meter

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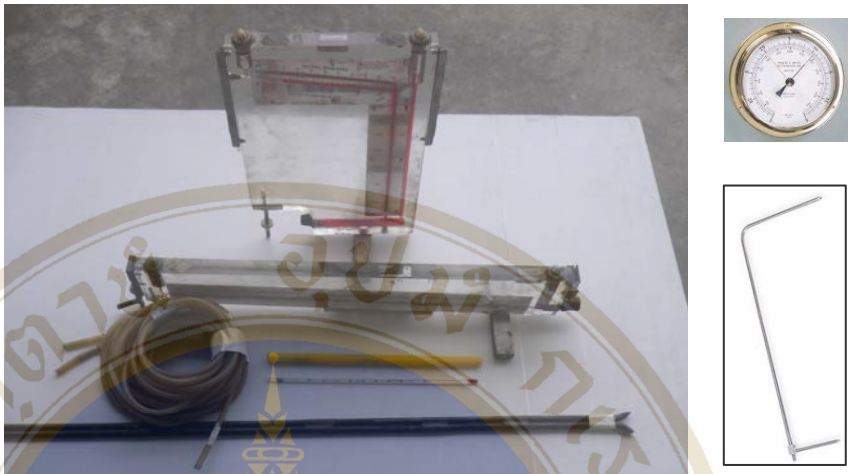

Figure B-3 Set of measures velocity in duct

Figure B-4 Set of measure exhausting air

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APPENDIX C
CALIBRATION

Table C-1 Show the result of VelociCalc Plus calibration
Model: 8386A-M-GB Serial: 03120366
Date of calibration: 28 November 2008.
T = 29.3 ^{O}C, P = 758.5 mmHg, RH = 43.4 %

Experiment	Time	Velocity (m/s)	Velocity that can read (m/s)	Velocity average (m/s)
1	1	0	0	0
	2		0	
	3		0	
	4		0	
	5		0	
2	1	2.5	2.96	2.95
	2		2.95	
	3		2.94	
	4		2.96	
	5		2.95	
3	1	5	5.55	5.55
	2		5.55	
	3		5.55	
	4		5.55	
	5		5.55	
4	1	10	11.4	11.4
	2		11.4	
	3		11.4	
	4		11.4	
	5		11.4	

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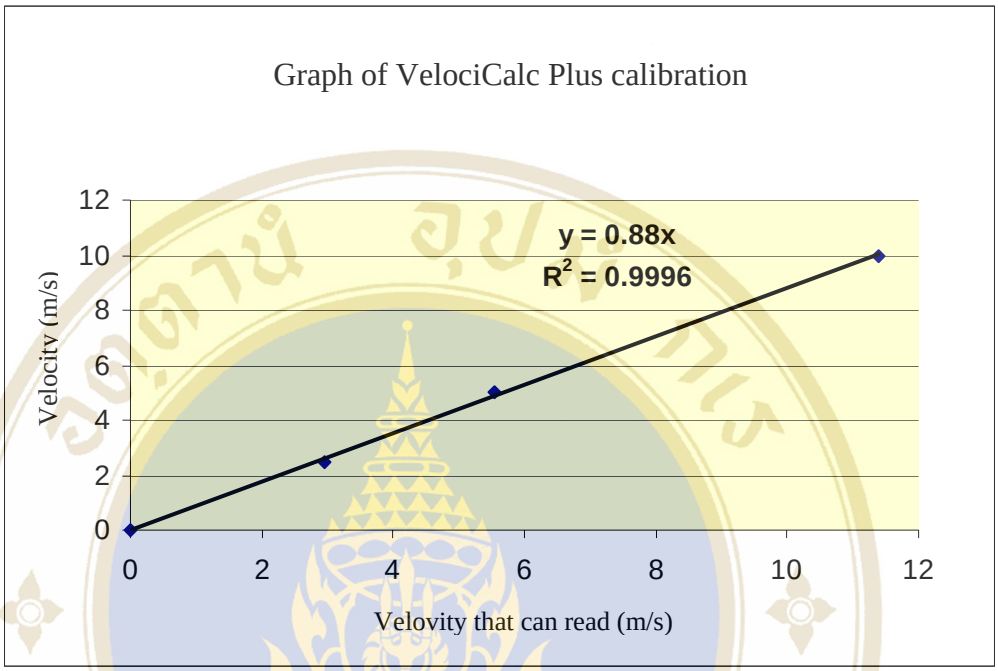

Figure C-1 Graph of VelociCalc Plus calibration

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APPENDIX D

BUILT LABOLATORY

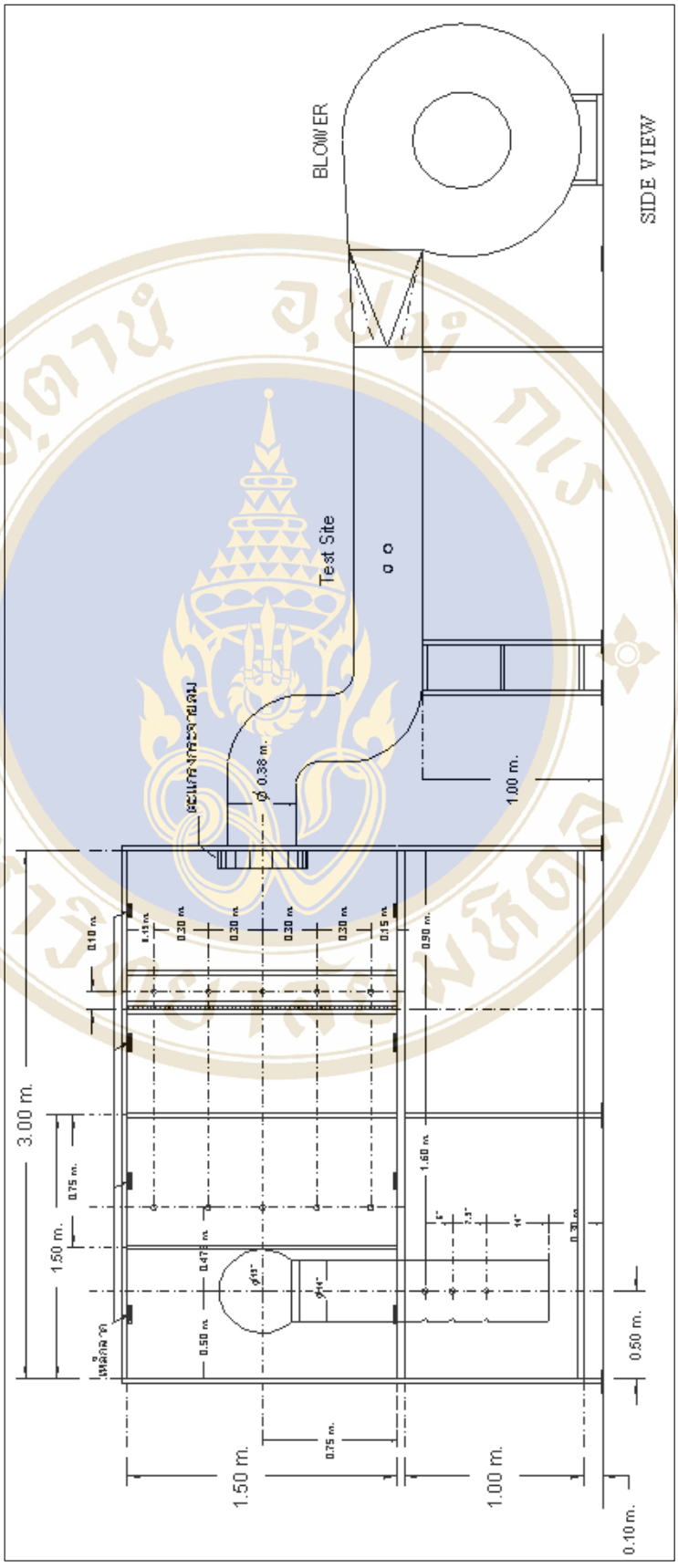

Figure D-1 The simulation laboratory

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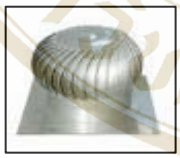
APPENDIX E
QUESTIONNAIRE

คำชี้แจง กรุณากรอกข้อมูลลงในช่องว่าง และทำเครื่อง ✓ในช่องสี่เหลี่ยม

1. ชื่อสถานประกอบการ _____
2. ที่อยู่ _____
3. ประกอบกิจการ _____
4. สถานประกอบการของท่านมีการติดตั้งพัดลมระบายอากาศบนหลังคา (หรือลูกหมุนระบายอากาศ) หรือไม่?

   ☐ มี ☐ ไม่มี
5. ลักษณะอาคารที่ติดตั้งคือ (เช่น โกดังสินค้า) _____
6. ขนาดของอาคารที่ทำการติดตั้ง กว้าง _____เมตร ยาว _____เมตร สูง _____เมตร
7. ท่านติดตั้งลูกหมุนระบายอากาศเพื่อ

   ☐ ระบายความร้อน ☐ ลดมลพิษที่เกิดขึ้น ☐ อื่นๆ (ระบุ)_____
8. ลูกหมุนระบายอากาศที่ท่านใช้งานอยู่มีลักษณะเป็นแบบใด?

☐  ☐ ☐

☐ ☐

☐ อื่นๆ (โปรดวาดภาพร่างคร่าวๆ)

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9. สถานประกอบการของท่านมีการใช้ลูกหมุนระบายอากาศมาเป็นเวลาประมาณ_____ปี เคยมีการรื้อถอนเพื่อ
ทำการติดตั้งใหม่หรือไม่? ☐ มี ☐ ไม่มี ☐ ไม่แน่ใจ

10. ท่านคิดว่าการติดตั้งลูกหมุนระบายอากาศมีความจำเป็นหรือไม่? ☐ มี ☐ ไม่มี ☐ ไม่แน่ใจ

11. ท่านคิดว่าการที่ลูกหมุนระบายอากาศมีการหมุนแสดงว่ามีการดูดหรือระบายอากาศใช่หรือไม่?
☐ ใช่ ☐ ไม่ใช่ ☐ ไม่แน่ใจ

12. ท่านเลือกซื้อลูกหมุนระบายอากาศตามข้อใด? (สามารถเลือกได้มากกว่า 1 ข้อและขอให้เรียงลำดับความสำคัญ)

_____ ☐ คำแนะนำของบุคคลอื่น (เช่น เพื่อน คนรู้จัก)
_____ ☐ เลือกซื้อตามโรงงานอื่น
_____ ☐ เลือกซื้อตามคำแนะนำของบริษัทผู้ขาย
_____ ☐ พิจารณาจากคุณลักษณะของลูกหมุนระบายอากาศ ราคา และความเหมาะสมในการติดตั้ง
_____ ☐ อื่นๆ (โปรดระบุ) _____

13. ลูกหมุนระบายอากาศที่ท่านใช้อยู่นั้นได้รับมาตรฐานหรือใบรับรองหรือไม่?
☐ มี คือ _____ ☐ ไม่มี

14. ท่านมีการตรวจสอบประสิทธิภาพเของลูกหมุนระบายอากาศหรือไม่?
☐ มี คือ _____ ☐ ไม่มี

15. ท่านคิดว่าลูกหมุนระบายอากาศที่ใช้งานอยู่มีประสิทธิภาพเป็นอย่างไร?
☐ ดีอยู่แล้ว
☐ ควรปรับปรุง ในเรื่องของ _____
☐ ไม่แน่ใจ เนื่องจาก_____

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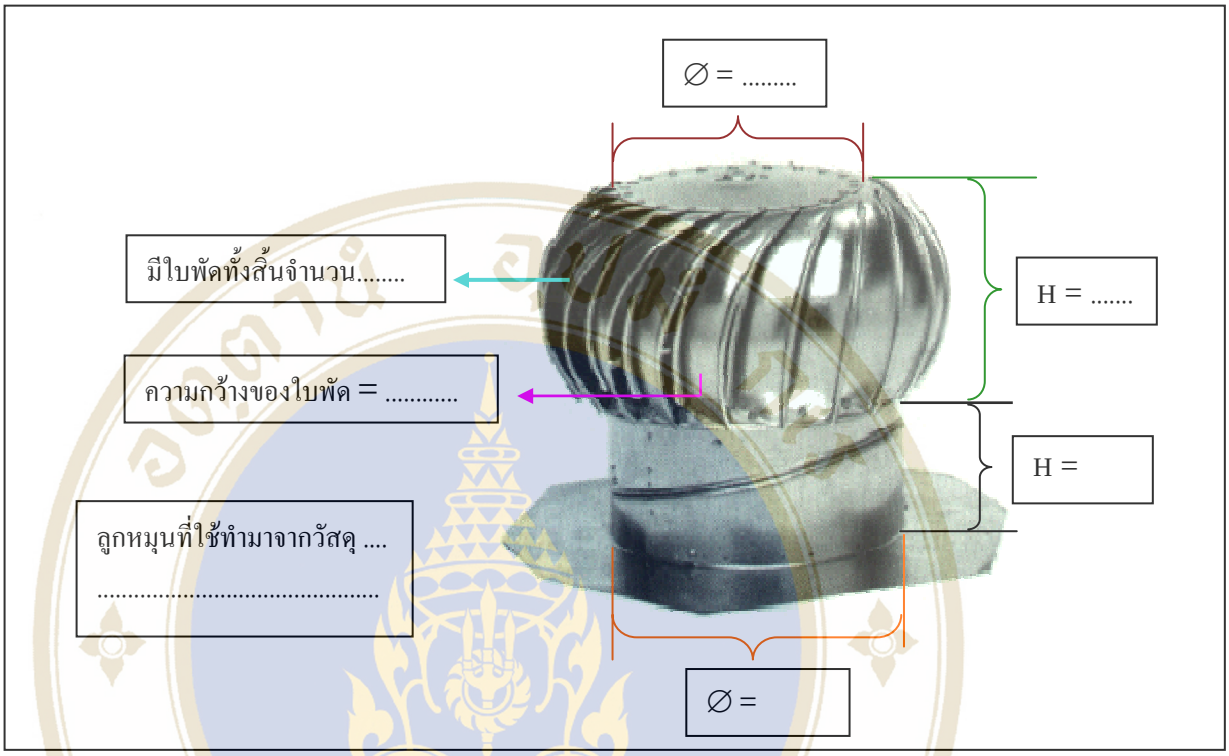
16. โปรดใส่ขนาดของลูกหมุนที่ท่านใช้งานอยู่ลงในรูปด้านล่าง



ตำแหน่งผู้ให้ข้อมูล _____

ลงวันที่_____เดือน_____พ.ศ. 2550

(ขอบคุณทุกท่านที่ตอบแบบสอบถาม)

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