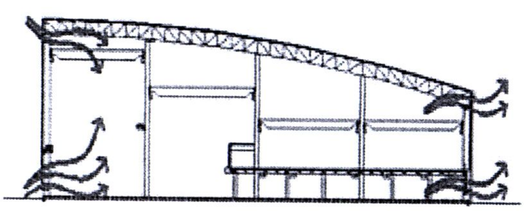
CHAPTER 4 RESULTS

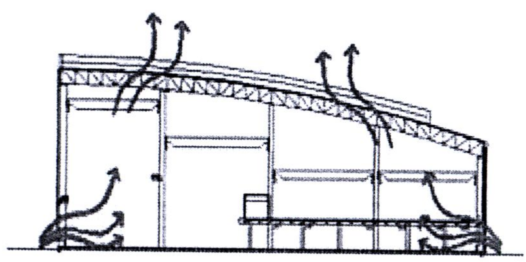
The experiment is conducted from hypothesizing of integrated design strategies due to analysis of data acquisition, afterwards experimental model will be defined comparing between base case and design cases, and the results will be discussed. The aim of this experiment is to find the appropriate design strategies integrated in the industrial building performances by stimulating in limited parameter of natural ventilation, air velocity, thermal radiation and daylighting. The model composed of office zone which operated with HVAC, and factory zone which operated with natural ventilation, is shown in the previous chapter. The experimental models exhibit that the location of the model relates to direction of wind by facing long side to the south-north and facing narrow side to the east-west of sun.

4.1 Result of Natural Ventilation and Air velocity

Natural ventilation in comparison of conventional case and experimental case is moderately different. The conventional case using basically cross ventilation effect driven by natural wind through low and high louver is not workable for industrial buildings because of their large sizes; distance from inlet and outlet is greatly long as shown in Figure 4.1. Whilst the experimental case using stack ventilation effect is driven by natural wind from low louver inlet to roof monitor outlet is more effective, airflow rate can be increased.



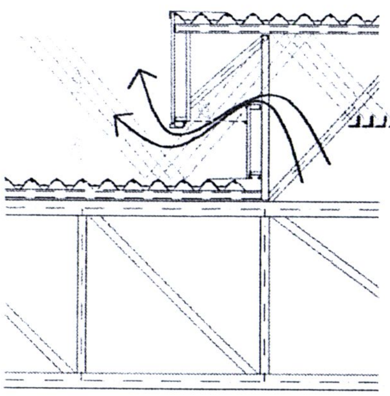
Cross section of conventional case



Cross section of experimental case

Figure 4.1 Natural ventilation in comparison of study models.

Height is a significant parameter to be studied and varied from 18m to 31m. Furthermore, regarding information from field survey, roof monitor is proposed for natural ventilation due to stack effect in case of ceiling height is high; it is helpful for airflow. In addition, roof monitors could save more running cost from skylights when granted horizontal opening or translucent wall with indirect light as shown in Figure 4.2.



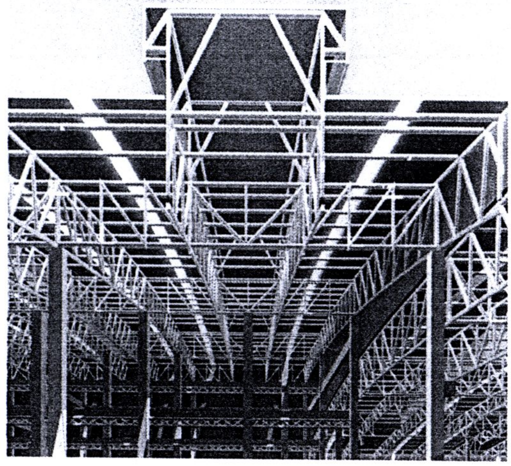


Figure 4.2 Integrated roof monitor detail and indirect skylight.

As for the building envelope of wall design, a typical type represents the opening of conventional wall for manufactures that allows natural ventilation through ventilation blocks or louvers at the low level, but there are limitations on wind velocity and rain protection. An integrated type represents the proposed wall opening detail that can solve mentioned problem both of wind velocity and rain protection. Because of the large size of industrial building, in order to grant self-shading and rain protection, the façade could be designed with the consideration of horizontal opening between setting back lower and higher walls. In this experiment, the integrated type of 1m wide horizontal opening among lower and higher through the wall allowed wind to flow into the building more than the typical type of 1m high lower walls of ventilation block as shown in Figure 4.3. It could save cost of louvers and shading devices for the same place and function. Furthermore, PV installation on the roof surface which always had solar exposure should be taken into account enthusiastically. In Thailand, radiation plays a critical role in comfort and energy consumption in buildings. Therefore roof material should be well insulated with mass associated rather than reflective coating material on the roof solely.

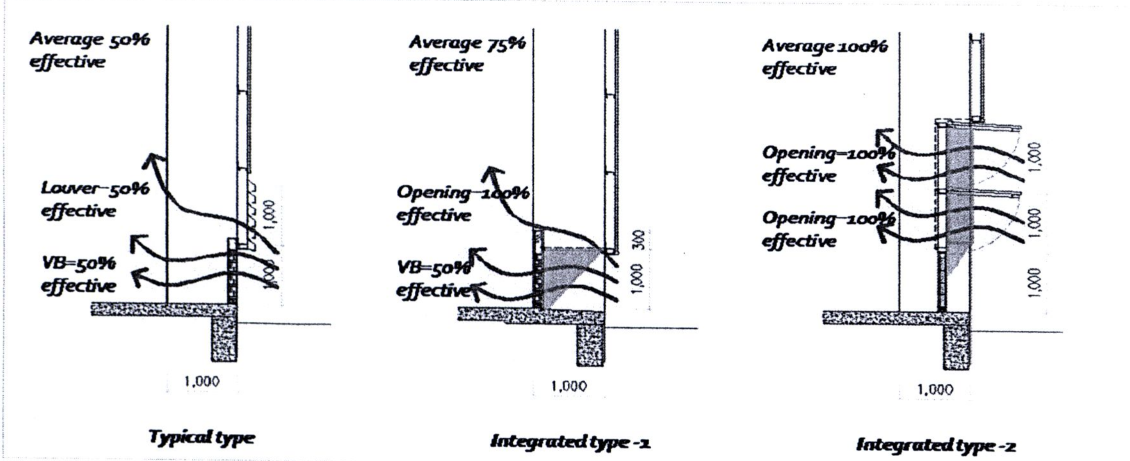
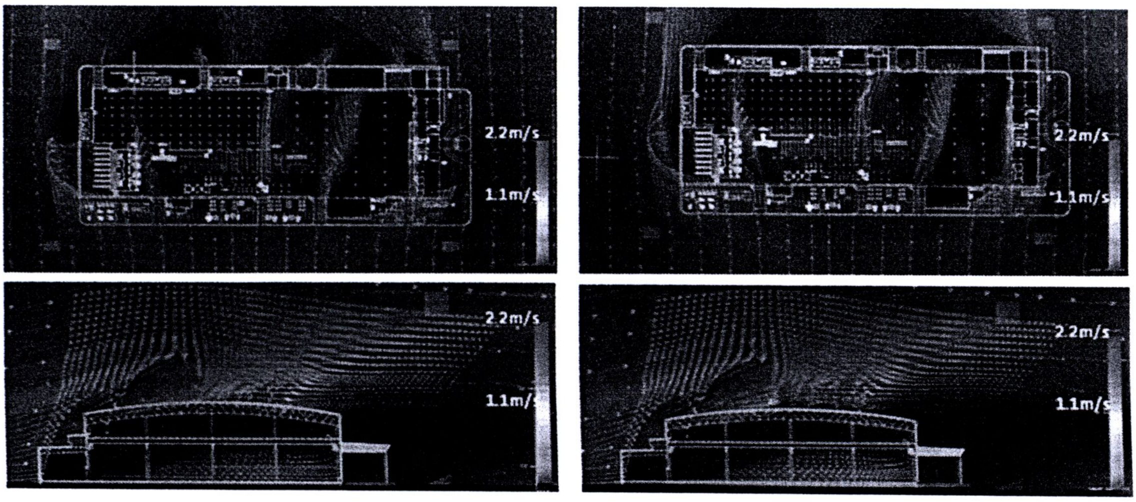


Figure 4.3 Comparison of wall detail between typical type and integrated type.



Conventional case: Low and high louver   Experiment case: Horizontal voids w/ roof monitor

Figure 4.4 Simulating result of airflow in comparison of study models.

In the experiment, airflow had been investigated through the air velocity in the building by FloVENT program for CFD analysis by plotting 40 monitoring points scattering all around inside the study model in grid pitch 20m x 20m. The result of air velocity inside the building from the experiment is revealed that average AV of base case through low and high louver is 1.22 m/s, whilst average AV of integrated case through horizontal voids with roof monitor is 1.45 m/s (outside AV is 2 m/s). Average AV in the building of the integrated case using horizontal voids with roof monitor can be increased 19.25% from base case through typical louvers. Stack ventilation is to flow the heat under roof from machine or process due to the rule of thumb the heat buoys to higher space and the cooler air blows instead, like roof monitor is needed for heat generated buildings.

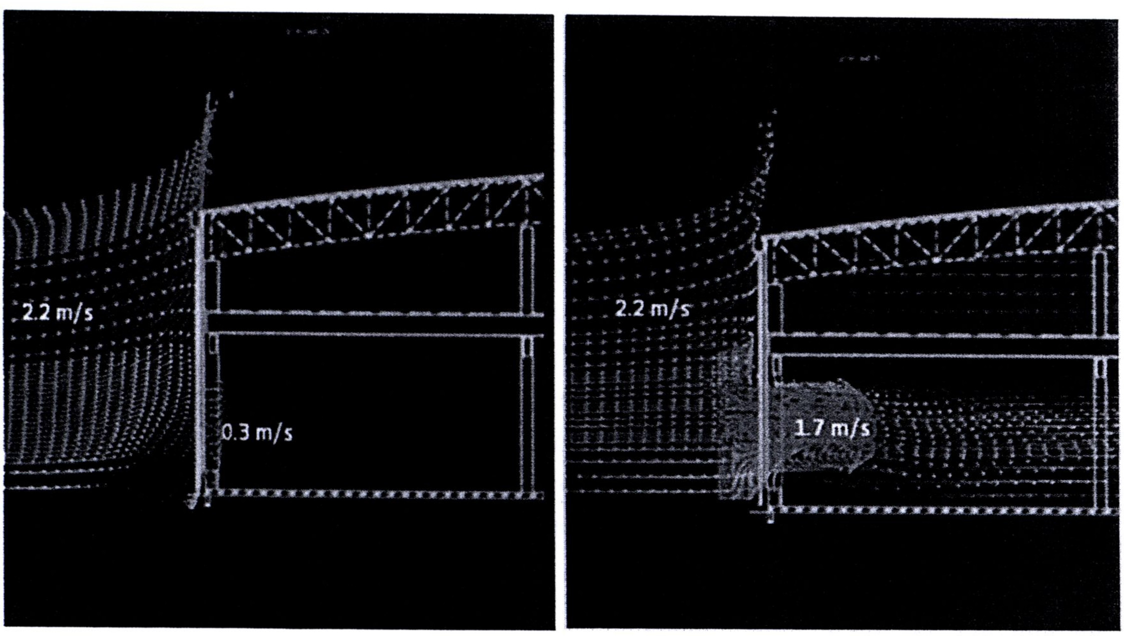


Figure 4.5 Result of air velocity at opening wall.

In depth, the result of air velocity at opening wall was indicated that 50% effective louver at low level H=2m and high level H=1m in typical design could induce the wind blowing from outside 2 m/s through inside the building; air velocity after passing the louver is approximately 0.3 m/s then fades away into the building. Whilst 100% effective opening with roof monitor in integrated design could induce the wind providing air velocity after passing the opening approximately 1.7 m/s then fades away into the building. This could be applied for the opening wall design in industrial buildings to protect rain splash since it was able to open by simply manual operation.

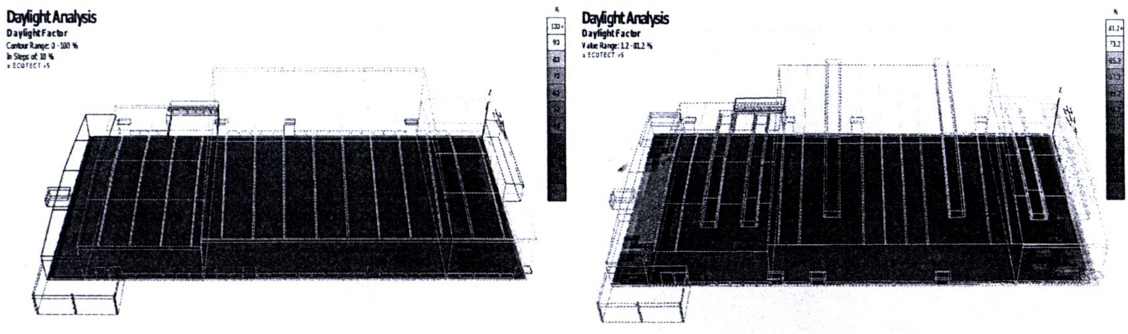
From the result, it had been found that building height and opening area were significant parameter for airflow and natural ventilation, because the volume of airflow induced by wind generating at a height of roof by the hotter surface as stack effect in the experiment that could be calculated as the following formula;

$$Q = C_d \times A \times [2gh (T_{in}-T_{out})/T_{in}]^{1/2}$$

Where; Q = Volume of air flow (m^3/s)
C_d = 0.65 of a discharge coefficient
A = Area of inlet opening (m^2)
g = 9.8 (m/s^2) of the acceleration due to gravity
h = The height of midpoints between inlet and outlet (m)
T_{in} = Average temperature of indoor air (K)
T_{out} = Average temperature of outdoor air (K).

4.2 Result of Daylighting

The industrial building attributes are mostly large and wide span constructed in one storey, thus a design method of daylighting that covers all over the building is using translucent skylights at the top roof, assuming that the visible transmittance of the skylight is 30 %. In the experiment simulating by Ecotect program, skylight area of conventional case is 3.8% of total roof area compared with integrated case which is 3% of total roof area with additional roof monitor. The result indicates that daylight factor (DF) will be increased from 6.8% to 17.4% due to the illuminance of indirect light from roof monitors. Both of conventional case and integrated case are strongly daylit exceeding 5% DF, while the proper balance between lighting and thermal aspects for human perception is between 2-5% depending on the activities. Even though the DF is exceeded, it affects comfort zone a bit since the building height of the building is more than 18m high, enough from direct heat radiation. By the use of daylight, electricity bill for lighting can be greatly reduced. However, more skylight configurations as well as its effect on temperature should be investigated in next experiment of thermal comfort.



Conventional case | Integrated case

Figure 4.6 Simulating result of daylighting in comparison of study models.

Table 4.1 Simulating result of daylighting in the experiment.

Experiment	Conventional case	Integrated case	Difference
Skylight area/ roof area	3.8%	3%	-0.8%
Average DF (%)	6.8%	17.4%	+10.6%

Recommended light conditions by Illuminating Engineering Society of North America (IESNA) for industrial buildings is approximately 300 Lx in average, depending on type of task/activity with more uniform brightness ratio in a visual field of view and good color appearance, whilst the daylight availability in Thailand can be introduced through skylight where annual average solar radiation on horizontal plane in Thailand is 383.4 W/m2 (Chirarattananon, 2005).

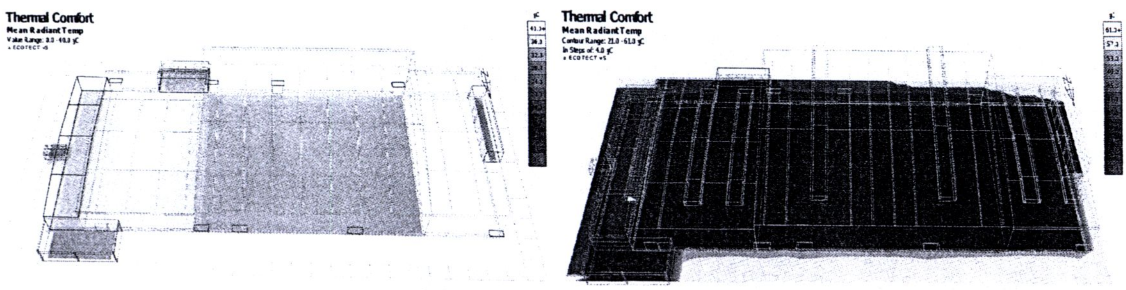
4.3 Result of Thermal Comfort

Thermal in the experiment, simulating by Ecotect and affecting to human comfort in industrial building model, is mainly from the roof rather than the wall since it is the largest area hit by the sunbeam. Thus, mostly, the manufacturer selected to protect direct heat from sunbeam by additional roof insulation. The potential of heat gain reduction is to change material specification and to add the insulation. In this experiment, the insulated roof with glass wool 25mm thick (U-value=0.26 W/m^2K) reduces heat gain rather than that without insulation or (U-value=0.9 W/m^2K) of the conventional case.

Mean Radiant Temperature (MRT)

Average MRT from roof, wall, and floor in base case, 36.5˚C, is gradually decreased in the experiment cases due to exposure areas decreased from setting back wall of opening design, shading of roof monitor, roof insulation, and integrated all these 3cases accordingly. Average MRT in experiment cases of case-1, case-2, and case-3 are

35.7°C, 34.4°C, and 33.6°C respectively as shown in Table 4.2. Whilst average MRT in experiment case-4 (integrated case), 32.5°C, is the lowest that can be approached to comfort zone for Thailand if air velocity inside the building is 0.5m/s [Khedari et. al]. It is noticeable that the average MRT of building 32°C of high zone, comparing with 36°C of low zone, is lower due to the height of building is different. The higher roof could transfer heat directly from the exposure lower than the lower roof.



Conventional case Integrated case

Figure 4.7 Simulating result of Mean Radiant Temperature in comparison of study models.

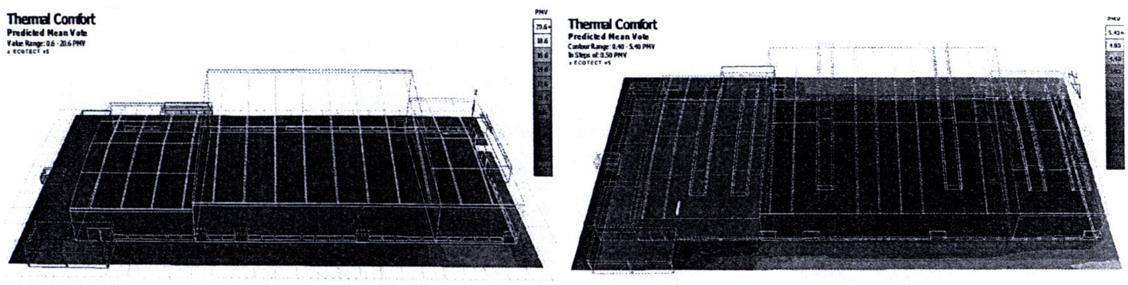
Table 4.2 Simulating result of MRT in the experiment.

Experiment	Base case (Conventional)	Case-1 (Opening)	Case-2 (Roof monitor)	Case-3 (Roof insulation)	Case-4 (Integrate d)
Average MRT (°c)	36.5	35.7	34.4	33.6	32.5
Decreasing (%)	0	2.2	5.8	7.9	10.9

It is known that thermal comfort is a function of temperature, air velocity, relative humidity, and mean radiant temperature. Temperature and velocity recommended by Olgyay's Bio Climatic chart for warm climate, comfort zone fall between 21°C~30°C under still air and can be increased to 32°C, 33°C and 36°C under velocity of 0.1m/s, 0.4m/s and 1m/s respectively. Mean radiant temperature should be kept as low as air temperature to avoid discomfort condition due to heat from radiation. Besides thermal comfort, acoustical and visual comfort must be considered to provide better than acceptable conditions for industrial buildings in tropical climate.

Predicted Mean Vote (PMV)

Predicted Mean Vote (PMV) is the thermal sensation scale of a large population of people exposed to a certain environment. PMV is derived from the physical load of heat transfer between the body and the environment combined with an empirical fit to sensation. PMV is related to MRT; the greater the load, the more the comfort vote deviates from zero. In this experiment, average PMV of conventional design in base case is +2.8; people felt hotter than mean. Besides integrated case (case-4), roof insulation of glass wool 25mm thick in case-3 of +1.5 PMV could make people more satisfied but still not enough comfort comparing with Average PMV in integrated case (case-4) of +0.8 PMV, which is nearly achieved to comfort zone particularly at high zone.



Conventional case Integrated case

Figure 4.8 Simulating result of Predicted Mean Vote in comparison of study models.

Table 4.3 Simulating result of PMV in the experiment.

Experiment	**Base case (Conventional)**	**Case-1 (Opening)**	**Case-2 (Roof monitor)**	**Case-3 (Roof insulation)**	**Case-4 (Integrated)**
Average PMV	+2.8	+2.4	+2.1	+1.5	+0.8
Decreasing (%)	0	14.3	25	46.4	71.4