Chapter 5

Air Handling Unit (AHU) Detail Design

The concept design referred as "Concept 4" is selected as the master concept design for Air Handling Unit (AHU) design improvement. To get the final design of AHU, the concept design is disassembled to the small section of parts. The researcher and researcher and design team are focus on the system equipment selection for each section. The technical background is presented as the technology references for each equipment selection.

Only the frequently used AHU's parts/equipment is focused for detail design, because there are wide ranges of parts/equipment that can be equipped into the AHU but only limited number of part is suitable to the customer demands. The further discussion of the focused parts/equipment is in the section 5.1.

5.1 Focus Equipment Module & Unit Size

The researcher and design team will focus only on the key components since they play major role on the performance of the AHU. This Air Handling Unit (AHU) design improvement will focus on following equipment selection:

- ✓ Structure
- ✓ Wall Panel
- ✓ Floor Panel
- ✓ Chilled Water Coils
- ✓ Drain pan
- ✓ Fan and Drives
- ✓ Filters
- ✓ Mixing Box and Dampers

Those key equipment modules are commonly used in all industries.

5.1.1 Module Sizing

The Air Handling Unit (AHU) ranges are commonly divided by cooling/heating capacity or air volume. Thailand HVAC industries are using two measuring standard, the Imperial Unit (I-P) and the System International of Units (SI). For this design improvement the dimensions of the design product will be shown only in SI unit.

For the modularity design, the unit size is referred as the "Module" or represented by the alphabet "M". Each module shall be in square cube shape which dimensions are equal to the internal dimension unit (Height x Width x Length) of the Air Handling Unit (AHU), which is **305 mm.**

Air Handling Unit (AHU) sizing is identified by number of modules in the height and width of the module cross-section. For example: the Concept-4 size 3x6 is the 3-module height and 6-module width in the cross section dimension.

At this step the researcher and design team need to identify the ranges of the Air Handling Unit (AHU) that will be used on the design. The capacity of the AHU depends on various factors i.e. the size of the coil, the air velocity through the coil, fan sizes, and water flow rate. From the industry practice the general ranges of the AHU are from 1,000 to 76,000 m^3/h (600-45,000 CFM (ft^3/m)). For the larger AHU capacity over 76,000 m^3/h (45,000 CFM (ft^3/m)) shall be considered the special order module and will not be considered in the module sizing for this study.

In developing the ranges of the AHU for commercially production, economical point of view is also another factor that is taken for consideration. The Air Handling Unit (AHU) ranging has to consider from two aspects, engineering and economical.

From the engineering aspect and the historic records of AHU design of reference company in the past, following design limitations are taken for consideration:

- ✓ The maximum length of one sheet metal work is limit to 10 feet or maximum of 9 modules.
- ✓ The limitations of the old AHU structure in case of using the old structure as the part of the design are as follow:

  For module width less than three (3) modules the maximum continuous module length is limited to nine (9) modules

  For module width from four (4) to six (6) modules, the maximum continuous module length is limited to eight (8) modules

  For module width over six (6) modules, the maximum continuous module length is limited to seven (7) modules.
- ✓ The maximum height of unit is 8 ft. (7 modules) due to the limitation of transportation.
- ✓ For serviceability point of view, the maximum module width relative to module height is equal to module height x 2 + 1

  From the study of the economical cost of construction, researcher and design team found that capacity/cost of construction factor ratio can indicate the economic cost of construction. Old model of AHU is used because of the historic records of cost construction. The result of the 27 models economic cost calculation, which is based on standard configuration of; Forward Curve Centrifugal Fan + 4 Row full-face Chilled water Coil + Aluminum Pre-filter + 2 way Mixing Box, is shown in table 5.1. The data in the table 5.1 is plotted for graphical comparison of the Capacity/Cost Ratio in the Figure 5.1. From the assessment and comparison of the calculated data, researcher and design team found that unit with module width higher than the *module height x 2+1* have lower

Capacity/Cost ratio than other unit size that deliver same range of capacity. The lower Capacity/Cost ratio means that at the same output of air volume, the AHU that have low Capacity/Cost ratio is more expensive than the AHU that has high Capacity/Cost ratio.

Unit Size	Rated Capacity Cu.ft./min.	Cost of Construction Factor	Capacity/Cost of Construction Ratio
2x2	2,000.00	48.00	41.7
2x3	3,000.00	90.00	33.3
2x4	4,000.00	144.00	27.8
2x5	5,000.00	210.00	23.8
2x6	6,000.00	288.00	20.8
2x7	7,000.00	378.00	18.5
2x8	8,000.00	480.00	16.7
3x3	4,500.00	108.00	41.7
3x4	6,000.00	168.00	35.7
3x5	7,500.00	240.00	31.3
3x6	9,000.00	324.00	27.8
3x7	10,500.00	420.00	25.0
3x8	12,000.00	528.00	22.7
4x4	8,000.00	192.00	41.7
4x5	10,000.00	270.00	37.0
4x6	12,000.00	360.00	33.3
4x7	14,000.00	462.00	30.3
4x8	16,000.00	576.00	27.8
5x5	12,500.00	300.00	41.7
5x6	15,000.00	396.00	37.9
5x7	17,500.00	504.00	34.7
5x8	20,000.00	624.00	32.1
6x6	18,000.00	432.00	41.7
6x7	21,000.00	546.00	38.5
6x8	24,000.00	672.00	35.7
7x7	24,500.00	588.00	41.7
7x8	28,000.00	720.00	38.9

Table 5.1: The Capacity/Cost of Construction Ratio

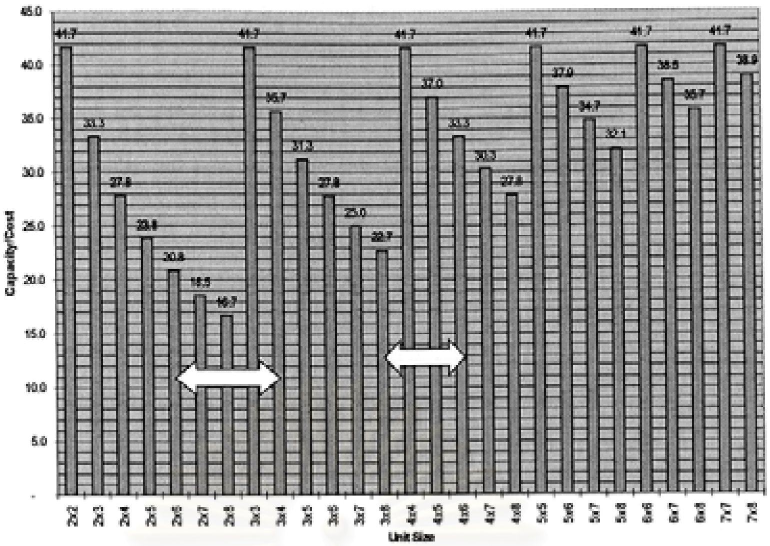


Figure 5.1: The Capacity/Cost of Construction Ration of Air Handling Unit (AHU)

Figure 5.1 illustrates the bar chart represent the data of table 5.1, the arrows show the pair of the unit size that have the same capacity but different in Capacity/Cost ratio. For example the AHU size 2x6 have ratio equal to 20.8 while the AHU size 3x4 have the ratio equal to 35.7. Both AHU have capacity of 6,000 CFM so the AHU size 3x4 is selected for manufacturing.

The capacity/cost of construction ratio shall be one of the reasons that the designer used to follow production knowledge base of the company.

The Cost of construction factor is derived from the "Confidential" Production Cost of each unit designation.

To verify the unit sizing ranges, focused brand sizing ranges were compared with the competitors in the market. From comparison, the researcher found that the pattern of the sizing range is similar.

Finally, the manufacturing size ranges is chosen for the "Concept-4" design. Total 23 Standard AHU sizes are in the design range with the minimum module size is 2x2 and the maximum size is 7x8. The sizing ranges are presented in the figure 5.2

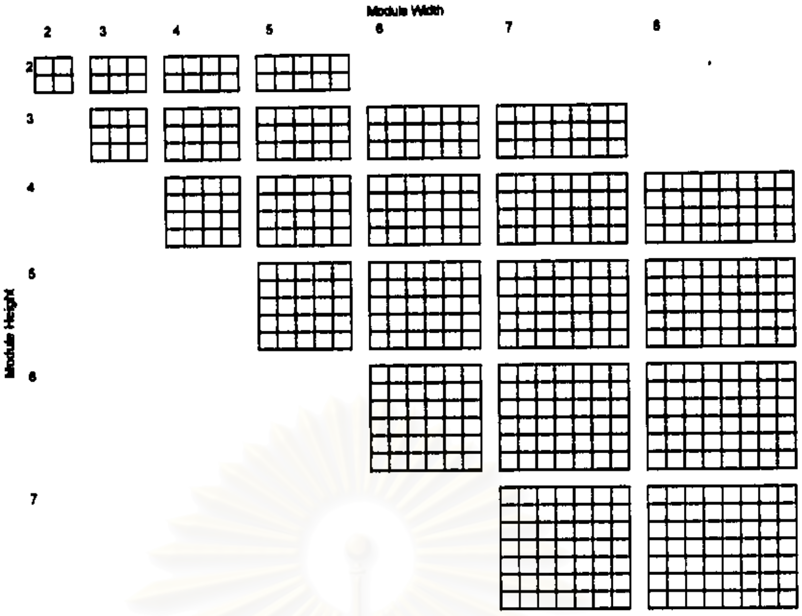


Figure 5.2: The Concept-4 Sizing Range

Figure 5.2 illustrates the cross-section dimension of the AHU, the vertical axis represented the module height, and the horizontal axis represented the module width. All dimensions are show in number of modules.

The AHU unit ranges will be set as the references; the detail design on parts will not effect any change on this modular sizing.

5.2 The Air Handling Unit (AHU) direction designation

For further design of the Air Handling Unit (AHU) the Right Side and Left Side designation must be clarified. The Right and Left are indicated by looking toward the airflow stream of the supply air as shown in figure 5.3

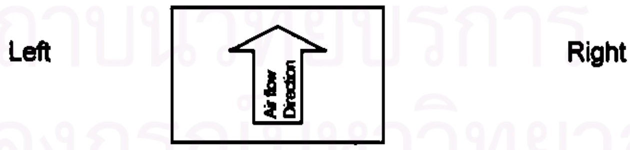


Figure 5.3:Left-Right Designation

Figure 5.3 illustrates the unit designation of AHU, the arrow shown the reference direction of the airflow.

5.3 Main Structure of "Concept 4"

The structure of the Concept-4 should have following features:

- ✓ Knock-Down Capability
- ✓ Modularized (AHU is able to consist of several modular unit)
- ✓ Be able to withstand the load of the higher level stack unit
- ✓ Be able to Withstand the additional load of 5 working person on the roof top (approximate 400 kg)

5.3.1 Technical Background

For designing steel structure researcher and design team needs to have references for design verification. The important technical issues that the researcher and design team must use as the reference:

- ✓ The Reference Industrial Standards

The standard for the construction material such as ASTM, JIS, DIN, BS standard that related to the sheet metal property and design guideline are referred.

- ✓ Material Physical Property from the material supplier

Galvanized sheet metal is the major parts of the construction, the actual material property that available in the market will ease the designer in calculating the strength of the structures. Actual material properties allow the design to be more accurate and reduce the chances of design error that caused from using the general published material property table.

- ✓ Limitation of the manufacturing tools

The manufacturing capability of the current manufacturing facility is one major point that needs to concern, not only on the structure design but also include to other parts and equipment design. The designer must be awared of the current manufacturing process to ensure that the designed product can manufacture as design. The design changes made at the manufacturing are costly and must be avoided.

5.3.2 Modular Section of AHU

The "Concept 4" AHU have three dimension modular structure. The AHU modular dimension is ranged from 1 to 9 modules. So the dimension of structure and panel is 1 module minimum and 9 modules maximum. AHU components can be put into a single section of modular structure or can be divided into multiple modular section and assembled at site to complete the system. This feature is also called the section modularity.

5.3.3 Corner Piece

The corner piece is designed that based on the sheet metal process for cost saving in the small volume production. The sheet metal used is 3 mm thick for tough construction. The sheet metal is cut and pressed to form the flat sheet with dimple guides as shown in figure 5.4 and 5.5.

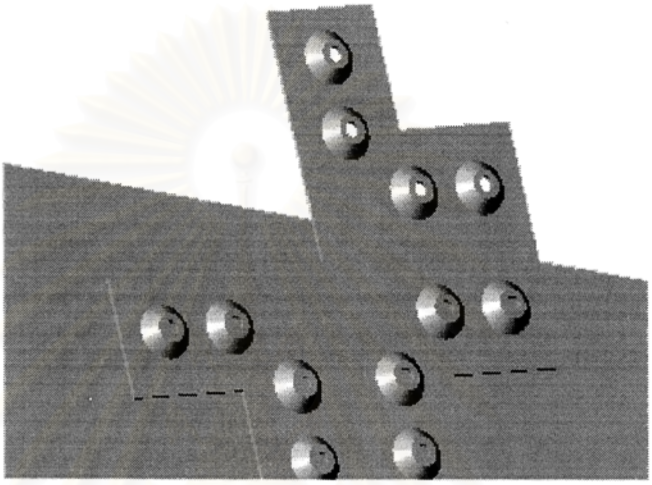


Figure 5.4: Flat Plate of the Structure Corner

Figure 5.4 illustrates the pre-folded corner piece. The dimple guides provided on the corner piece are used for the self-aligning hole in assembly. The completed corner piece is shown in Figure 5.5

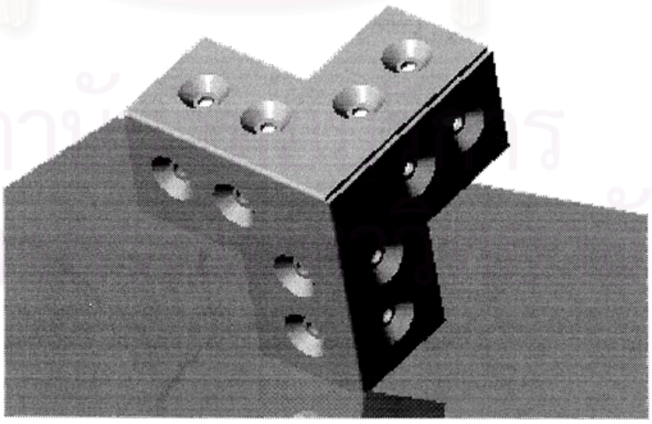


Figure 5.5: Structure Corner

Figure 5.5 illustrates the completed corner pieces that folded, welded and color coated. The self-aligning holes will ease the assembly and also provide the foolproof assembly.

5.3.4 L-shape Equal Leg Structure Post

The frame is made of the folded galvanized steel. Both ends of the steel have punched-out holes and the pressed dimple guides. Structure Frame dimple-guides and the Corner Piece dimple-guides have similar dimension. The assembly of the frame to corner piece is easy by the aid of dimple-guides on frame and corner piece. The frame is construct of sheet metal rolled-formed or folded into the L-shape cross-section. The 2mm thickness steel equal leg profiles have cross section dimensionof 50mmx50mm dimension.

The corner of the profile is 45 degree edge as shown in the figure 5.6

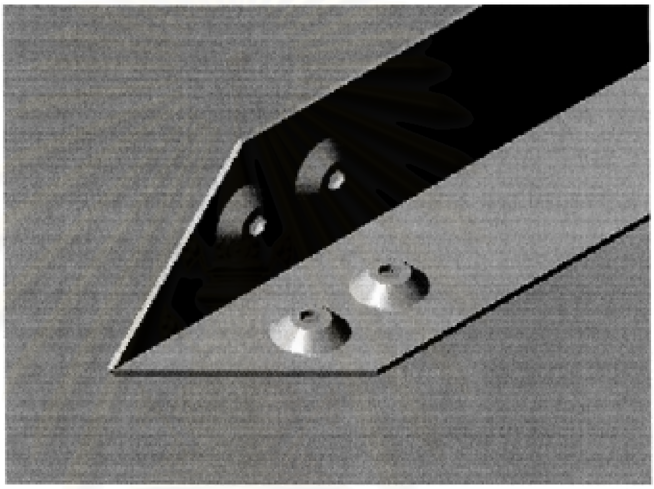


Figure 5.6: Frame Structure End

Figure 5.6 illustrates the end of the frame structure. Both end of the frame structure are 45 degree cut. The reason to cut out 45 degree is to make the frame structure connected to each other when assembled to the corner pieces and form the smooth external surface from the AHU structure. Following figure shows the cross-section of the AHU L-shape steel profile.

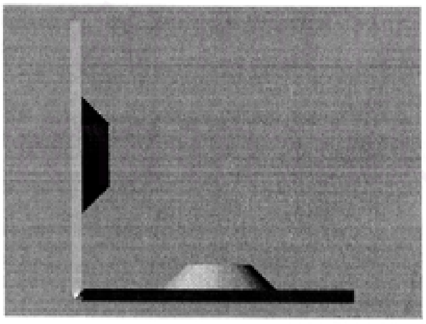


Figure 5.7 Frame Structure Cross Section

Figure 5.7illustrate the cross-section of the L-shape profile, the height of the L-shape is 50mm and the width of the L-shape profile is 50mm. Variety of lengths are cut to meet the modularity size. The completed post is shown in figure 5.8

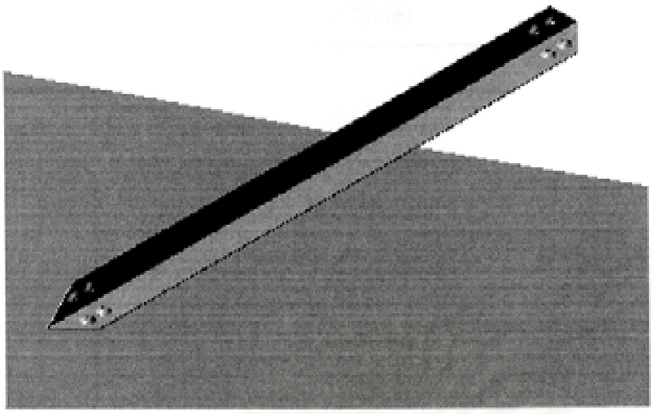


Figure 5.8: Completed Frame Structure

Figure 5.8 illustrates the completed L-shape frame post structure of the "Concept 4". The same design is carried out for the entire ranges with the same structure relation of Number of Module x 305mm + 100mm. Table 5.2 is the list of frame length that used in the design.

Number of Module(s)	Frame Dimension (Length), mm
1	405
2	710
3	1015
4	1320
5	1625
6	1930
7	2235
8	2540

Table 5.2: List of the Frame Length

5.3.4.1 Final Design of Structure

The structure post is made of 2mm galvanized steel with the pre-drilled hole and dimpled for assembly. The galvanized steel post is color coated with the epoxy paint for cleanliness and corrosion proof as shown in the drawing illustrated in figure 5.9.

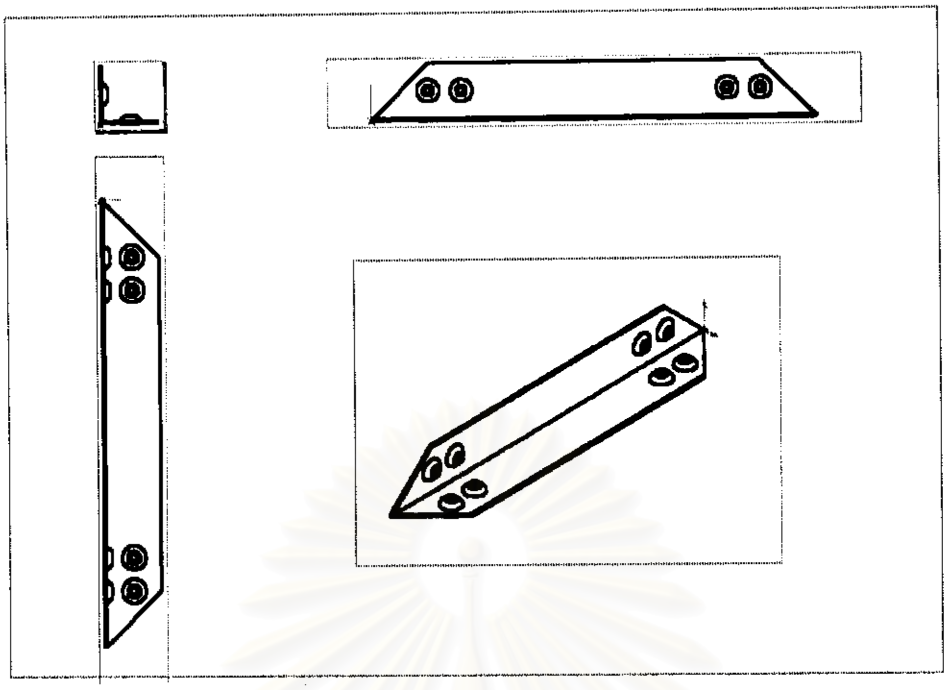


Figure 5.9: Drawing of the frame structure

Figure 5.9 shows the drawing of the frame structure in top view, front view, and side view and isometric view.

The corner pieces of the "Concept 4" is the 3mm thick galvanized steel drilled, dimple pressed and folded to formed the corner piece as shown in drawing figure 5.10

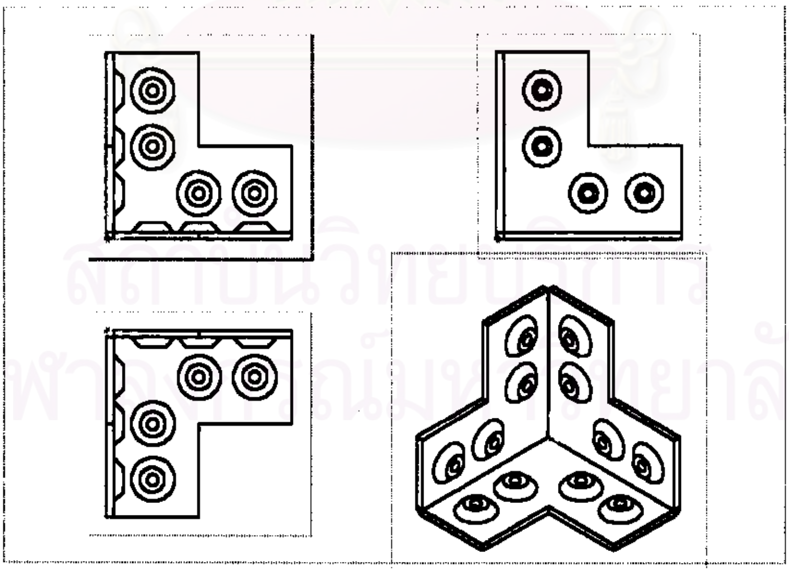


Figure 5.10: Drawing of the "Concept 4" corner pieces

Figure 5.10 illustrates the drawing of the "Concept 4" Corner piece.

The assembly of the "Concept 4" L-shape steel profile and the corner pieces is displayed in figure 5.11

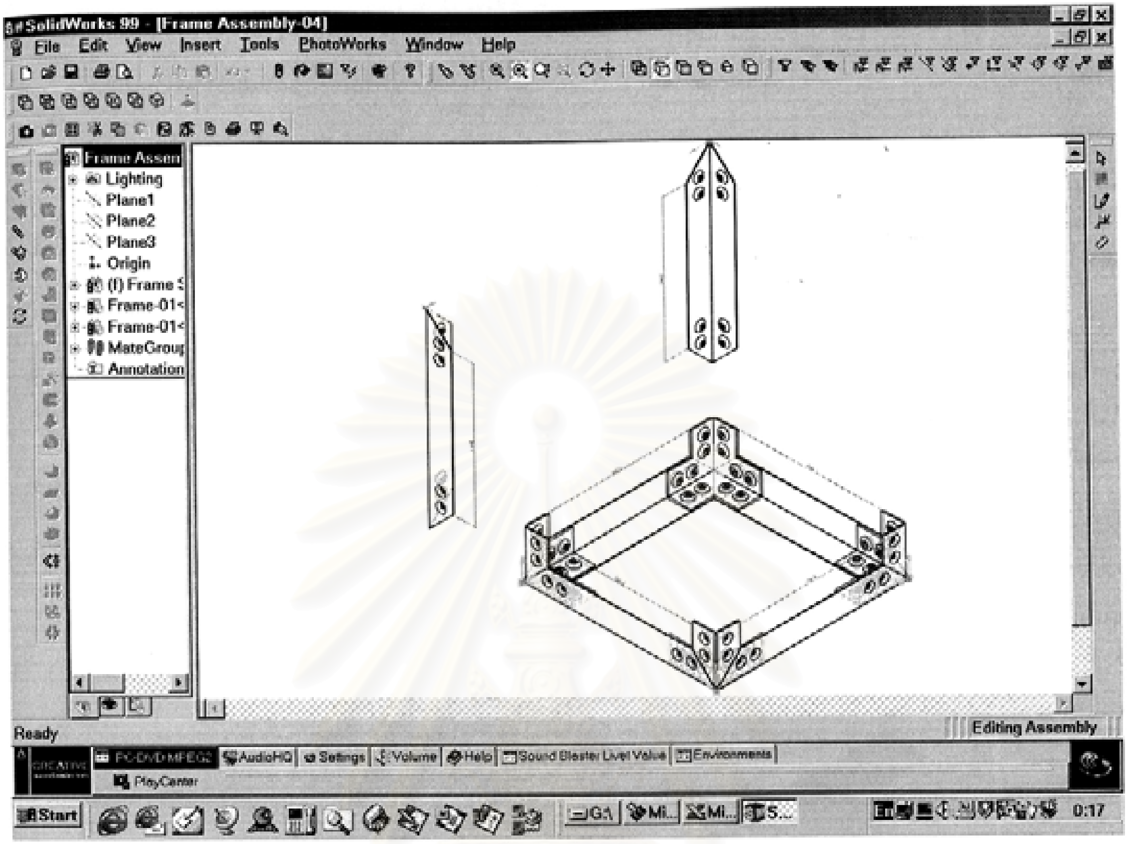


Figure 5.11: Assembly of the corner piece and L-shape frame

From the figure 5.11 the L-shape and the corner is assembled together by the bolts. The bolts are fastened through the pre-drilled holes. The render images of the completed frame assembly is displayed in figure 5.12

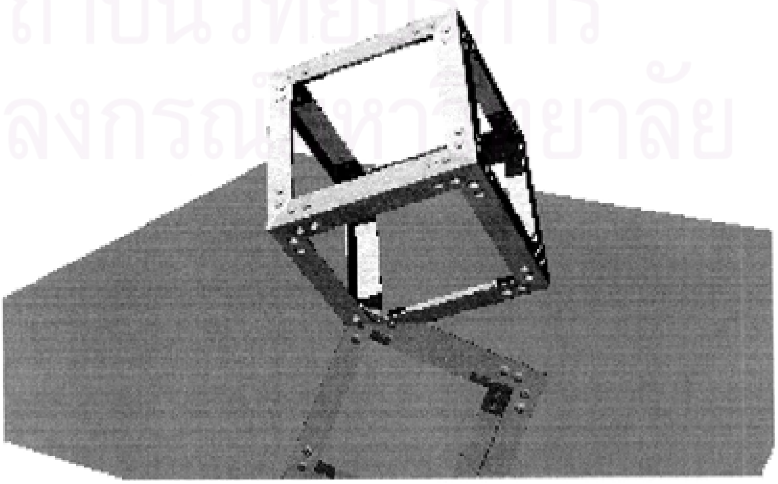


Figure 5.12 Complete Assembly of Air Handling Unit (AHU) Structure

The frame structure show in the figure 5.12 is ready for further AHU assembly. The external surface of the frame structure is insulated by the neoprene sheet to prevent the thermal insulation and work as the wall and floor panel gasket.

5.3.5 Base

Base frame is holding whole unit weight during operation and transportation. The purpose of the base frame is:

- ✓ To elevate the machine from the machine room level, prevent the Air Handling Unit (AHU) body from rusting and for ease of leveling
- ✓ To elevate the drain pan for proper drainage of the condensation water
- ✓ To support structure for lifting by both forklift and the lift hook

The base design is the 100mm height by 50mm width C-Channel with color coated. The bolt and the angle connectors hold the frames to each other. The Bolt and angle connectors provide the flexibility and knockdown capability to the base structure. The design of base structure is displayed as in figure 5.13:

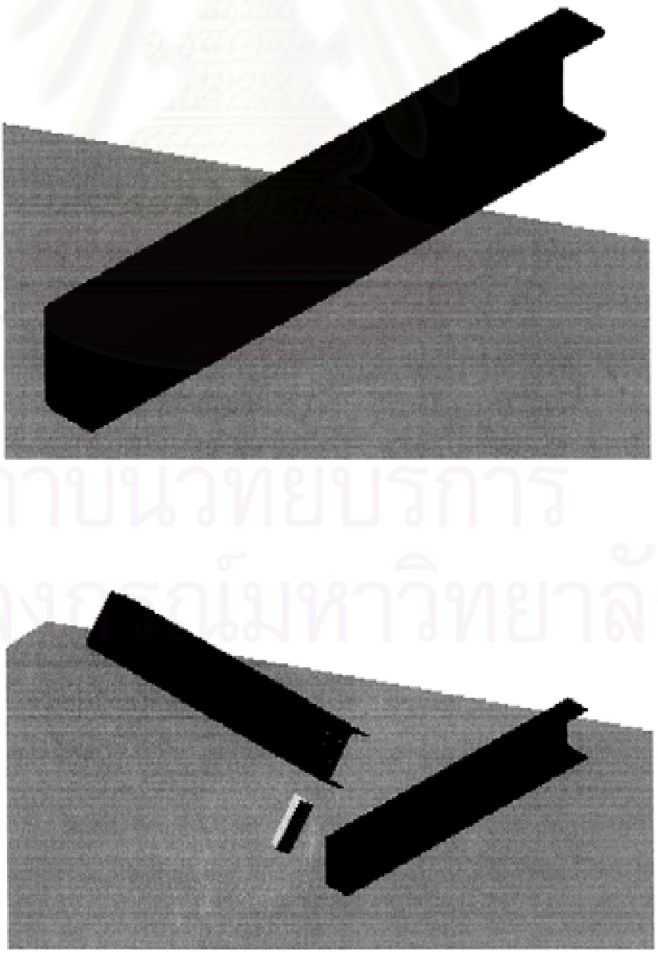


Figure 5.13 C-Frame

Figure 5.13 illustrate the part of the base frame, the C-profile is assembled together by welding or by bolts.

This base is the standard Air Handling Unit (AHU) base structure that used by all brands in the market. Only the color coated is adding to the standard feature for more durable.

The complete base structure for the prototype unit size 3x3 is shown in figure 5.14

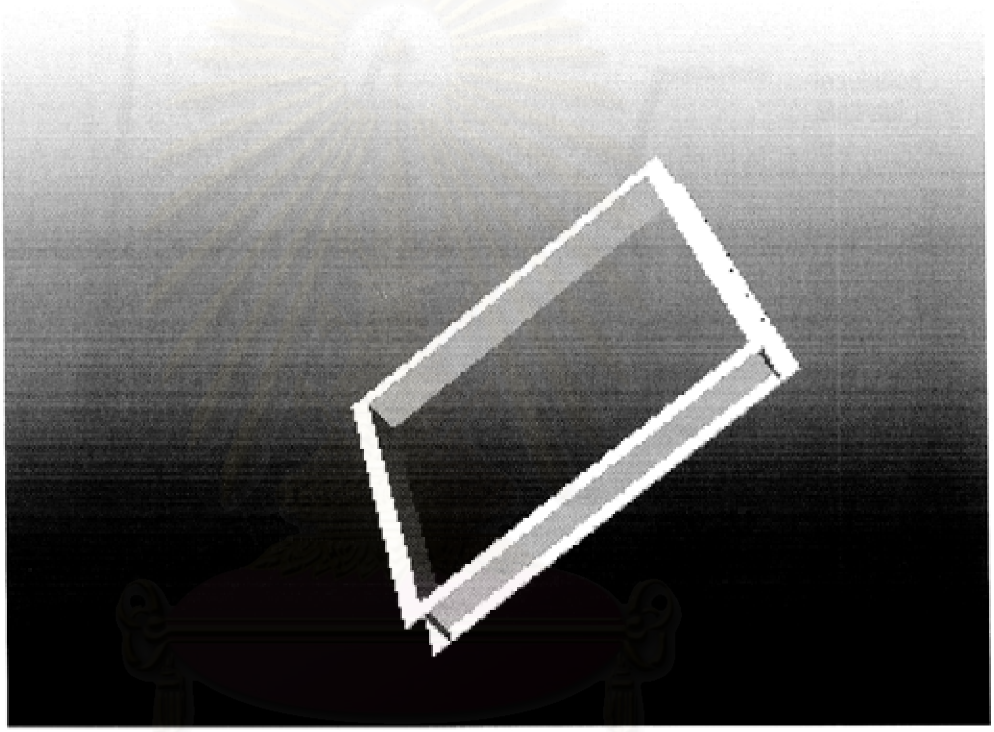


Figure 5.14: Complete Base Frame

5.4 Wall & Floor Panel

Wall Panel and Floor Panel are the key part to make the AHU design flexible, air tight and cold bridge free. The optimum goal of this design task is to develop the new concept of the wall panel, which increases the flexibility of the wall thickness. The capability of using any kind of insulation material is another benchmark that has to be accomplished.

Wall and Floor Panel are formed by the "double skin" construction. External sheet metal and internal sheet metal can be of various materials, inserted with edge profiles made of color coated dry wood or the reinforced plastic extrude. Edge profiles serve two functions, firstly they are used to hold the sheet metals and insulation material together and secondly they are usedto prevent metal contact from internal sheet metal and external sheet metal.

The closed panel is inserted with the insulation, of any kind that conformed to the customer specification such as, injected polyurethane 40kg/m^3, rockwool, fiberglass or polystyrene. The cut section of the new design wall panel is display in figure 5.15

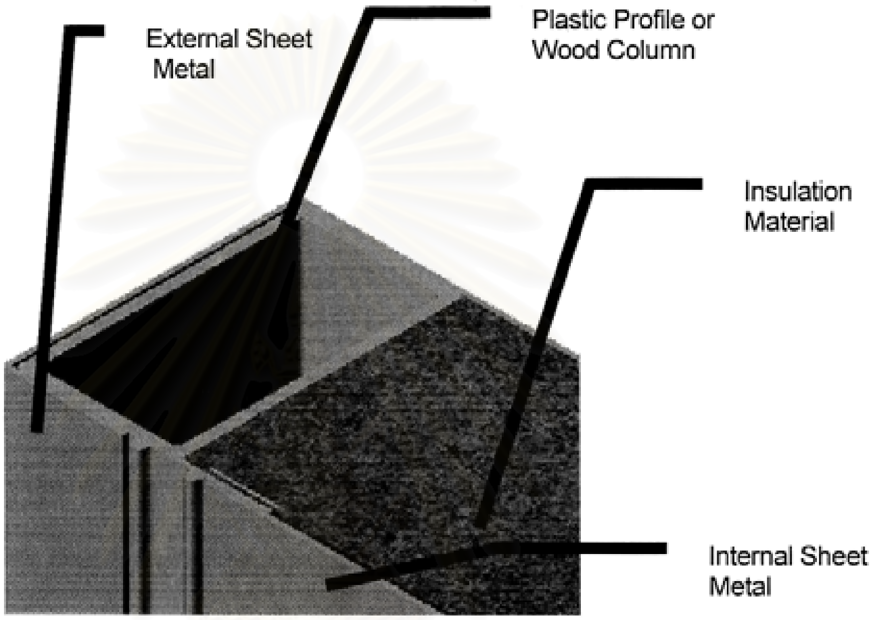


Figure 5.14 Concept 4 Wall Panel and Floor Panel Design

After the decision of taking the wall panel as the focus issue, additional requirements from the Quality Function Deployment (QFD) are adding to the feature of the wall and panel. The first generated idea of the concept wall panel shall be improved to reduce cost and increase the flexibility of expanding the wall thickness by stressing on the following points.

- ✓ The complex shape plastic profile is replaced with the simple shape plastic profile
- ✓ the plastic profile is replaced by Wooden profile that completely dry which coated with the water repellant color in case of low AHU volume production and special wall thickness that not meet the standard thickness of plastic profile i.e. 3 inches or 2.5 inches
- ✓ The floor panel plastic profile will be inserted with the rectangular pipe or the c-channel to increase the stiffness. The plastic performance on the vibration load is not good due to low fatigue resistance. See figure 5.15

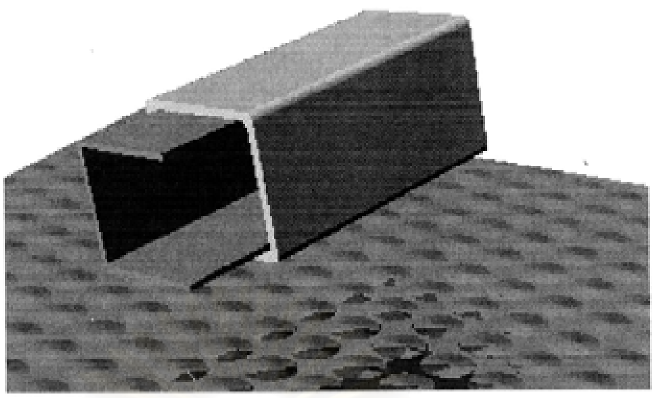


Figure 5.15 Reinforced Plastic Profile

From figure 5.15 the section of plastic profile used as the internal frame of the wall panel is shown. The c-steel profile is inserted to increase the strength. The plastic profile is assembled to the wall panel as shown in the figure 5.16

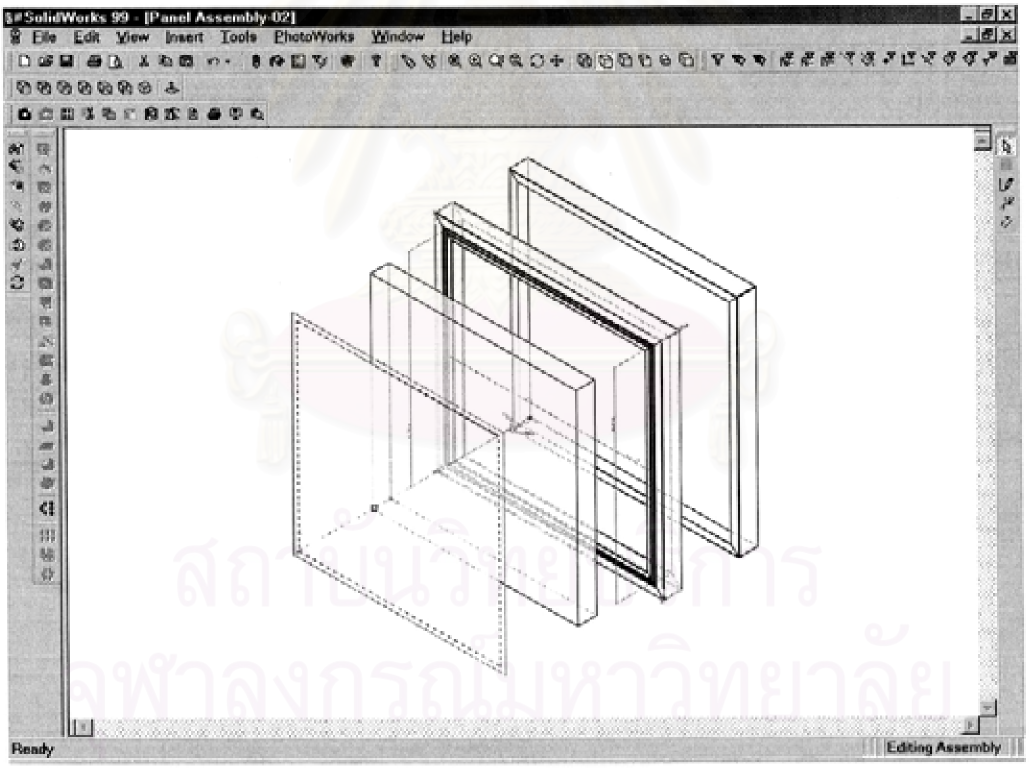


Figure 5.16 The exploded view of wall panel, from, front to back: internal sheet, insulation material, plastic profile and external sheet metal shell

Figure 5.16 illustrates the exploded view of the wall panels from the internal to the external. The plastic frame is inserted into the external shell and then the insulation is filled and covered by the inner sheet metal. The cut section of the panel is shown in Figure 5.17

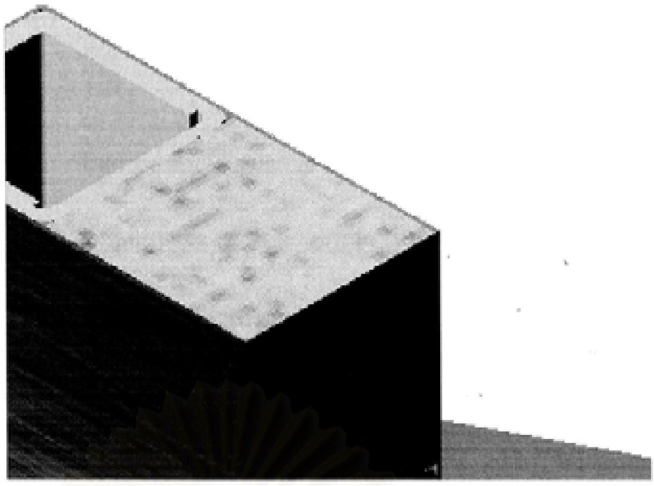


Figure 5.17 Cut Section Improved Design Wall & Floor Panel

Figure 5.17 illustrates the cut section of the wall panel and floor panel of the "Concept 4". The panel is filled with the insulation between the inner sheet and external shell sheet metal. The plastic profile shown in figure is inserted with the C-Channel steel profile to increase strength.

5.4.1 Technical Background of Heat transfer through the wall panel

Key technical background that concerns the design of the wall is the heat transferred through the wall. The wall must be able to minimize the heat transfer from the internal surfaces to external surfaces so that the external surface temperature shall not drop to dew point temperature. This shall protect the external skin of AHU from condensation. The goal of the design is to have the overall heat transfer coefficient (U) of the insulation not to exceed the 1.4 W/sq.m. /K within the 50mm thickness of the panel.

To calculate the heat transfer rate of the designed panel, following equation is used.

R_T = Overall thermal resistance of the panel

= $R_i + R_w + R_o$

R_i = Inside air film thermal resistance

R_o = Outside air film thermal resistance

R_w = Resistance of the construction from inside surface to outside surface

R_i = $1/h_i$

R_o = $1/h_o$

$R_w =$ $(x_1/k_1) + (1/C) + (x_2/k_2) + \ldots$

U = $1/R_T$

h_i , h_o = Inside and Outside heat transfer coefficient

x_1, x_2, x_n = Thickness of individual construction material

k_1, k_2, k_n = Material thermal conductivity

C = Air space conductance

U = Overall heat transfer coefficient

5.4.2 *Heat Transfer Trough Wall*

The overall heat transfer coefficient of the considering wall panel can be calculated by the following procedure:

<u>Case 1</u>

Wall panel is composed of materials and its thermal property as:

A: 2-mm thick galvanized sheet steel	k=46.7	W/m.K
B: 6-mm neoprene sheet insulation	k=0.036	W/m.k
C: 1-mm thick galvanized sheet steel:	k=46.7	W/m.K
D: 48-mm thick Wood edge profile area:	k=0.115	W/m.K
E: 1-mm thick internal galvanized sheet steel:	k=46.7 W/ m.K	

<u>Solution</u>

R_T = $R_i + R_w + R_o$

R_w = $R_A + (1/C) + R_B + R_C + R_D + R_E$

=(0.002/46.7)+(0.16)+(0.006/0.036)+(0.001/46.7)+(0.048/0.11)+ (0.001/46.7)

= .000043 + .16 +.167 + .0000215 + .436 + .0000215

= 0.76 sq.m. K/W

R_i = 0.044 sq.m. K/W

R_o = 0.11 sq.m. K/W

R_T = $R_i + R_w + R_o$ = 0.11+0.044+0.76 =0.917 sq.m. K/W

U = $1/R_T$ = 1/0.917= 1.09 W/sq.m. K

Conclusion

The panel design can achieved the U lower than 1.4 W/sq.m. K with the use of wood which have lower Thermal Resistance, if the plastic profile is used instead the U will be slightly lower.which can be proved in the following solution:

Case 2

Wall panel is composed of materials and its thermal property as:

A: 2-mm thick galvanized sheet steel	k=46.7	W/m.K
B: 6-mm neoprene sheet insulation	k=0.036	W/m.k
C: 1-mm thick galvanized sheet steel:	k=46.7	W/m.K
D: 10-mm thick plastic edge profile area:	k=0.023	W/m.K
E: 1-mm thick internal galvanized sheet steel:	k=46.7	W/ m.K

Solution

$R_T = R_I + R_w + R_o$

$R_w = R_A + (1/C) + R_B + R_C + R_D + R_E$

$=(0.002/46.7)+(0.16)+(0.006/0.036)+(0.001/46.7)+(0.01/0.023)+(0.001/46.7)$

$= .000043 + .16 + .167 + .0000215 + .434 + .0000215$

$= 0.76$ sq.m. K/W

$R_I = 0.044$ sq.m. K/W

$R_o = 0.11$ sq.m. K/W

$R_T = R_I + R_w + R_o = 0.11+0.044+0.762 = 0.916$ sq.m. K/W

$U = 1/R_T = 1/0.916 = 1.092$ W/sq.m. K

5.4.3 Final Design

After the satisfied design verification, Detail drawing of the wall and floor panel is generated. The designer will use the wood profile prototype since the plastic profile extrusion is costly and needed volume production

The external sheet and the internal sheet metal will be riveted to the wood or the plastic profile for securing the sheet and rigidity of the panel. Over the edge of the sheet metal, 50mm x 3mm section of the neoprene gasket is sealed around to prevent air leakage when secured the panel to the structure, and to prevent metal contact between the structure and the wall. On the other hand, the neoprene gasket sealed off the moisture that can be penetrated into internal insulation of the wall panel.

The self-tapered bolts and plastic bush is used secure the wall to the structure. The plastic bush is used to prevent the metal contact between the bolt and the wall panel. The bolt head is then covered with the plastic cap for thermal insulation, as show in figure 5.18

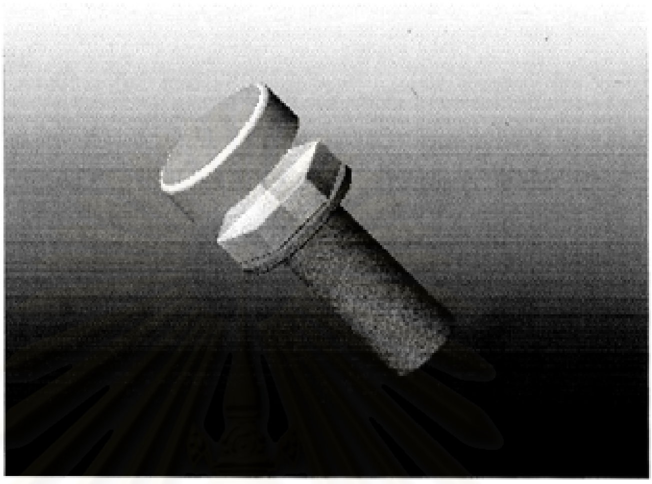


Figure 5.18 Cap-Bush & Bolt

The figure 5.18 illustrates the assembly of the bush, cap and self tapered bush that used to install the wall panel to the structure. In installation, the bush is inserted into the drilled hole on the wall panel. The bolt is tightened through the plastic hole and fixed the wall panel to the structure. There are no metal contact between the bolt and the wall panel since the plastic hole of the bush is worked as the metal contact guard. The only thermal bridge is the head of the bolt. Finally the plastic cap is capped to the head of the bolt to prevent the head of the bolt exposed to the external air. The cut section of the plastic bush, bolt and cap is shown in figure 5.19

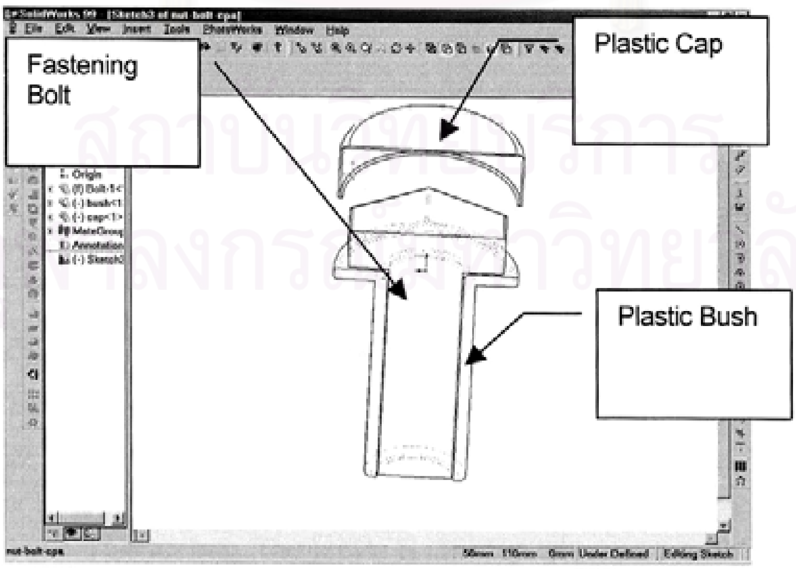


Figure 5.19: Cut section view of the plastic cap, plastic bush and bolt for panel fastening to the structure.

Figure 5.19 illustrates the cut section of the plastic bush, bolt and the plastic cap. The plastic bush will have the length slightly less than the wall thickness, which is designed at 48mm. When the wall panel is fully compressed by tightening the bolt to the structure the surrounding gasket at the structure will be compressed and filled in the gap and sealed the bolt end. The bolt area will be airtight and thermal bridge free. This design also allows quick access to the internal parts with simple equipment and hand tools for removing the wall panel and the AHU is easy to maintenance.

5.5 Service Door Panel

In some area of Air Handling Unit (AHU) machine's equipment that the technician frequently accesses for maintenance, the removing of the door panel is not a good solution. The access time is too long. The operation is inconvenient. The service door is the perfect solution for such requirements.

The service door must be airtight, to prevent any air leakage in or out the Air Handling Unit (AHU). Also it should perform like the wall panel in the thermal insulation. The door should be swing-out for the easy access. The hinges should removable for removing the door for long period of servicing.

5.5.1 Detail Design

The researcher and design team are working on several of the service door concepts. The cut section of the final design is shown in figure 5. 20

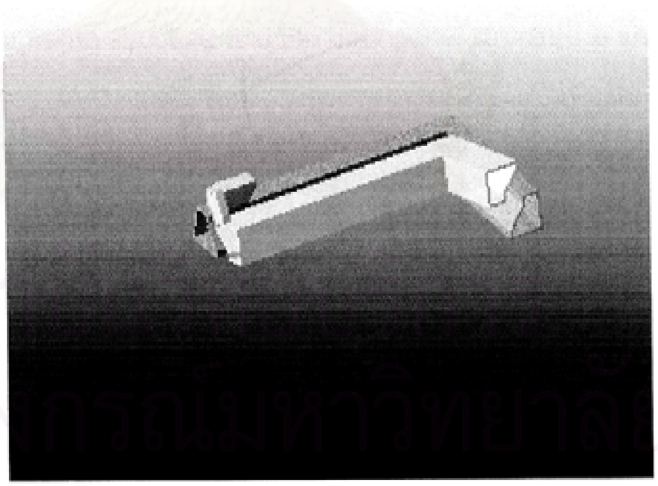


Figure 5.20: Cut Section Access Door Corner

Figure 5.20 shows the 45-degree self-support door edges are used as the major concept. The gasket, flat type neoprene is installed to the 45-degree area of door and frame for both airtight and the thermal insulation. Hinge is installed from external by screw into the profile structure. The profile is inserted between two sheet metals to form the hollow box, which filled with the insulation. The edges of door frame and door panel are insulated by gasket for improving the thermal insulation around the frame and also acted as the airtight seal. The sheet metal that served as the door internal and external panels are mounted to the doorframe by the same approach in mounting the sheet metal to the wall panel frame. No metal contact existing between the internal sheet metal and external. The assembly of the door panel and doorframe are illustrated in figure 5.21

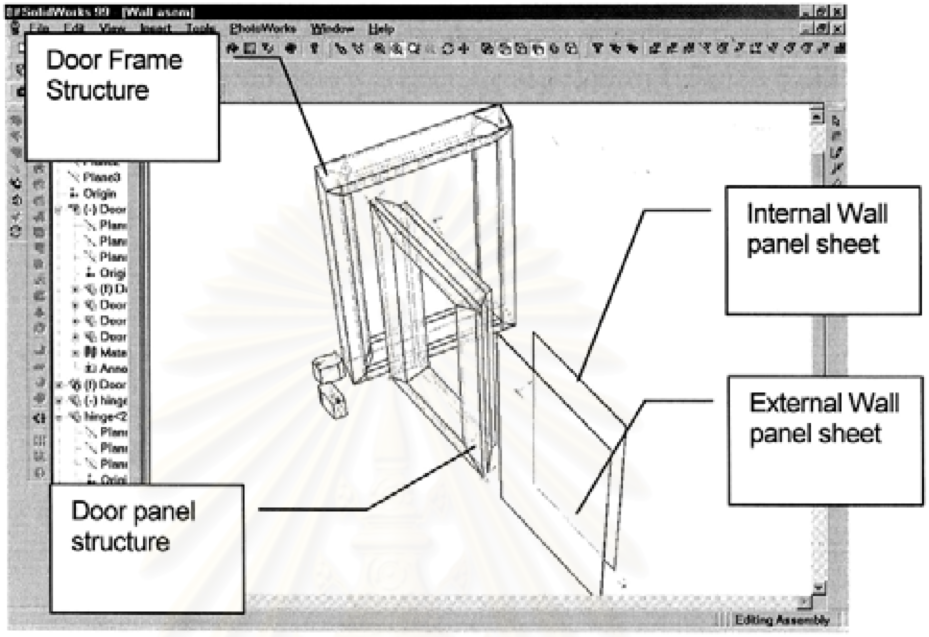


Figure 5.21: The exploded assembly of "Concept 4" door frame

Figure 5.21 shows the exploded view of the door panel and door frame assembly. The frame of the wall and door are the same extruded structure. The extrude plastic served as the door frame structure and the door panel structure is shown in figure 5.22

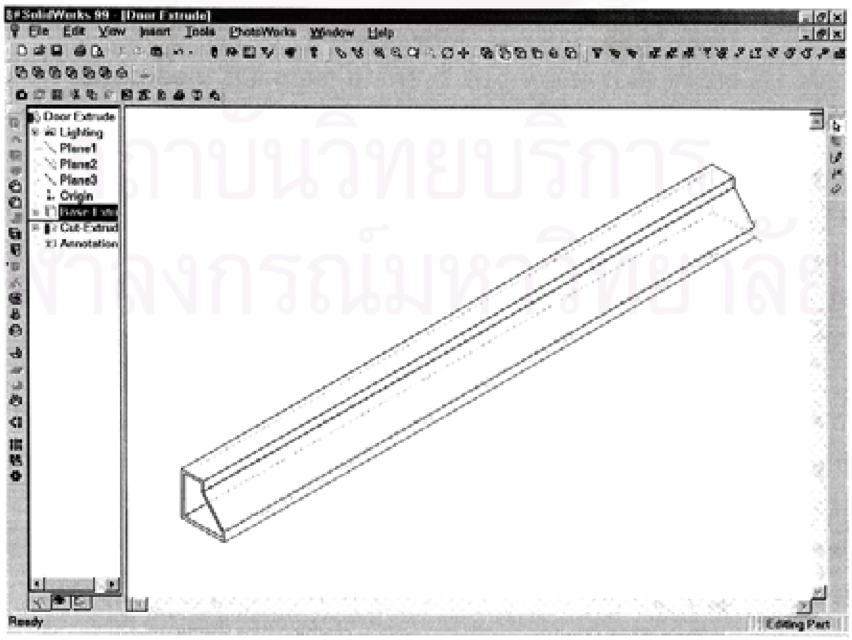


Figure 5.22 Plastic Extrude for door frame and door panel construction

From the figure 5.22 the plastic profile which served as door panel frame and door frame structure is displayed. The extruded frame is symmetrical so the wall edge and door edge can be placed over another on the 45-degree side. The doorframe is installed into the opening of the wall panel, which is prepared with the supporting profile. In small unit the doorframe can installed directly to the frame structure with the same method that used to install the wall panel. The door latch is accessed from external only. The complete assembled of doorframe and door panel is shown in Figure 5. 23

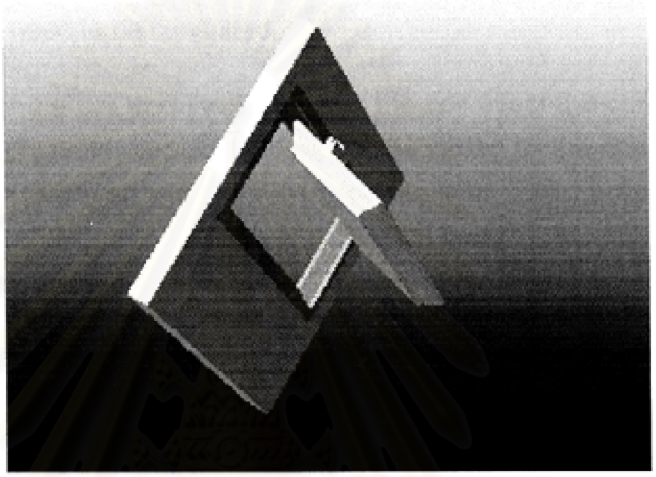


Figure 5.23: Complete Access Door Assembly

5.6 Coil Section

The heat exchangers in Air Handling Unit (AHU) are usually of the fin and tube type, commonly refereed as coils. It is the key component of the Air Handling Unit (AHU). Coils are used for air cooling and heating application with or without dehumidification application. But most of the chilled water coils in the Air Handling Unit (AHU) are both air dehumidification and sensible cooling at the same time. Despite the cooling function, coil also has the diversified function in air cleaning, odor adsorption or frost prevention application, by wetting the coil with the water or hygroscopic liquid. In the "Concept-4" coil selection, the researcher and researcher and design team will focus on the general comfort air conditioning, cooling, dehumidifying coil only. And the focused coils are the fin-tube cooling coils.

The industrial practice of coil manufacturing is using the aluminum sheet fin, continuous sheet over the height and depth of heat exchanger, spaced along the copper tube. Each fin is side by side laid together with the constant density of the number of fin per length called "fin pitch". In high corrosive operation environment, other material such as copper or coated aluminum may replace the plain aluminum fin. The fins are fixed to the tubes by the mechanical expansion to achieve good thermal contact with the fin collars. The copper tubes are circuited by the headers and return bend joints, which provide the flow and heat transfer at acceptable coil circuit pressure drop. All edge of the coil is bounded with the galvanized steel sheet for strong construction.

The header and the return bend are normally sealed to the tube by soldering, brazing or welding. In some case, particularly aluminum to aluminum joint of fin-tube, header, return bend, the special adhesive is applied instead of welding or soldering. Common arrangement in the industries four to eight tubes rows for chilled water coil. The common tubes outside diameter are 5/16, 3/8, 1/2, and 5/8 inch. The tube thickness or the tube material depends on the operating pressure and the hydrostatic burst pressure of the application. So, when designing the coils, standard, regulation and specific specification of customer need to be consulted.

The depth of the coil and the fin pitch of the coil effect the coil air pressure drop. The proper coil air pressure drop adjustment can be varied by the characteristics of fin-pitch of the coil, the fin pitch can vary from 4-18 fins per inch. Constructions of coil are different from one manufacturer to another depend on each design and application.

Form the recommended of American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), Good design chilled water coils should be based on following criteria:

- ✓ No air and water trap in the water coil circuit
- ✓ Water circuit can be fully drained by means of gravity during the off cycle
- ✓ Minimum pressure drop
- ✓ Equal feed and returned of each coil circuit by supply and returned header
- ✓ Coil circuit lengths should be equal
- ✓ Equipped with manual or automatic Air-Vent

5.6.1 Cooling Coil Installation in Air Handling Unit (AHU)

Coils in the Air Handling Unit (AHU) can be of drawn through coil type or blown through coil type, depended on the selection, design and application of each unit. The coils that used in the Air Handling Unit (AHU) are the standard coils that mass-produced. Variety of circuits, tube arrangements, tube heights, fin lengths and rows of the coil can be selected form catalogues to meet the engineering requirement on each coil application.

The requirement of coil installation for this "Concept 4" AHU design are:

✓ Drain Pan must be installed and extended to the downstream side

✓ The cooling coil height over 45 inches must be split and have the intermediate drain pan. The accumulated water form the top of the coil will block the lower part and the water may be blown out to the air stream.

✓ The cooling coil air face velocity over 600 FPM must have the water droplet eliminator on downstream side.

✓ Extending Drain pan along the direction of the air flow through coil should be at least equal to the one third of the coil height.

5.6.2 Coil performance & Rating

When selecting the coil for the system, coil must be tested to meet the ARI standard 410-87[1]. The air cooling coils are usually rated within following parameters:

✓ Entering air dry-bulb temperature: 65 – 100 °F

✓ Entering air wet-bulb temperature: 60 – 85 °F

✓ Air face velocity: 200-800 FPM

✓ Entering Chilled Water Temp: 35-65°F

✓ Water Velocity 1 –8 ft/s

5.6.3 Coil Selection

Coil selection should consider the following points:

1. Function Requirement of Coil, Cooling, Dehumidifying
2. Coil Capacity
3. Condition of the entering air
4. Cooing media and operating temperature
5. Space Limitation
6. Air Quantity and limitation
7. Allowable air friction resistance/ pressure drop

[1] ARI Standard 410-87, Forced-Circulation Air Cooling and Air Heating Coils

8. Allowable water friction resistance/ pressure drop

9. Installation Requirement

10. Characteristic of individual coil design

Gathered data are the input of the coil selection process. Today Air Handling Unit (AHU) manufacturers are using the computer software package for coil selection. The software packages are different from one manufacturer to others but the output should be approximated closed to each other.

Though coil is standardized for manufacturing in mass production, the variety of the coil capacity is in the large range. The factor concerning the coil capacity is very extensive. One change in particular factor will change the coil capacity. In designing Air Handling Unit (AHU) for this study, the researcher and researcher and design team should not be specific on the cooling capacity of the coil but rather using the common manufacturer standard capacities.

One coil can generate hundreds of capacity when varying the air velocity, the entering water temp and water flow. For example, the "concept-4" prototype size 3x3 that build for the test of this "Concept 4" double skin AHU design has following size limit.

Concept-4 unit 3x3 coil dimension limitation:

Coil Tube Height:	20	in.
Coil Fin Length:	44	in.
Row:	4	row
Fin Pitch	12	Fin/ inch
Entering Water Temp	44	°F
Entering Air Dry Bulb	80	°F
Entering Air Wet Bulb	67	°F
Air Flow trough coil	3500	CFM
Water Flow Rate	12	GPM

The coil selection software used in this study generated coil selection output as shown in figure 5.24:

```
TYPE FINS - ALUMINUM .006 INCHES
TUBE WALL THICKNESS  .016  INCHES

 EDB     EWB     EWT    SCFM     GPM    FPI  ROWS   TH     FL      FPM
80.00   67.00   44.00   3500.    12.0   12.    4.   20.    44.     458.

 LDB     LWB     LWT    WTR    APD    WPD   CIR   TMBH      SMBH     WFPS
61.16   59.61   57.96 13.96    .38     .5   B     83.94     72.11     1.0

60.44   58.91   59.19 15.19    .38    1.4   C     91.35     74.86     1.5

59.99   58.47   59.95 15.95    .38    3.0   D     95.91     76.58     2.0

59.44   57.94   60.88 16.88    .38    8.7   E    101.40     78.67     3.1

59.13   57.63   61.41 17.41    .38   18.8   F    104.56     79.89     4.1
```

Figure 5.24: The output of coil selection for sample of "Concept 4" AHU

From the coil selection output value in figure 5.24, one size of coil with fixed the coil tube height, fin length and the row depth, the coil capacity is varied by the coil circuit. The top four lines of the figure are the input condition that keyed in by the researcher, the computer generated the variety of coil circuit that have variety of coil capacity.

In designing the Air Handling Unit (AHU) coil is the variable parts that can be fixed only the size but not the capacity. So the opening area for the coil in the Air Handling Unit (AHU) is listed in following table.

Unit Size H \ L	2		3		4		5		6		7		8	
H	TH	FL	TH	FL	TH	FL	TH	FL	TH	FL	TH	FL	TH	FL
2	12	20	12	32	12	44	12	56						
3			20	32	20	44	20	56	20	68	20	80		
4					30	44	30	56	30	68	30	80	30	92
5							40	56	40	68	40	80	40	92
6									60	68	60	80	60	92
7											68	80	68	92

TH = Tube Height
FL = Fin Length

Table 5.3: Coil Size in Tube Height and Fin Length

From table 5.4, the unit sizes indicated by H: Height and L length is the cross section dimension of the AHU which the unit is in modules. The number of TH and FL at each module size coordinate indicate the maximum allowable of the coil Tube Height and the Fin length for this "Concept 4" AHU. The number is generated by assess the internal dimension of each unit size and the coil headers and the internal foil fixing components clearance is already taken for account.

5.6.4 Coil Slide in/Out structure

Another feature of the "Concept-4" is the coil sliding in/out capability and top removing capability for maintenance. Typical installation of air handling unit's coil is fixed to the structure. When replacing the old coil after running for several years, the unit structures are ribbed off. The coil changing is time consumed, labor intensive, and expensive. Because of the new concept of knockdown structure and easy access wall panel of the AHU's structure, the coil access can be faster. The knockdown structure allow the coil to be accessed and removed from the top by disassembled few removable structure. Also coil can be accessed from the access panel on both coil ends and removes by sliding out.

5.6.5 Condensation Drain pan

The independent Slide in/out Condensation Drain Pan is elevated over the lower structure edge and separated from coils. The drain pan can be easily removed by sliding out from either sides of the unit. The drain pan is constructed with the plate slope from one end to the other form a V grooved shaped as shown in figure 5.25.

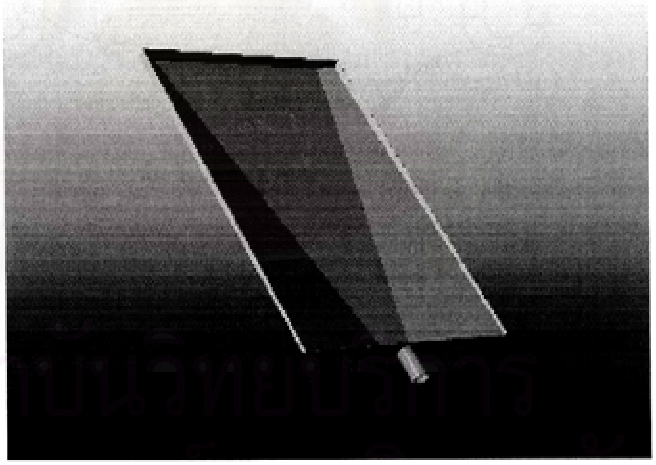


Figure 5.25: V-Grooved Sloped Drain Pan

The slope of the drain pan, which is elevated from the horizontal plane of the AHU floor and the height of the base structure, allows the drain pan to be completely dry during off cycle.

The drain pan's pipe is extended through the wall panel and tapped to the machine room drain system when installed. The proper trapping of drainpipe or "U-trap" to the drain pan should be carefully installed. The height of the U-trap level should be varied with the operating air pressure of the Air Handling Unit (AHU). The height (H) can be determined by calculating the differential pressure between inside and outside Air Handling Unit (AHU) under running condition plus a safety factor margin of 20% for the varying of pressure loss. Each 10 Pa (0.04 in. Water) of pressure equal to 1-mm height of the water column and equal to the (H) that the "u-trap" shall be installed. Depending on the position of the drain pan, either on suction (drawn through) or pressured (blow through) side of fan, the siphon has to be differently designed. The Failure to proper calculation may cause the flooding inside the Air Handling Unit (AHU). The U-trap height requirements are shown in figure 5.26

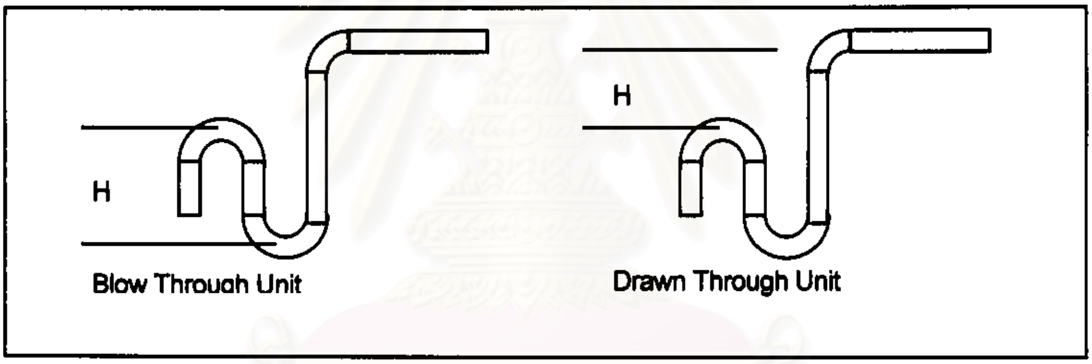


Figure 5.26: Drain pan U-Trap Connector

From the figure 5.26, the drain pans U-trap height requirement for blows through and drawn through unit are shown. H indicates the height required that could be calculated from the different pressure from inside and outside AHU.

5.7 Fan and Drives Section

Fan is the heart of the AHU, which carries the air passing through the chilled water coil to the air duct system. Four common fan blades in centrifugal fan are radial, forward-curved, backward-curved and air-foiled fan shape. The air enters the centrifugal fan in the center of the rotor and is accelerated by the rotation to the periphery. Air then leave through the blades in to the volute which transforms a part of the dynamic air velocity pressure into the air static pressure and directs it to opening of the fan outlet. Fan characteristic can be examined by the fan curves or fan diagrams.

Air volume and total pressure, of the fan will identify the operation point of the fan. On the fan curve, the operating point of the fan is dependent on the fan speed, air volume and total pressure lost. The head loss of the duct system and the internal losses of the air handler are added together to obtain the static pressure. Velocity pressure has to be included to the static pressure to obtain the total pressure.

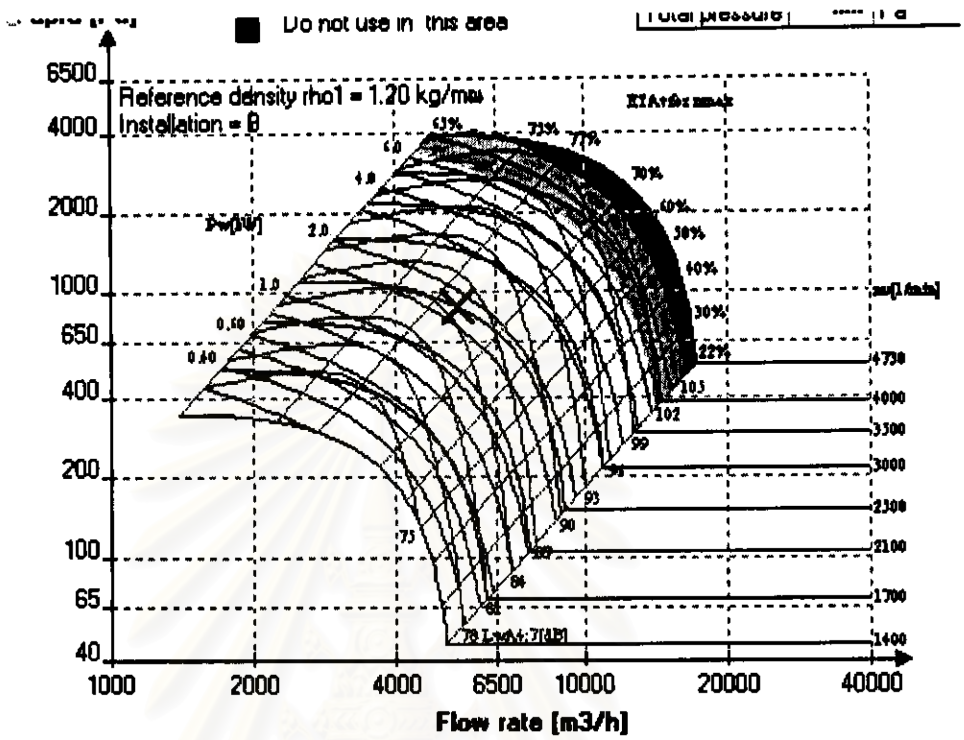


Figure 5.26: Fan Curve, Fan Diagram,

From figure 5.26 the fan curved of one fan supplier is illustrate. The mark X is shown the operation point of the fan, which the flow rate is at 5000 m^3/h at 800 Pa total pressure. The fan is operating at the rotation speed of 2500 rpm with the power on fan shaft requirement of 1.8kW. The sound level at operating point is at 86 dbA.

If the revolution of the fan is not modulated simultaneously, the operation point will travel along the fan curve with the specific revolution, thus resulting in a change of air volume. The steeper the fan curve the less is the deviation in volume, which is the typical characteristic of backward-curved blades.

Another advantage is the fact, that fans with backward-curved blades do not tend to absorb much more power when the total pressure drops., whereas fans with forward-curved blades do (a higher safety factor should be applied). Besides, backward-curved blades can achieve a better efficiency. The forward-curved fan is the common for the low static pressure application of air conditioning systems. Airfoil or backward curved fan is used in high-static pressure or high volume application on its efficiency advantages and lower sound level. In contrast, forward curved blades require less fan speed and are therefore at low air volume and low static pressure requirement it performed quieter and cheaper system.

5.7.1 Technical Background, Power, Efficiency and Fan Law

The power of the fan is equal to the power to raised the pressure and the power required to provided kinetic energy to the air, which called ideal power

$$\text{Ideal Power} = P_{\text{ideal}} = Q \times (p_2 - p_1) + (m V^2/2)$$

Where

Q	= Volume rate of flow (m^3/s)	
m	= mass rate of flow (kg/s)	
p_2-p_1	= Pressure rise, Pa	

The fan efficiency is determined by dividing the ideal pressure of the fan, by the actual measured fan power.

$$\text{Efficiency} = \text{Ideal Power/ Actual Power}$$

Another technical knowledge that needed in selecting the fan for Air Handling Unit (AHU) is the Fan Law. The fan law is the relationship of the fan performances. It identifies the effect of one performance changing to another. The fan law that is useful for application selection is the fan law that focus on changing the following condition:

Volume rate of flow: Q	cu.m. / s.
Rotative speed, : ω	rad/s
Air density: ρ	kg/ cu.m.
Static pressureIncrease through fan: SP	Pa
And Power required by fan: P	W

The laws are applied to constant systems that the duct and fitting have no change. The sign "~" and "∝" are representing "varies as"

Law 1:

Vary ω, Fix ρ

$$Q \propto \omega$$

$$SP \propto \omega^2$$

$$P \propto \omega^3$$

Law 2:

Vary ρ, Fix Q

$$SP \propto \rho$$

$$P \propto \rho$$

Law 3:

Vary ρ, Fix SP

$$Q \sim \frac{1}{\sqrt{\rho}}$$

$$\varpi \sim \frac{1}{\sqrt{\rho}}$$

$$P \sim \frac{1}{\sqrt{\rho}}$$

Those three laws are useful in the ability to predict the effect of the change in the fan condition.

5.7.2 Effect of Fan installation Location

Another factor that needed to be taken into account is space between the fan casing and the wall panel, which will influence the performance. The location of the inlet to the fan chamber can give a pre-rotational effect to the airflow. Protection grilles, belt guards, equalizers etc. will block the airflow path, which can reduce the fan performance. The distance of the casing enclosure wall to the fan inlet will have the effect on the fan performance. The effect is called blockage loss. The ratio of the wall distance to the fan diameter (=fan size) is used to determine these blockage losses. For ratio < 1 the air volume is reduced, thus the fan speed has to be increased to equalize this effect.

5.7.3 Fan, Motor and Drive Selection

In old days, the tabular and charts are used to select the size, speed and power required of the fan. Fan manufacturer will provide their fan performance curves for the design engineer so the proper fan size, drive speed, drive power can be determined. The information that required for fan selection is:

- ✓ Type of Fan that need to select
- ✓ Air Flow Rate
- ✓ Total Pressure or Total Static Pressure required for the systems

With operation ranges of the fan, size of the fan shall be determined by using the fan curves or fan diagram provided by the fan supplier. Other fan performance value, such as power consumption, noise level, driving speed shall be taken into consideration and the most suitable fan for the systems can be selected. Typically, in this "Concept 4" AHU fan selection researcher focus on selecting the fan that have lowest power consumption for general purpose Air Handling Unit (AHU), but in specific application sound and noise level are also used as the main selection criteria.

After selecting the fan from the fan characteristic diagram, the power input to the fan is calculated by multiplying the air volume with the total pressure and correcting by the fan efficiency. The motor must be always chosen to have a capacity larger than the calculated input power to the fan by taking into account of safety factor for variations and transmission losses. If all pressure is calculated accurately a safety factor of 1.1 for backwards curved fans and a safety factor of 1.2 for forward curved fan is minimum.

Then design engineers need to consult with the motor suppliers for selecting proper size of motor and drives to meet the fan power consumption. If the fan is belt driven, the design engineer need to work with the pulley and belt suppliers for determines the proper sizing of the belt, type of belts, size of pulleys and number of grooves required to satisfy the motor power transmission to the fan. Those fan-motor-drive selection processes take some times for completion.

The advancement of the computer technology eases the fan-motor-drive selection process. Large Fan suppliers develop the selection software for helping the design engineers select fans motors and drives in minutes. The input data for fan selection software is the same as manual selection. The ranges of the usable fan is then shown and compared. Software also recommended the best in the class fan that use the power consumption and noise level being used as the chosen criteria.

After selecting the fan, the software is automatically calculated the required size of motor, which can be varied by its poles and voltages requirement. Also the belt drive selection can be performed. In drive selection the estimated bearing service lifetime is calculated base on the torque applied to the bearing and speed of bearing. The printout selection will contain all fan technical data, curves, motor, drives and the drive-tensioning requirement for the selected fan at the given operating point.

5.7.4 Fan sizing for the Concept-4

In specifying the fan size for the Air Handling Unit (AHU), designer cannot explicitly point out the fan capacity easily, due to the variation of the pressure loss that then fan has to overcome in systems and also multiple configuration of fan can be specified by customers. In practice, the rated fan capacity of each unit is based on the 500-fpm (2.5 m/s) coil face velocity. For "Concept 4" AHU the fan selection is made on all

23 models on the average 500-fpm (2.5 m/s) coil velocity and at the operation static pressure of 750Pa

For example of fan selection for "Concept 4" fan selection the GebhardtVentlatoren™ ProSelectra™ fan selection program is used.

The fan operating conditions for fan selection example are listed as follow:

✓ Air Volume Required	3500 CFM (6000 m3/h)
✓ Static Pressure Required	3 in. WG. Or 750 Pa
✓ Fan Type	Backward curved double inlet , belt drive

The output of the Fan Selection Software is printed out for the example calculation. The whole list of detail, fan curve and fan drawing are shown in figure 5.28 which required 5 pages length.

Fan Selection Software Output: Backward Curved Fan

Specification: RZR 12-0355

High Performance Centrifugal Fan Gebhardt rotavent

Double inlet belt drive.
Lap jointed scroll of galvanised sheet steel with discharge flange and rectangular, angle side frames.
High performance impeller with 12 hollow section true aerofoil blades inclined obliquely to the shaft axis, welded in postion and painted.
Throat plate inclined obliquely in opposition to blade incination ! Inlet cones matched to the impeller reduce entry losses to a minimum. Impeller and shaft balanced as an assembly to Grade G 2,5 (DIN ISO 1940).
Shaft accurately trued and ground and machined at both ends to accept pulleys of standard diameters in accordance with DIN 748.
Noise tested maintenance free, radial insert ball bearings mounted in pressed steel housing/strut assemblies with rubber inliners.
Performance data to DIN 24166 Class 1 (BS 848 Class "A")

Liste of articles

Quantity of fans : **1**

Number	PartNo.	Designation		
1	24010	RZR 12-0355		
1	17555	Motor manufacturer : Siemens	100La-4	2,2 kW
1	31390156	Drive		

Fan Selection Software Output: Backward Curved Fan

Technical data

... for fan: RZR 12-0355

Installation acc. to DIN 24 163 part 1	:	A	
Flow rate (V)	:	6000	m3/h
Total pressure (dpt)	:	814	Pa
Dyn. pressure (pd2) at intake	:	64	Pa
Static pressure (dpfa)	:	750	Pa
Pressure losses (pv) at discharge	:	0	Pa
Reference density (Rho1)	:	1.20	kg/m³
Temperature t of the gas (t)	:	20	°C
Speed (n_V)	:	2045	1/min 1).
Power on shaft (Pw)	:	1.68	kW
Efficiency (ETA_t)	:	81	%
Fan weight	:	36	kg
A-Sound power level $LwA_{6;7}$	:	82	dB

1). *Fan speed tolerances of ±4% may occur when calculating the belt drive. This may cause technical data being slightly different to the values above.*

	63 Hz	:	81/80	dB
unweighted	125 Hz	:	78/83	dB
Octave sound power level	250 Hz	:	79/80	dB
acc. to discharge/intake	500 Hz	:	80/79	dB
$Lwokt_{6/7}$ at	1000 Hz	:	75/76	dB
Octave band frequency	2000 Hz	:	69/74	dB
	4000 Hz	:	65/68	dB
	8000 Hz	:	57/62	dB

... for motor: 100La-4

Size	:	100La-4	
Speed	:	1420	rpm
Power	:	2,2	kW
Voltage/Frequency	:	400/690/50	V/Hz
Electric current	:	4.9/2	A

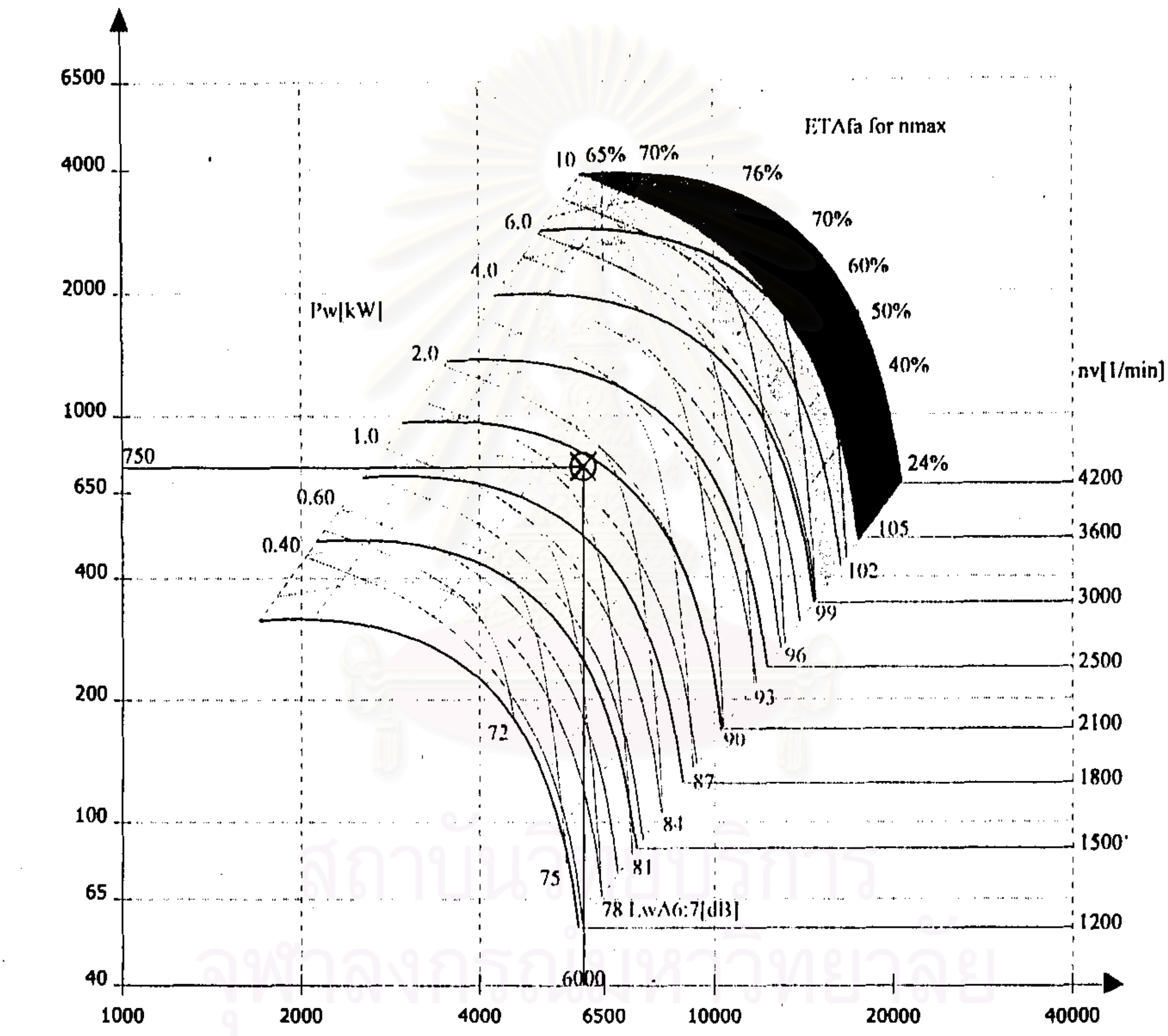
Fan Selection Software Output: Backward Curved Fan

Fan curves: RZR 12-0355

Basis:

Reference density (Rho1) : 1.20 kg/m³
Install ....: A

Stat.pressure [Pa]



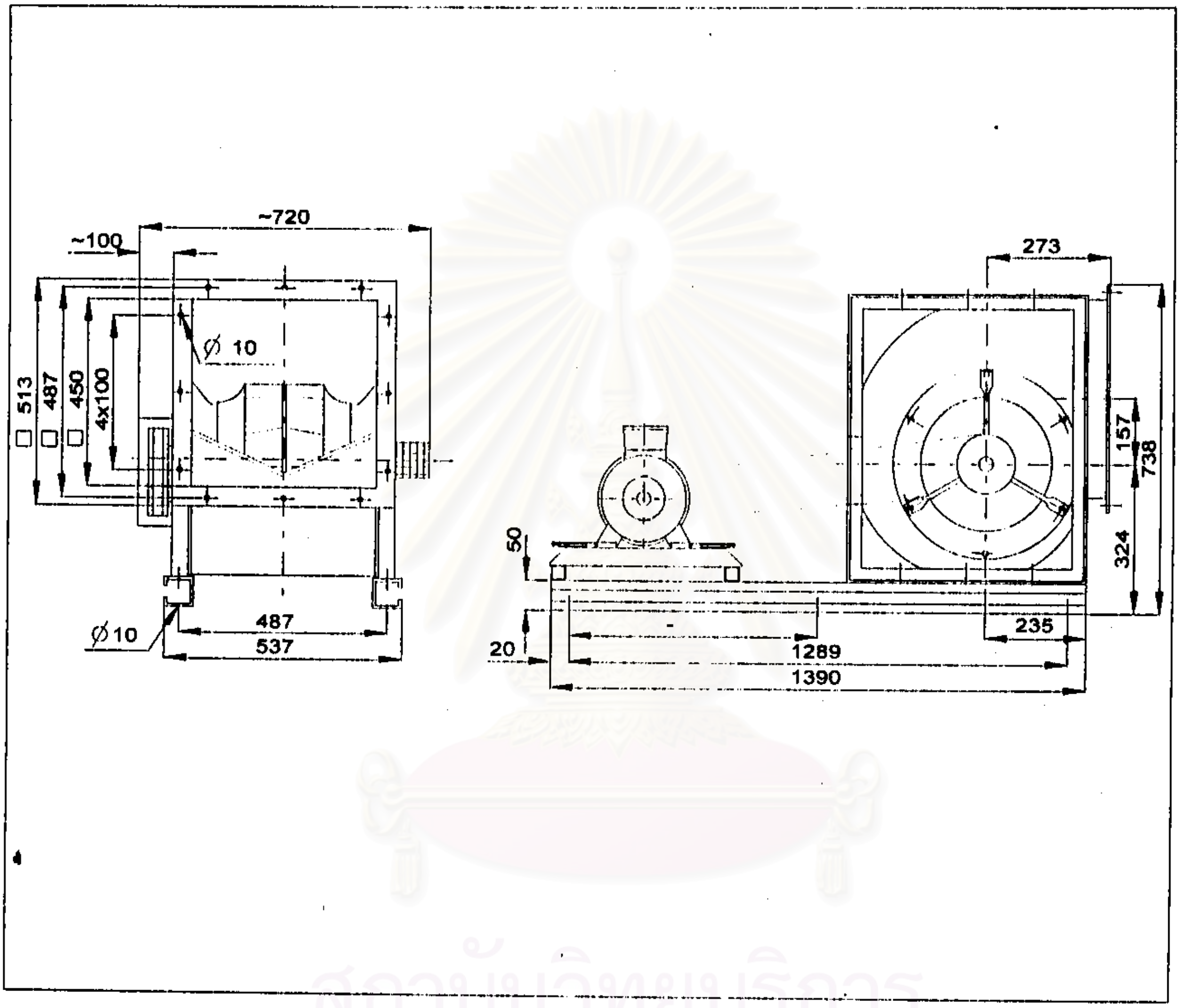
Flow rate [m3/h]

RZR 19- ... only

Do not use in this area

Fan Selection Software Output: Backward Curved Fan

Fan Dimensions: RZR 12-0355



Motor fitted to : Base frame

Rotation /Handing : RD/90/G

Fan Selection Software Output: Backward Curved Fan

Customer .. : **Thesis**	Order-No .... :	Date of order : **11.05.2000**
Reference .. : **Thesis**	Order confirmation No :	Made .... : **12.05.2000**
Remark ..... :		Name .... :

Technical data of fan, motor and drive

Fan: RZR 12-0355

Number 1

Installation acc. to DIN 24 163 part 1: A
Flow rate (V) .... : 5868 m3/h
Total pressure (dpt) .... : 779 Pa
Static pressure (dpfa) .... : 717 Pa
Reference density (Rho1) .... : 1.20 kg/m³
Speed (nv) .... : 2000 1/min
Power on shaft (Pw) .... : 1.57 kW

Rotation/Handing .... : RD/90/G
Rotation/Handing .... :

Motor

Number 1

Status/Id-Nr .... : Scope of supply/17555
Manufacturer .... : Siemens
Designation .... : 1LA7 106-4AA60
Size .... : 100La-4
Execution .... : B3
ISO Class .... : F
Protection .... : IP 55
Remark:

Speed .... : 1420 rpm
Power .... : 2,2 kW
Voltage/Frequency .... :400/690/50 V/Hz
Electric current .... : 4.9/2 A
Efficiency .... : 80 %
Power factor .... : 0.82

Belt Drive

Number

Fan pulley

1

Diameter .... : 71 mm
Profile .... : SPZ
Grooves .... : 2
Id-No. .... : 16135

Bush .... : 1108
Bore .... : 24 mm
Id-No. .... : 13978

Motor pulley

1

Diameter .... : 100 mm
Profile .... : SPZ
Grooves .... : 2
Id-No. .... : 16147

Bush .... : 1610
Bore .... : 28 mm
Id-No. .... : 13996

Be eware of pulley supplier´s balancing quality!

V-belt (assorted)

2

Profile .... : SPZ
Centre distance .... : 715 mm

No of sets .... : 1
Effective length .... : 1700 mm
Id-No. .... : 16249

Tensioning of V-belt

Test force .... : 8 N

Pressure-depth per belt .... : 11 mm

The test force indicated has to be checked after running in of the drive. New belts have to be checked after app. 0,5 to 4,0 hrs of operation.

Belt guard R9

1

Id.No. .... : 55428
Ø = 70 mm L = 725 mm

Remark:

Figure 5.28 Example of fan selection output

From determining the maximum fan size allowable to be installed into the AHU by the researcher, table below shows the maximum fan size allowable and the position of the motor for belt driven.

Table 5.4. Maximum Fan Size and Motor Alignment

Unit Size		Maximum Fan Size	Motor Positioning	Fan Module Length	
				Horizontal Discharge	Vertical Discharge
2	2	250	Back	3	3
2	3	315	Back	3	3
2	4	315	Back	3	3
2	5	315	Back	3	3
3	3	355	Back	3	3
3	4	355	Back	3	3
3	5	450	Side	3	3
3	6	450	Side	3	3
3	7	450	Side	3	3
4	4	450	Back	4	4
4	5	500	Side	3	3
4	6	630	Side	4	4
4	7	630	Side	4	4
4	8	630	Side	4	4
5	5	500	Side	4	4
5	6	630	Side	4	4
5	7	800	Side	5	5
5	8	800	Side	5	5
6	6	630	Side	4	4
6	7	800	Side	5	5
6	8	900	Side	5	6
7	7	800	Side	5	5
7	8	900	Side	5	6

Fan Module Length is base on the largest fan size, shorter module can be obtain from smaller fan size

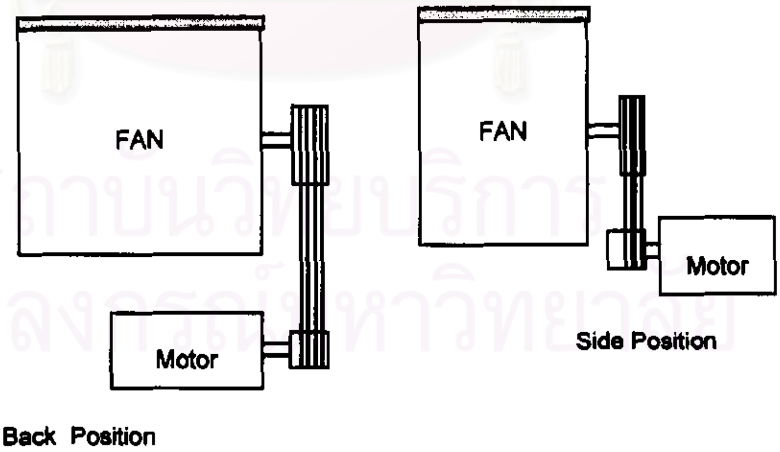


Figure 5.29 Motor Position Alignment Position

Figure 5.29 the motor-fan installation diagram. Two motor positioning is used in this "Concept 4" design, the back installation and the side installation.

5.8 Filer Section

The air quality is the major problem of all HVAC application. Worldwide increased in air pollution developed the concern of air cleanliness level. HVAC engineers are working to improve the indoor air quality in the buildings and factories. Hence, The double skin Air Handling Unit (AHU) is a part of solution in making the air cleaner. The double skin Air Handling Unit (AHU) provided the feature that minimal dust being generated from the structure. In order in make the Air Handling Unit (AHU) supply better air quality, various types of air filtration components are selected and installed into Air Handling Unit (AHU) to remove the unpleasant and polluted dust particle.

The effect of the air pollution created not only causes danger to health but also can cause a wide variety of problems in the industrial production. Thus, the HVAC systems in the facilities need to be proper designed. The proper selection of air filter that meets the specific environmental requirements is the key to reduce the dust and gas pollution. Hence, the air filter has ranges of efficiency and functions, the Air Handling Unit (AHU) must be designed to cope with all air filtration installation requirements.

In designing the Air Handling Unit (AHU), we build the modular section that coincident to the dimension of the filter modular size. For the low efficiency, the modularity is not important since the cost of made to order filters and standard size filters are not significantly different. In high-efficiency-air-filter requirement, the air filter manufactures produce the limited standard sizes, which common nominal sizes are 305x610mm (12"x24") and 610x610 (12"x12"). The non-standard air filter is very expensive and if the air handling unit design do not take the filter modularity in to consideration, the cost of the filter components will be very expensive. Filter service life is short and the filter is needed the most maintenance, the Air Handling Unit (AHU) design should concern about air filter changing or cleaning.

For the air filter selection for Air Handling Unit (AHU) the researcher and researcher and design team need to understand the nature of the dust particle, the method of measuring filter efficiency, filter service life and the filter energy consumption.

5.8.1 Technical Background

Various particle types and sizes pollute the atmosphere, which it is a circulated system consisting of a mixture of finely distributed solid or fluid particles. The types of the pollution particle of dust and mist can be distinctively separated by its property.

The **Dust** is the solid particle, which is settled out of the air. According to dust sizes the dusts settling is happened faster or lowers. Dust can be divided into three groups: *Coarse Dusts* have particle size ranged from 10 to 500 microns. *Fine Dusts* have the particle size ranged from 1 to 10 microns. The *Aerosol* is the dust with size less than 1 micron, which is difficult to settle. This type of dust is also called "Fume" The dust particle that ranged from 0.5 to 5 micron is the "Lung Damaging Dust".

The **Mist** is the distribution of the fluid substance in the air. It generally composed of drops with a diameter between 0.5 to 100 microns.

The size distribution of normal atmospheric particle: the proportionate weight of the particle size less than 1 micron is only 25% of the total particle weight but it takes the 85% of the volume, when counting the number of particle at less than 1 micron size 99.99% is obtain.

When assessing the quality of the air filter following criteria should be considered: Airflow Rate, Pressure Drop, Separation Efficiency, Efficiency test method, Service Life and Price.

The pressure drop of the air filters is depended on the air filter medium, and the filter media air velocity. When assessing the air filter of the same size and efficiency, the initial pressure (clean filter) drop at equal airflow rate should always be compared.

The Separation efficiency can determine and rated by following method: Penetration, Decontamination and Efficiency. Efficiency is commonly used and can be calculated from:

$$\textbf{Efficiency} = \quad n \quad = \frac{\textbf{(Inlet Concentration-Outlet Concentration)}}{\textbf{Inlet Concentration}}$$

The test methods of filter are measuring the concentration of particle at various points and calculate the efficiency. In the efficiency designation, the test method must be specified e.g. by particle weight, by number of particle or others to obtain the reliable and comparable efficiency. The particle separation efficiency of the air filter is due to various physical effects. The known individual separation mechanisms of air filter are *Diffusion Effect, Blocking Effect, Inertial impaction effect, Sieving effect, Electrostatic effect, Thermal Effect and Sedimentation effect.* The detail of the separation effect can be found in the NAFA[2] book "Guide to air filtration system[3]"

The air filter service life cannot be directly calculated but can be approximately determined through the historic records of the previous air filter statistic. The service life can be compared between two air filter types or systems by following formula:

[2] National Air Filtration Association, USA
[3] NAFA, Editorial, "Guide to air filtration systems", 1993 DC, USA

$$S1 = S2\ (F1/F2)^2$$

Where S1 = service life of comparing filter

S2 = service life of referenced filter

F1 = surface area of the filter media of the comparing filter

F2 – surface area of the filter media of the referenced filter

Energy consumption of the air filter pressure should not be taken for granted. The final pressure of the filter should not be selected too high as the power consumption rises and the air volume declines. Formula for extra power consumption Pe:

Pe =V*dp*h/(n*1000) in kW/hr

where
V = Air Volume in m3/s
h = Operating Hours
dp = Pressure Loss Difference
n= Fan and Motor Efficiency

5.8.2 Filter Selection: Suggestion to select a filter: Do and Don't

Do use roughing filters upstream to prolong the life of expensive high efficiency filters.

Do provide a manometer across each filter bank to determine when the filters should be changed.

Do make sure that air cannot by-pass the filters- a filter is only as good as it's holding arrangement.

Do fit access doors and allow sufficient clearance to ease filter changing.

Do select filters carefully when variable air volumes are involved. Too low face velocity can jeopardize the effectiveness of certain filters.

Do look at dust holding capacity as a means of comparing filters.

Do provide weather louvers with screens.

Do locate absolute filters within an AHU downstream of the fan section to prevent the inward leakage of unfiltered air that would result in loss of overall efficiency.

Don't site filters to close to steam humidifiers or similar devices, which may impinge, water droplets onto the media.

Don't overrate filters beyond the manufacturer's recommendations.

5.8.3 *Filter Selection: Application*

For proper application selection, the air filters supplier providing following guideline for the HVAC designer.

Applications	**Suggested EU Grade**
General Factory Areas	EU2
General Office Areas	EU3
High Grade Office Areas	EU6-7
Computer Rooms	EU4-7
Hospital Wards	EU6
Hospital Operating Theatres	EU8-10
Retail Stores	EU5-6
Food Factories	EU6
Pharmaceutical Manufacturing Areas	EU8-11
Restaurants	EU5
Airport Terminal Building	EU6
Leisure Centers, Swimming Pools	EU5
Theatres, Concert Halls, Cinemas	EU7
Hotels	EU 6
Exhibition Centers	EU6
Museums, Art Galleries	EU8
Schools	EU5

The EU Grade is base on the standard Eurovent 4/5, please refer to the Appendix 7 for filter efficiency conversion table.

There are also the gas-range filters, which can to adsorb various gases. Gas filters are using same installation approach in Air Handling Unit (AHU) and the detail is not focused.

5.8.4 *Filter Section Design*

In designing the air filter section, the Air Handling Unit (AHU) researcher and design team need only to determine the depth of the module required and how to install the filter holding frame to the Air Handling Unit (AHU) that can be easily accessed for each type of filter.

Most of the case the Air Handling Unit (AHU) is installed with the upstream filter section. Only high efficiency air filter is installed in the downstream. In practice the filter can be accessed through the service door at the mixing box section, for one stage of filter holding frame.

In case of multi-stages air filter, the Air Handling Unit (AHU) should provide the air filter section with access door, the minimum distance between two filter section is determined by the size of the air filter plus the area for service the filter. Recommend service area between two filters is 50 cm while the recommend door opening width at 60-cm minimum. In case of small size air handling unit, the area should be slightly larger.

The filter section that used in the Concept-4 is installed in full cross section area at return end of AHU. The filters installed are the 50mm, EU4 +300mm depth EU7 filter in one filter holding frame.

The cross section filter module arrangements for all 23 unit of Concept-4 are:

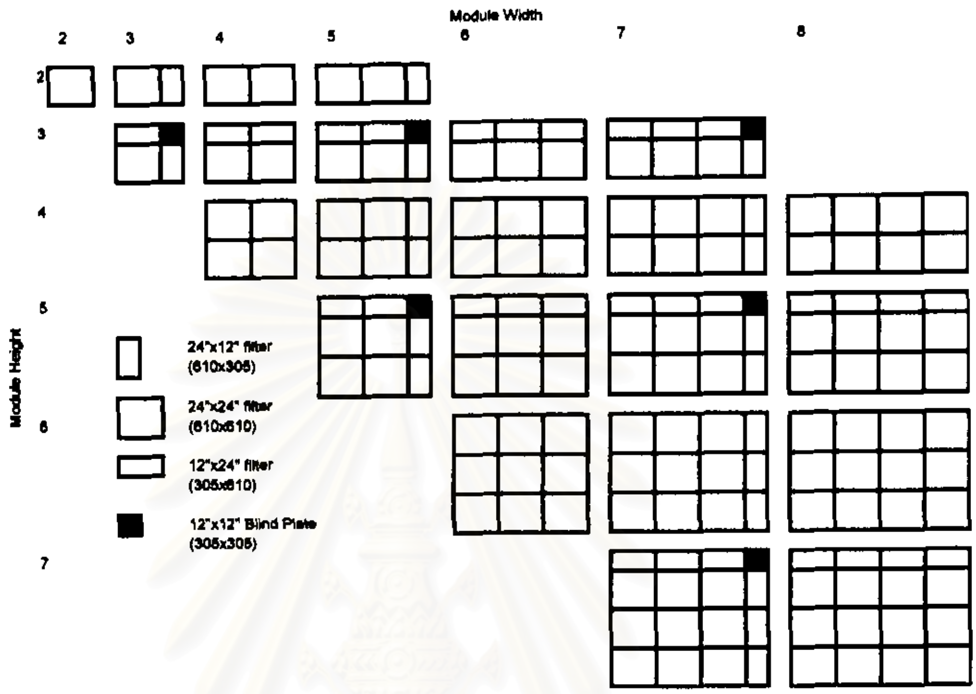


Figure 5.30 Filter Arrangement

From figure 5.30 the vertical axis represents the height of AHU and the horizontal axis is the width of the AHU, all unit in modules. The figure shows the standard size filer arrangement. The standard size filer are 12"x24", 24"x24", 24"x12" and the Blind Plate size 12inchesx12inches that used to block the bypass air stream.

5.9 Mixing Box and Dampers

The mixing box and dampers are the sections of the Air Handling Unit (AHU) that mechanically control and balance the air. The damper is the equipment that design to reduce the open area of the duct, thus, the air resistance is increased and the air volume is changed.

There are two types of damper, the opposed blade and parallel blade that named after its configuration. The opposed blade damper is commonly used in the industries due to its capability to control the volume of the air, more linearly. Various designs and configurations of damper blade are available in the market. Damper can be operated manually or automatically upon the customer demand. The design of the common used damper at mixing box are the two way damper, that introduce the fresh air and return air to the mixing box. There is one significant technical consideration on the limitation of selecting the damper: the damper air velocity.. Some supplier claimed the maximum air velocity across the damper up to 15 m/s but the maximum allowable damper air velocity should be 6 m/s due to the noise level limitation. Damper pressure drop should be also taken for consideration on calculating the total system pressure drop.

In the Concept-4 Design, if the return air that entering the Air Handling Unit (AHU) comes from the duct and AHU is in the warm machine room environment or on the roof top, the internal damper is recommended to avoid the condensation on the damper.

The damper also sized in modular for easy of selection and listed in table 5.5 below:

Damper Size

Damper Module Width	2		3		4		5		6		7		8	
Damper Module Height	H	L	H	L	H	L	H	L	H	L	H	L	H	L
1	227	532	227	837	227	1142	227	1447	227	1752	227	2057	227	2362
2	532	532	532	837	532	1142	532	1447	532	1752	532	2057	532	2362
3			837	837	837	1142	837	1447	837	1752	837	2057	837	2362
4					1142	1142	1142	1447	1142	1752	1142	2057	1142	2362
5							1447	1447	1447	1752	1447	2057	1447	2362
6									1752	1752	1752	2057	1752	2362
7											2057	2057	2057	2362

Table 5.5: Damper Size for "Concept 4"

Table 5.5 shows the dimension of the standard damper size that used in the "Concept 4" AHU. The damper height in module is on the vertical axis shown number 1 to 7. The damper module width is located on the top row on horizontal axis. The coordinate of the damper module will show the exact dimension of the damper frame. H and L indicate the height and length of the damper frame that used to installed in the "Concept 4". This H and L dimension are used to indicate the damper size for order the damper for the supplier.