

## **Chapter 4**

### **Product Design Improvement Using QFD approach Part-2**

This chapter will describe the process of product design improvement by using the QFD approaches start from concept design. The detail of each concept design is discussed and finally one of the four candidate concept designs is selected for detail design.

#### **4.1 Concept Design**

Concept design is the first step that the researcher and design team develops the visualized idea of AHU from the guidelines and requirements. The AHU guidelines and requirements are the results from previous chapter "Substituted Quality Characteristics", Proposed Function, and the result from QFD Matrix A3. Concept design is one of the important processes in AHU design development.

The design concept generated is the vital information that works as the controlled guideline and boundary of the AHU detail design. If the AHU concept is not properly selected at the first time, the product will be designed in the wrong way. Final design will not meet the customer demand and the whole design process must restart again.

The researcher and design team should bear in mind that good concept design process must be guided with the boundary of the customer requirements. The creativity of the designer if properly guided with the customer demands will generate the good-quality product design. If the researcher and design team does not concern about the customer expectation on AHU, the designed AHU tend to miss the customer's expectation the product will not success in business. Hence, the concept design is very important, the researcher and design team should find the proper approach to guide the concept generation without limiting the creativity of the designer.

Quality Function Deployment (QFD) is one of many approaches that available in design technology and tools. In this AHU design development QFD is already selected and used to transform the "Customer Demands" into the key "Substituted Quality Characteristics". Also the design references and guidelines that generated from the QFD Matrix A1, A2 and A3 is prepared for further concept design generation. The AHU design guidelines and boundary that generated from the previous QFD process will be the vital information to the designer for AHU concept generation. Furthermore, QFD will be used as the concept design selection tools. The selected concept design will be passed to detailed design to produce the AHU prototype.

## 4.2 Concept Generation for Air Handling Unit (AHU) design improvement

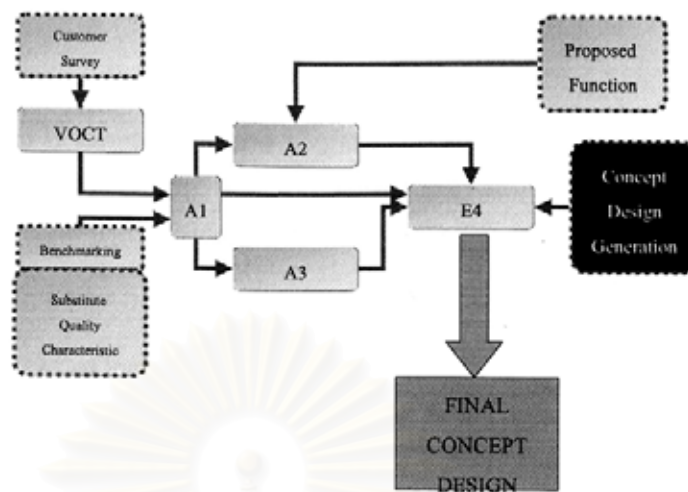


Figure 4.1: Quality Function Deployment (QFD) process flow, Concept Generation

Figure 4.1 illustrates the current step that the design that AHU researcher and design team is approaching. At this step of AHU design improvement the design guidelines that taken from QFD Matrix A1, A2 and A3 is used.

After the first part of Quality Function Deployment (QFD) is finished, the researcher and design team now equipped with the design guidelines that set by following data:

- ✓ Key Substitute Quality Characteristic
- ✓ Key Design Prioritys
- ✓ Key Product Functions
- ✓ Substitute Quality Characteristic Interrelationship (Matrix A3: Appendix 6)

Generated design guidelines are used by the researcher and design team to control their creativity. The design guidelines also shown the researcher and design team the opportunities to make the improved AHU outstanding among competitors in market. Concepts of AHU design improvement are generated under the responsibility of the researcher and design team. All generated AHU design improvement concepts are candidates for design selection process. In order to select the "Best in the class" AHU design improvement concept, Quality Function Deployment (QFD) Matrix E4 is used as a selection tool.

The researcher is developing various concepts with the researcher and design team and four key AHU design improvement concepts are generated. Each concept is shown in next four sections along with the concept description. The four concepts were named "Concept-1", "Concept-2", "Concept-3" and "Concept-4". In design concept development process, the design was written on the sketchbook and the copy of

the concept was put on the presentation board for comments and adding features. We will discuss the detail of each developed in following sections.

### 4.3 Concept 1

From the QFD requirement the "Concept 1" is developed by the researcher and design team using the improvement of old double skin structure, changing material, wall sandwich panel configuration and some panel locking procedure.

#### 4.3.1 Construction

The main post of the AHU is made from sheet metal formed into the shape by the rolled forming or sheet metal folding. The post is serve as the vertical beam or horizontal beam. Same section of the post minimized the number of parts requirement and also can control the strength of the structure. The sketch of the post is shown in the figure 4.2.

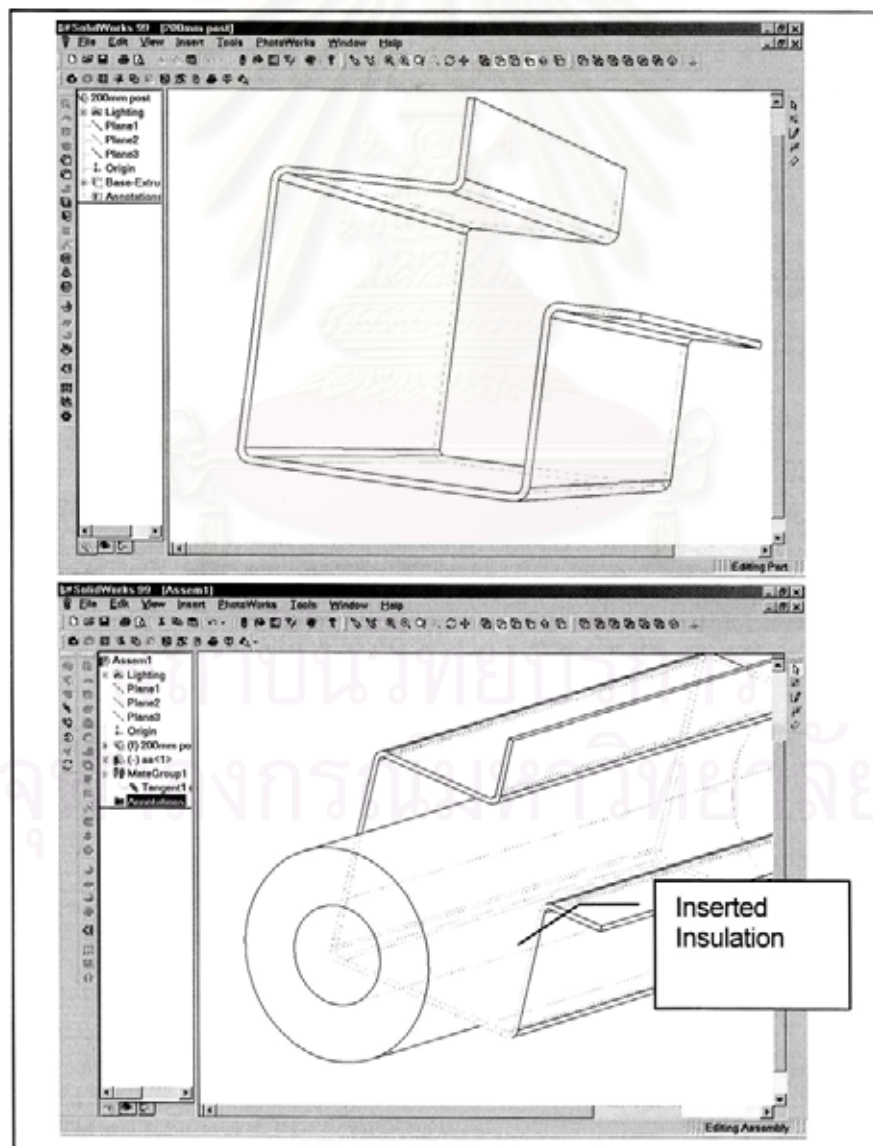


Figure 4.2: The Sketch of the "Concept-1" main post

Figure 4.2 illustrate the sketch of the section of the post structure on the SolidWork99™ screen. From figure the main post can be internally insulated, as illustrated to improve the thermal transmission resistance, which the thermal bridges will be dramatically, reduced. The length of the post can be fixed to any length requirement to meet the modular structure.

The structure is formed into the box by the special design corner pieces. The corner pieces will hold each post together and will increase the strength of the structure at the corner. The corner is formed by the cast aluminum piece as shown in the figure 4.3

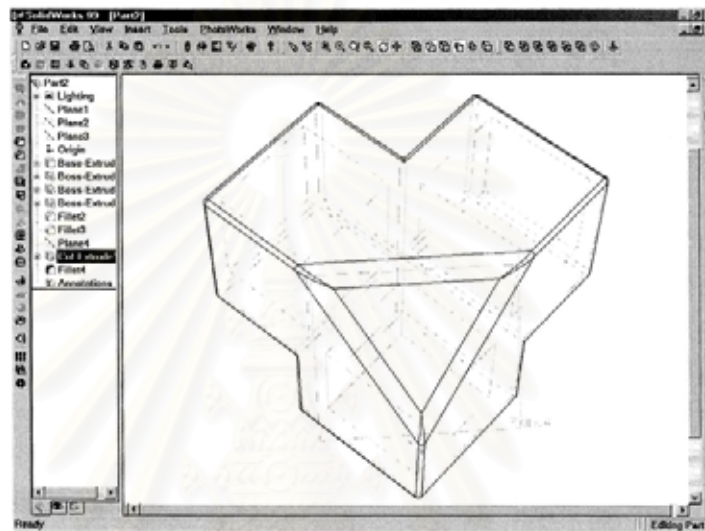


Figure 4.3: The "Concept-1" Corner piece"

The figure 4.3 illustrate the "Concept 1" corner piece and the assembly of the corner pieces to the posts. The post is bolted to the corner pieces by the self-tapered philips screws. The post and corner assembly is shown in the figure 4.4.

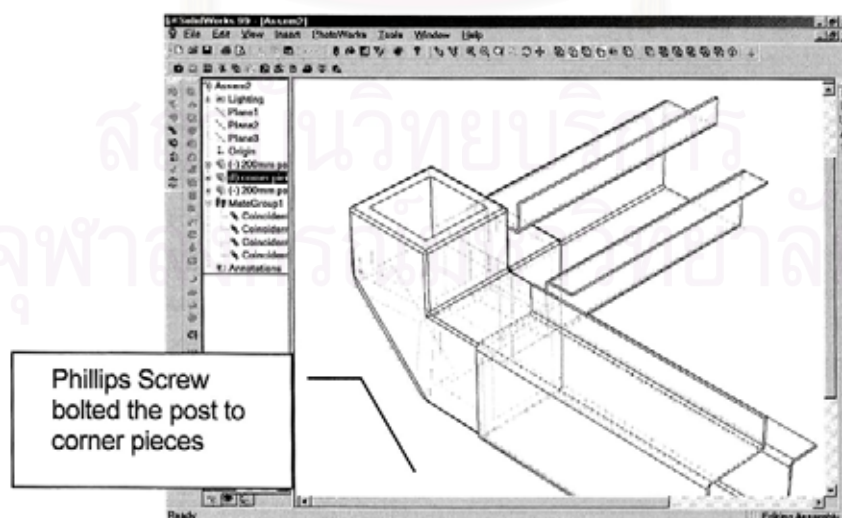


Figure 4.4: "Concept 1" Post + Corner Assembly

Figure 4.4 illustrate the post + corner pieces assembly of the "Concept-1". This structure is the improved version of old AHU that used the aluminum profile post.

#### 4.1.2 Base floor structure

The floor of the unit is constructed with the C –Frame galvanized steel sheet or the cold rolled C-profile steel as shown in figure 4.5.

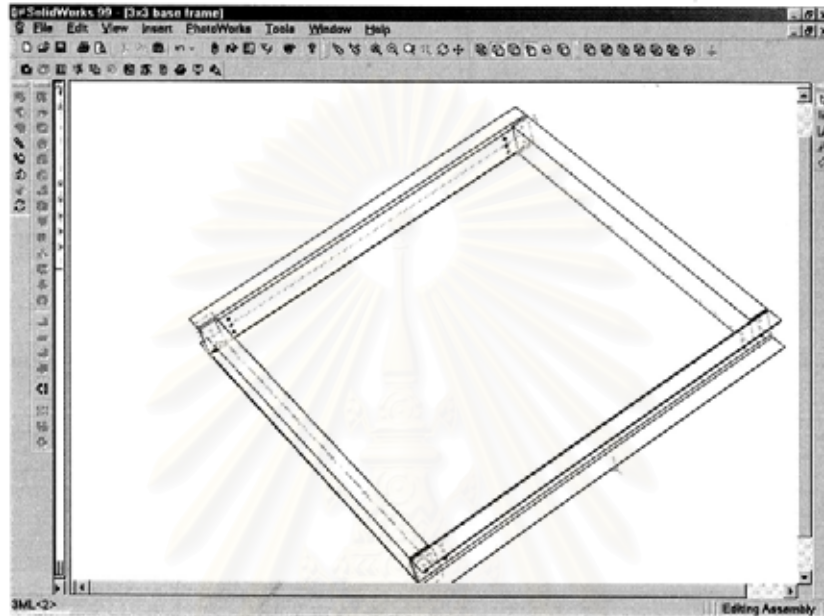


Figure 4.5 Base Frame for "Concept 1"

From figure 4.5, the base frame is shown. The base frame structure beam is welded together or bolted together to form the strong structure for supporting the whole AHU weight. The base frame is made in modular size for each section and will be used for each AHU section separately.

#### 4.1.3 Wall Panel and Floor Panel

The wall panel is made of three parts, the insulation, the internal flat sheet metal and the external shell structure. The internal and external sheet metal can be any kind upon the customer requirement. The bolts are tightening through the panel into the post to secure the panel and gasket to the post. Panel insulation can be made of any kind of insulation material, such as Polyurethane, polystyrene, mineral wool or the fiberglass. The drawing of the wall panel is illustrated in figure 4.6.

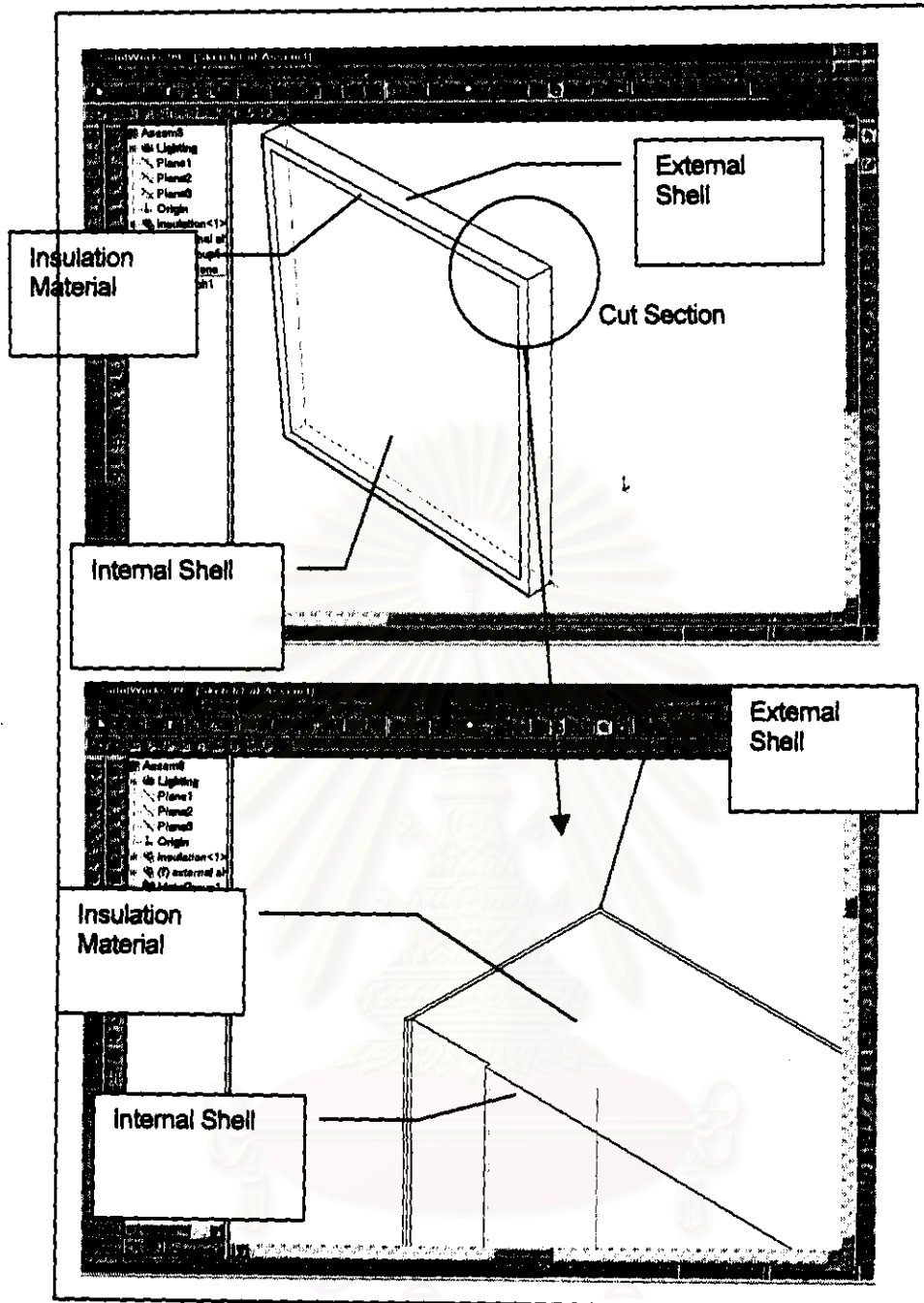


Figure 4.6: The wall and floor panel of "Concept 1"

The figure 4.6 illustrates the full piece wall panel and cross-section of the wall panel. From the cross section of the panel, there is no metal contact between internal and external sheet metal. The interior and exterior hold together with the adhesion force of the adhesive that holds the insulation to the sheet metal. The gap between the edges of external shell and the internal sheet metal is wide enough so that the bolt that used to secure the panel is not create the internal/ external metal contact.

#### 4.1.4 Service Door, Service Panel

The researcher and design team has two options for the internal AHU access; service door and service panels as shown in figure 4.7.

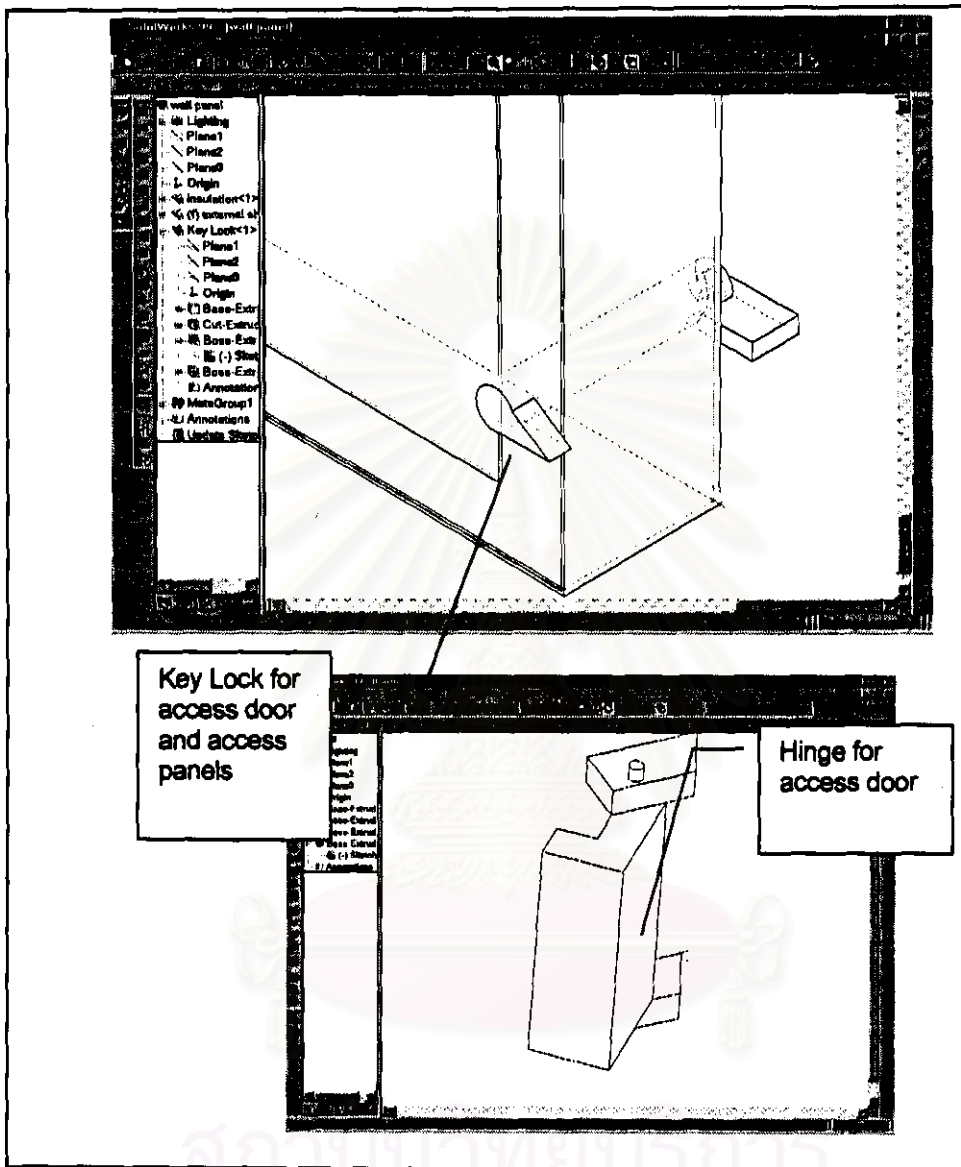


Figure 4.7: Concept Access Panel and Access Door

Figure 4.7 illustrate two options of the AHU internal access the service door and service panels. At the non-frequent service requirement area or the service area of small AHU, the quick access service panel is used. The service panel quick key-access locks are used instead of the bolts for fast access. No service door is provided for small unit. For large unit the service door is provided using the standard external bolt hinges and the quick key-access panel lock as the door lock. The door opening at the panel for service door use the post as the doorframe insulated by the insulation sheets. The hinge can be removed, by removing the strut of the hinge and the door is loosened.

#### 4.1.5 Module Assembly and Module Connection

To assembly the parts together, first the floor panel is placed to the lower parts of the post and corner pieces, as shown in figure 4.8.

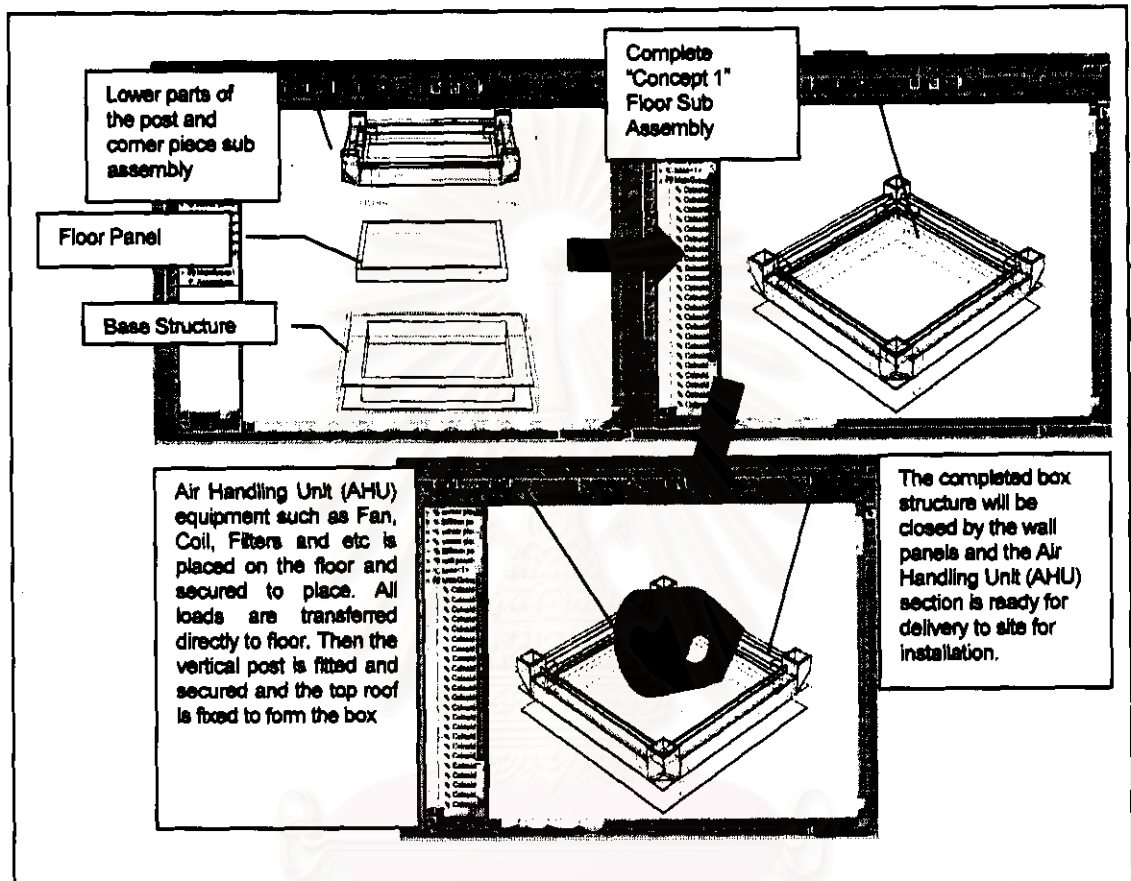


Figure 4.8: The assembly of the "Concept 1" AHU

Figure 4.2g illustrate the assembly of the "Concept-1" AHU. The floor of AHU with the semi-assembly post structure is put over the base floor structure. Few bolts are tightened to fix the base panels and frames together. The AHU components are put in place and four vertical posts are assembled. Top roof is fixed on the top of four vertical posts to form the box structure. The last step is to place the panels to close the AHU box. This completed assembly is done for each Air Handling Unit (AHU) section. For the multi-sections AHU assembly, additional section clamp is needed.



The section clamp is a simple c-profile with the bolt as shown in figure 4.9

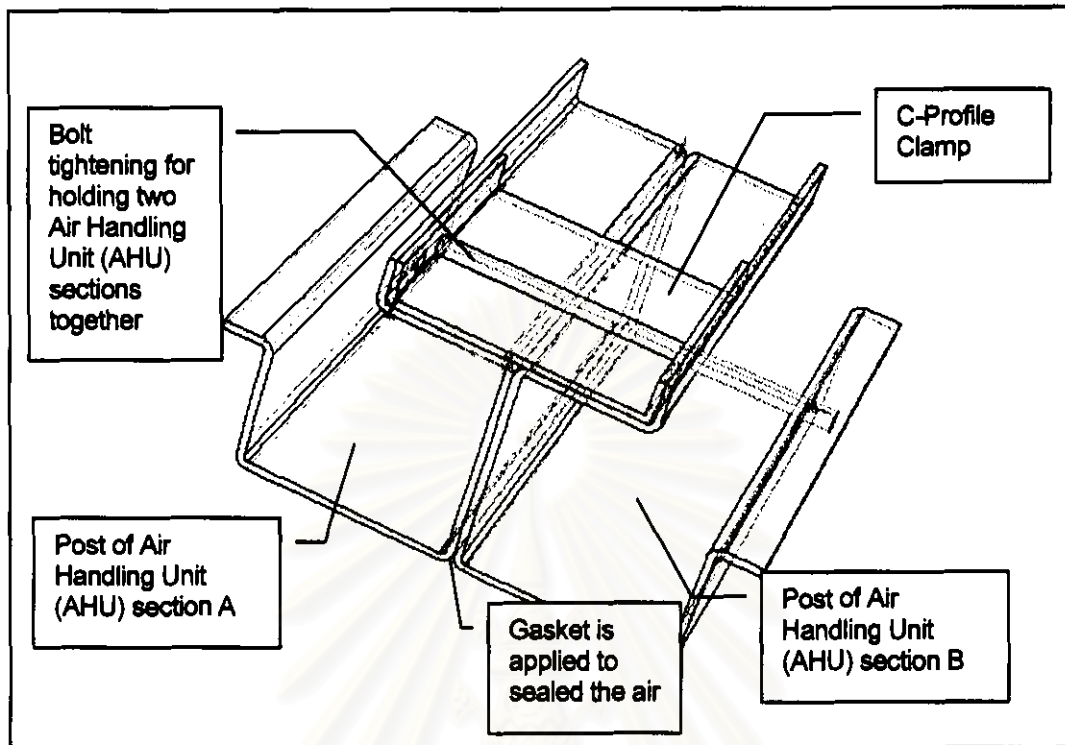


Figure 4.9: C-Clamp for holding two "Concept 1" AHU together.

Figure 4.9 illustrate the clamp that used to hold two "Concept 1" AHU together. The multiple clamps are applied along the edges of two AHU sections. The bolts are tightened to secure the clamps and two AHU end flange together. Between the Air Handling Unit (AHU) post the gasket is applied to seal the air and preventing the thermal bridges.

#### 4.1.6 Equipment Installation

In order to install AHU equipment such as, fan, filter, coil, and etc. all the section shall be placed on the AHU floor. The load of the components is directly transferred to the floor so the vertical posts and the roof do not received any weight from the components. The figure 4.10 shows the example of fan installation on the base floor.

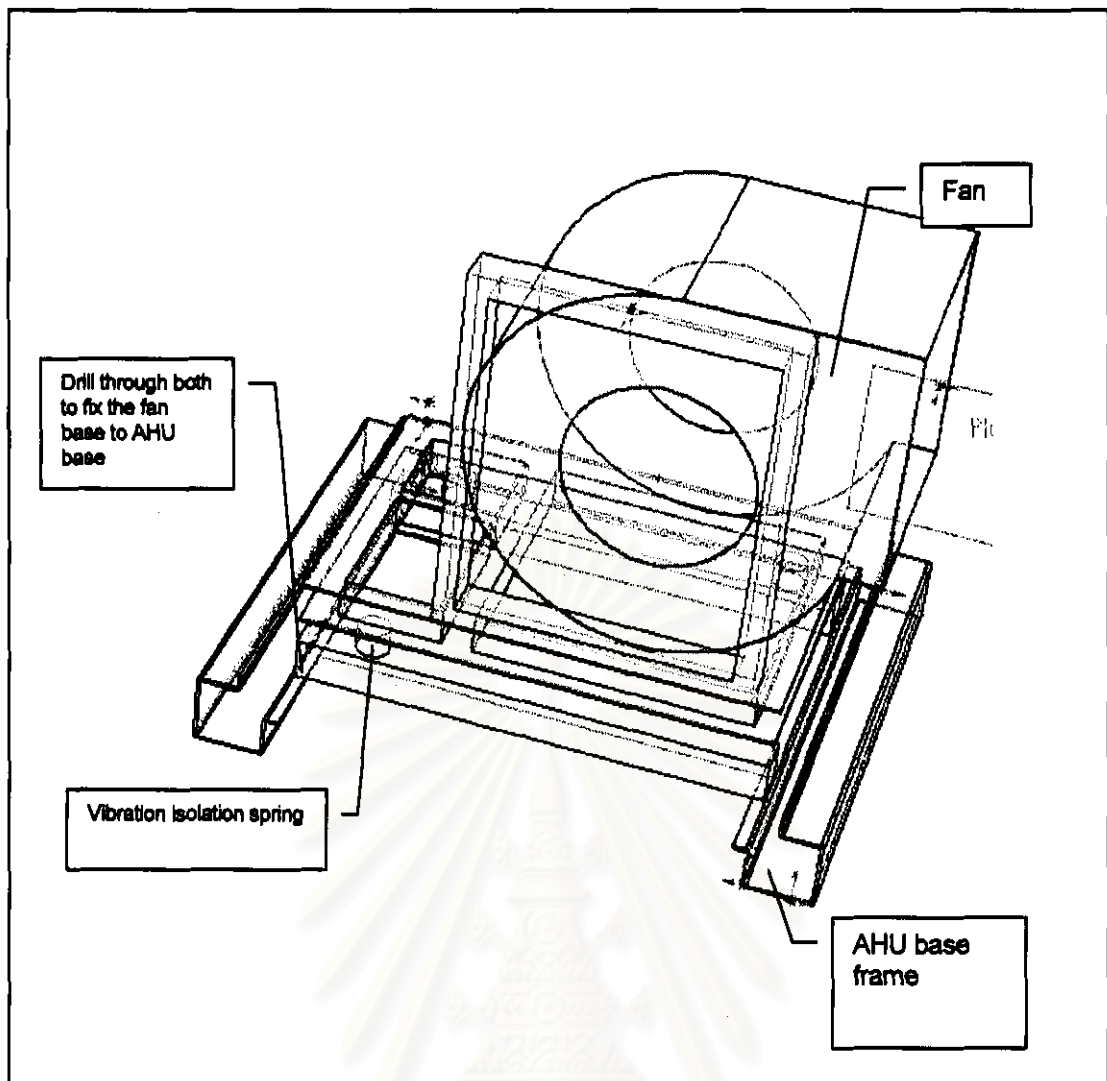


Figure 4.10: The section installation of Fan to the base frame of "Concept 1"

From the figure 4.10, The fan base frame is mounted to the floor using the drill-through bolts. The motor and fan sit on the sub-frame in which the fan vibration is isolated by the damper spring.

In installation of other component, same basis of installation is applied. The components must bolted on the post of the base floor of "Concept 1" only.

#### 4.1.7 Drain Pan, Coil

The drain pan at coil section is raised over the lower edge of the post for slide out. The standard cooling water coil is used. The coil size can be varied through all the cross section size. The height of the coil is the height of the internal open cross section less the height of the drain pan.

#### 4.1.8 Miscellaneous

The power connection terminal is equipped at the fan section, and if the unit have the heating section the control and power terminal will be provided. The internal air handling unit dimension is the modular of 305mm and the equipment section arrangement can be varied according to the customer demands.

## 4.2 Concept 2

The "Concept 2" is newly designed based on the information and design guideline from the QFD developed by the AHU researcher and design team.

This concept-2 Air Handling Unit (AHU) structure is located externally so only double skin panel's interior contact with the internal environment. Thus this will generate very smooth and very clean internal Air Handling Unit (AHU) face area.

### 4.2.1 Construction

The C pose frame is the main structure of this Air Handling Unit (AHU) the odd looking C-shape provide the strength and holding point to all vertical and horizontal structure. This C-post frame is displayed in Figure 4.11

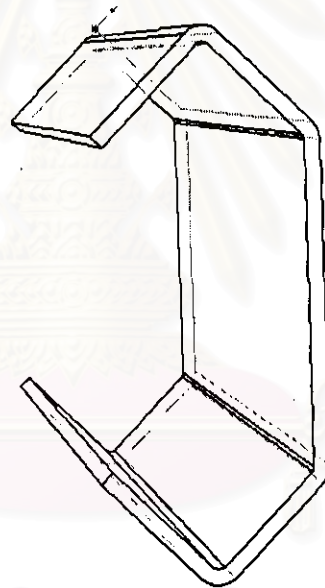


Figure 4.11 C-Structure: Concept-2

From the figure 4.11, the C-channel frame is made of the galvanized sheet metal, color coated sheet metal or stainless steel. This rectangular structure is the main structure of the AHU. Floor and Wall panels are bolted to the structure to form the box of the AHU. This newly developed structure design increase the flexibility of the Air Handling Unit (AHU) construction by minimizing the number of parts required to assembly the AHU.

#### 4.2.2 Floor & Wall Panel

Similar design is applied to the floor and wall panel. The sandwich panel made of two identical steel sheets, which are inserted, with the insulation in the middle. The internal frames of floor and wall panel are the plastic profile, which are internally inserted by square section of steel pipe for strength. The sheet metal is hold to the insulation with the adhesion force from the adhesive or from the polyurethane insulation injection as shown in figure 4.12

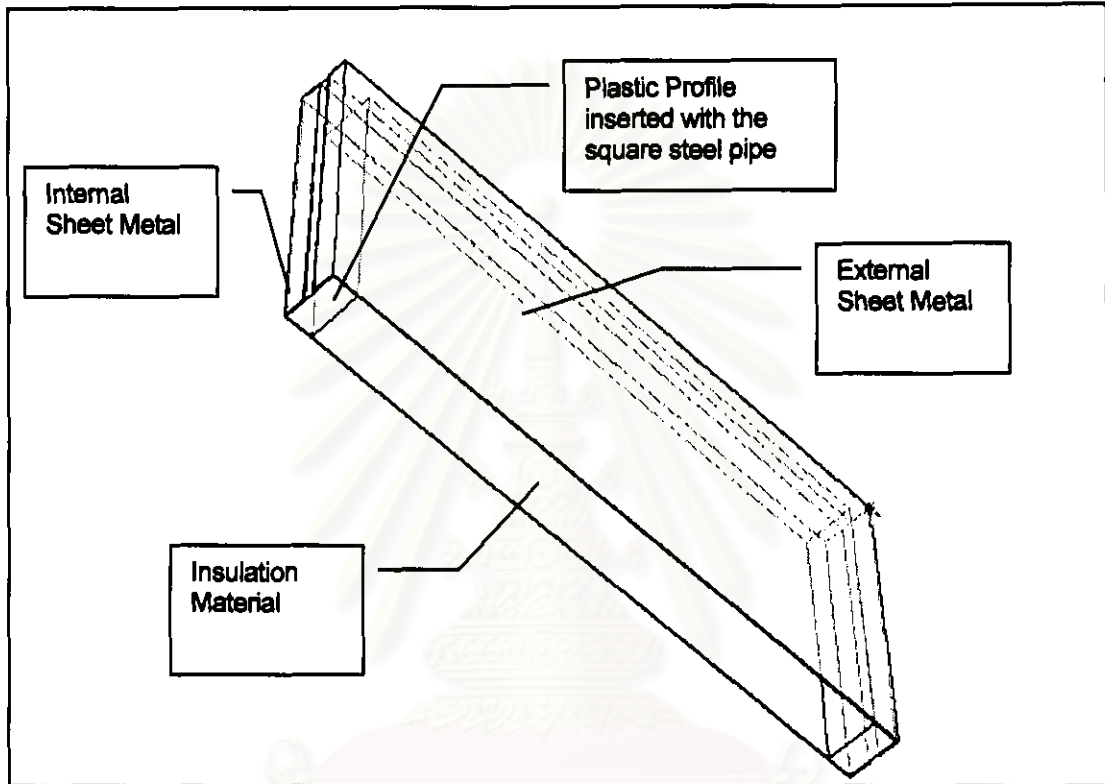


Figure 4.12: The cut section sketch of the wall and floor panels of "Concept 2" AHU

From figure 4.12, the internal and external sheet metals are not contacted to each other. The thermal bridge free construction provided the advantages and aim to meet the customer requirement from the QFD process. The plastic profile is insulate the wall panel edges while the inserted square steel pipe or folded steel sheet will increase the wall and floor strength. This "Concept 2" the wall and floor panel are used to received the forces from the components installed. The wall and panel also received the weight load of the AHU which transfer through the wall panel to the floor panel via the "C-channel"

In construction, the wall and the C-channel frame is assembled together as presented in Figure 4.13

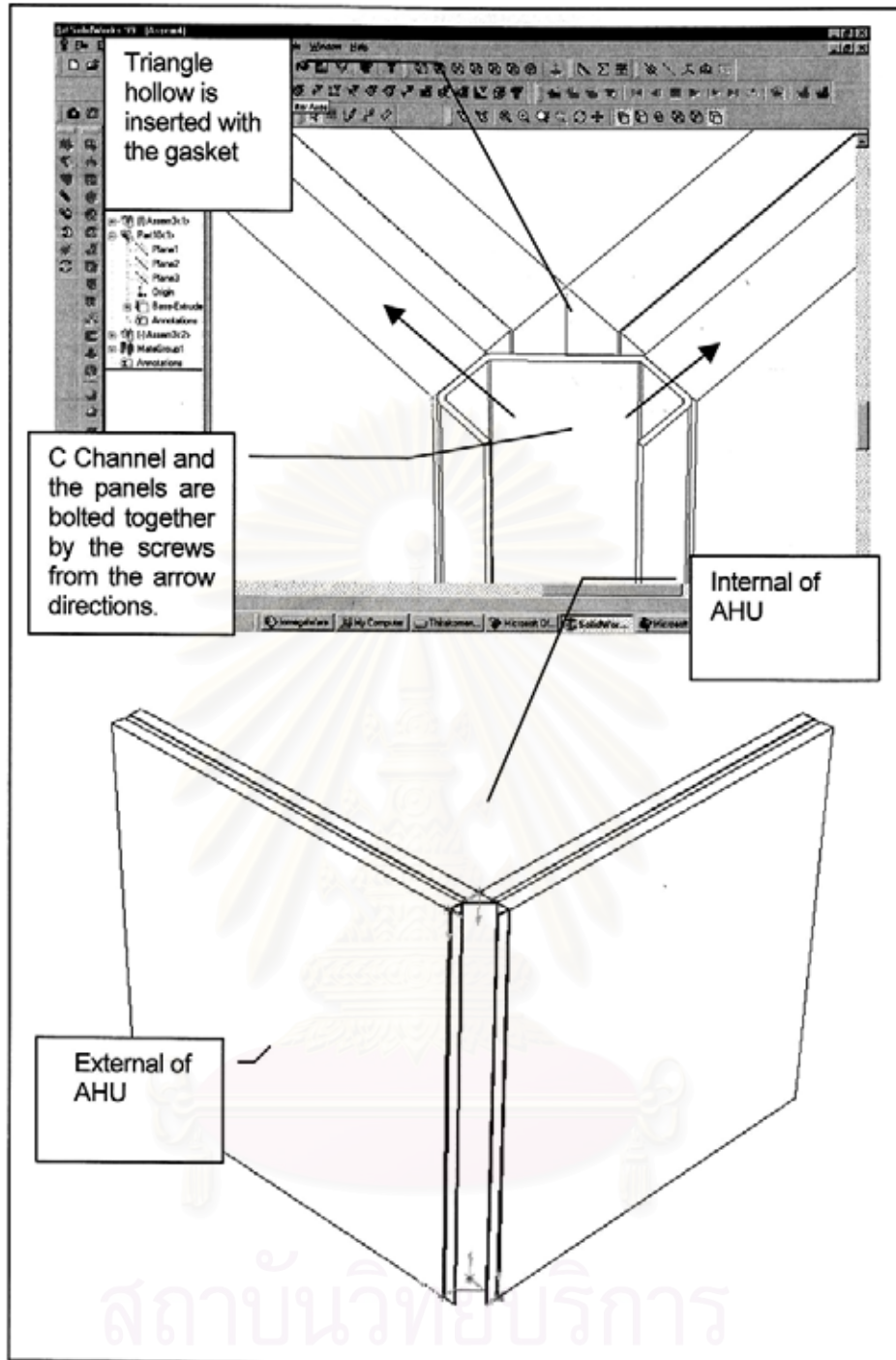


Figure 4.13: The panel assembly to the C-channel of the "Concept 2"

From Figure 4.13 two images is displayed, the full size of the panel assembly to the C-channel and the zoomed corner of the assembly. In the top images the triangle hollow at the corner will be inserted by the neoprene gasket to prevent the air leakage and improve the thermal insulation at the corner. C-channel and the panels is bolted together by the self tapered screw as shown by arrows in Figure 4.13.

### 4.2.3 Service Door Service Panel

The service panel is not used in this "Concept 2" construction but the access door is provided instead. The panel is opened for the door assembly by using the plastic frame with the steel pipe insert as the doorframe. Internal Thick sheet metal is forming the square flange and used as the door internal support and sealing flange, as shown in figure 4.14.

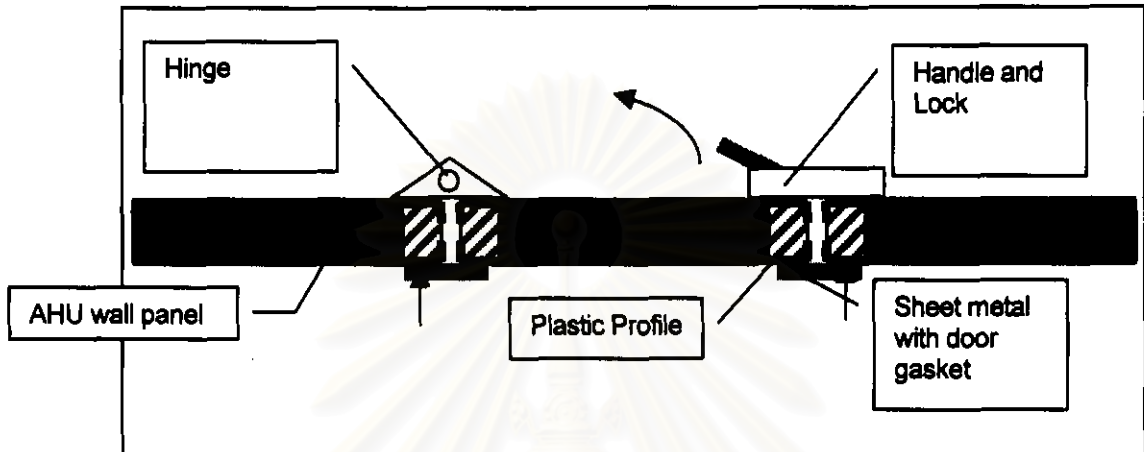


Figure 4.14: Access Door for "Concept 2"

Figure 4.4 illustrate the cut section of the door panel, look from the top view. The hinge is externally bolted to the panel. And the door lock is located externally.

### 4.2.4 Equipment Installation

The AHU equipment such as Fan, coil, heater and other heavy equipment is mounted on the floor at the edge. The components are bolted at the plastic profile internal frame of the floor panel. Since reinforce structure is provided the component can be held rigidly. The example of fan installation to the "Concept 2" is displayed in the figure 4.15

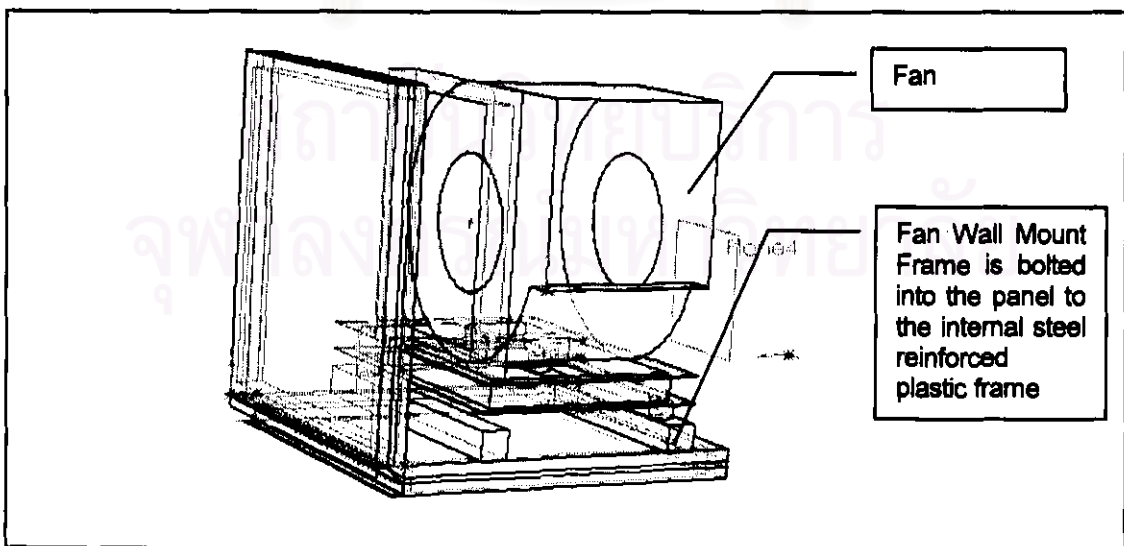


Figure 4.15: The fan installation example of the "Concept 2"

#### 4.2.5 Drain Pan, Coil

The drain pan is located at the floor level, the coil holding slide-in frame is mounted to the floor and ceiling edges for the rigidity, coil can be slide-in/out for maintenance.

#### 4.2.6 Miscellaneous

Filter section, and other equipment can be installed in the internal modular section. The lift hooks and the forklift accesses are at the base structure. The base structure is the same structure used in "Concept 1" in figure 4.16

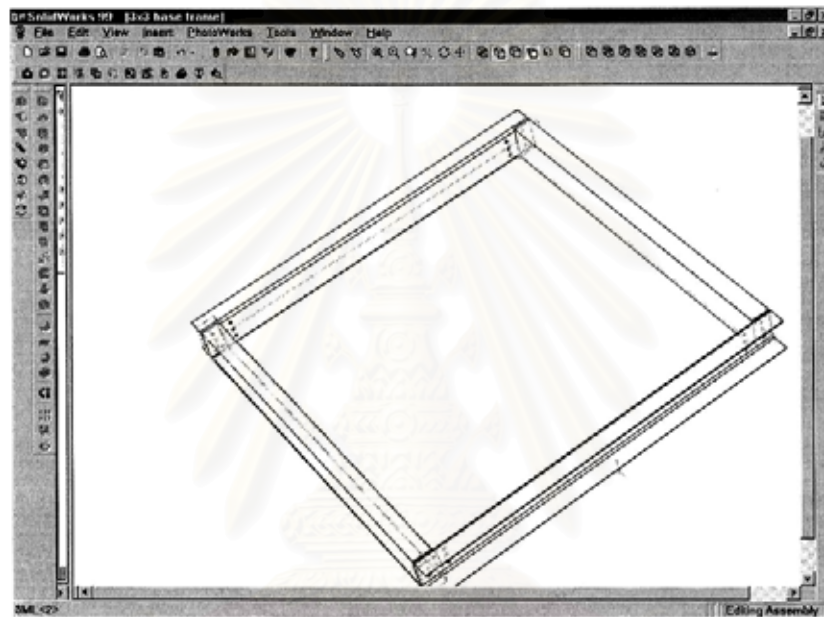


Figure 4.16: The base frame structure of "Concept 2"

From figure 4.16, the base frame shown is similar to the base frame of the "Concept-1". This type of Air Handling Unit (AHU) base frame is commonly used without causing problems to the Air Handling Unit (AHU).

### 4.3 Concept 3

"Concept 3" is the combination of the "Concept 1" and "Concept 2". This "Concept 3" is developed by simplified the "Concept 1" post construction into the market standard square section steel profile. The "Concept 3" wall panel is taken from the wall and floor panel of concept 2. Figure 4.17 show the modified construction post section and the corner piece from "Concept 1" to "Concept 3".

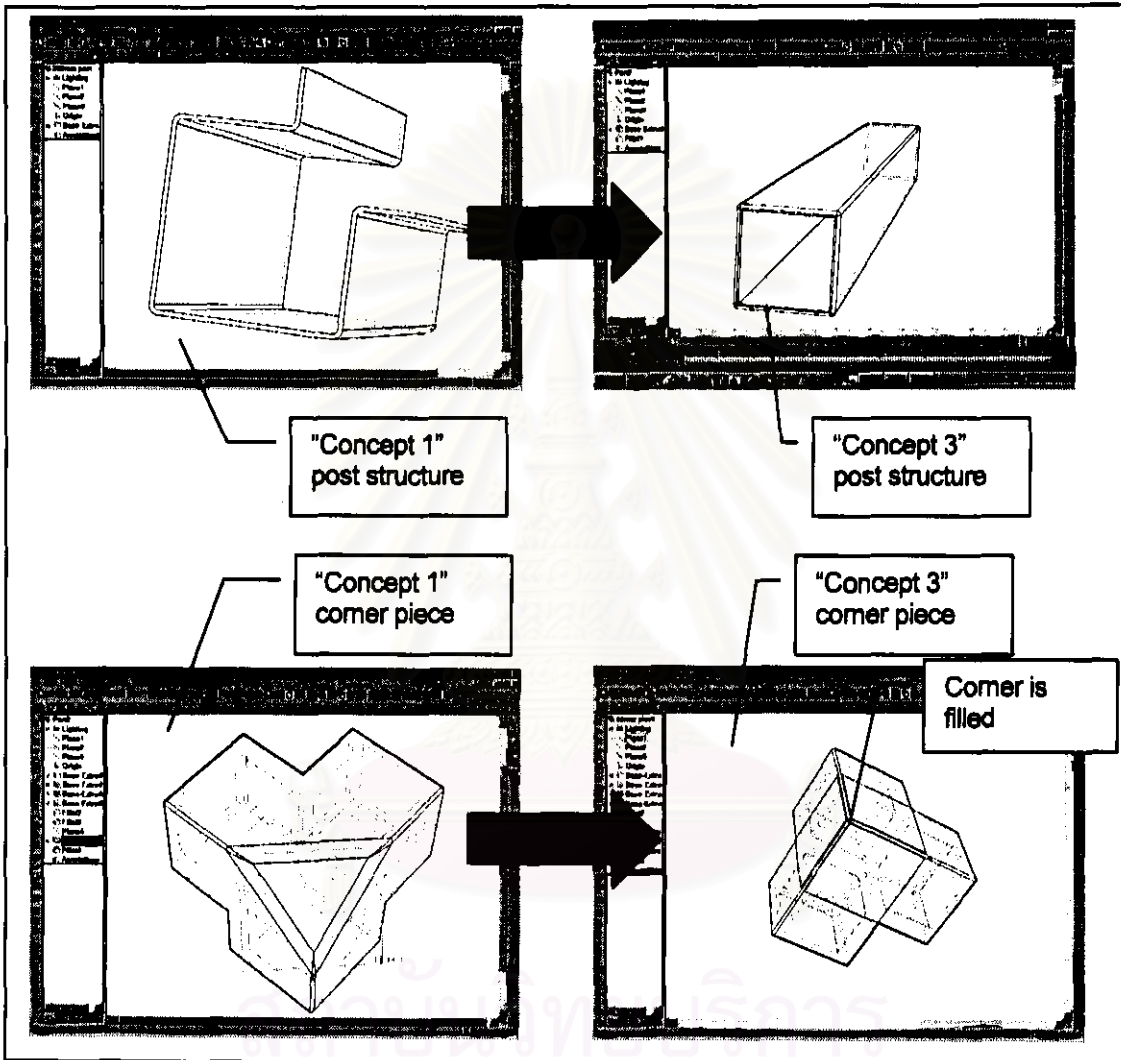


Figure 4.17 "Concept 1" part modification to "Concept 3" Post structure and corner piece.

Figure 4.17 illustrate the modification of the "Concept 1" parts to the "Concept 3" part. The "Concept 1" sheet metal processed post structure is replaced with the industrial standard square steel profile. The aluminum cast "Concept 1" corner piece is simplified to simple shape aluminum cast "Concept 3" corner pieces.

The reason that the "Concept 1" post structure is replaced with the "Concept 3" steel profile, is to reduce the manufacturing process time. The "Concept 3" steel profile can be cut to size without any additional manufacturing process while the "Concept 1" need to be rolled form or folded to shape. Thus, the parts tolerances and process time





From figure 4.19, the completed structure of the "Concept 3" is shown. The external side of the frame is flat and smooth. The flat external side will be served as the plane for the wall panels and floor panels to be installed on by the bolts. The insulation is adhered on the outer side of the structure frame, which is used for air tight and thermal insulation.

#### 4.3.2 Wall Panel, Floor Panel and service door

The "Concept 3" wall and floor panels are borrowed from the "Concept 2". The panel, which served as the floor and roof, will have the thicker sheet metal. The plastic profile in the floor and roof panels will be reinforced by the C-steel profile inside the plastic profile as shown in figure 4.20.

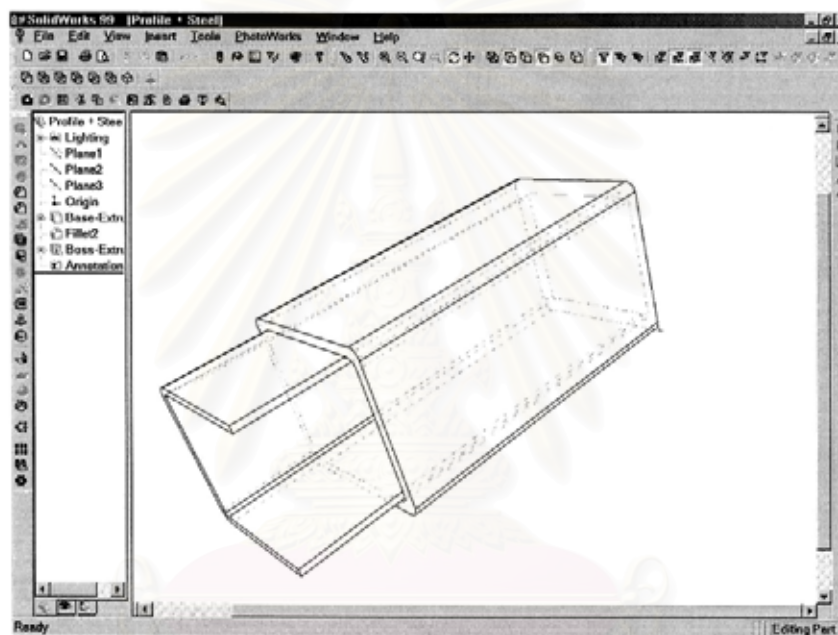


Figure 4.20: Inner panel plastic profile frame reinforced with the C-channel steel profile for roof and floor panel application.

From figure 4.20 illustrate the cut section of the plastic profile that used in the floor and roof panel, which is reinforced with the C-channel steel profile. The reinforced plastic profile is increasing the ability of the floor and roof panel to be able to carry the weight and loads of the AHU and the components. The "Concept 3" floor panel is directly received the whole AHU load that transfer from the frame structure to the floor panel and then transferred to the base structure.

#### 4.3.3 Base Structure.

The C-channel steel profile assemblies are used as the base structure. This base structure is similar to the "Concept 1" and "Concept 2" structure. In installation floor panel to the base structure, the floor panel is bolted to the top of base frame. Then the structure frame is laid on the wall and then bolted to secure the structure to the floor panel.



From Figure 4.21, two parts of the picture shown. Upper part is the illustration of the modules connection and show the C-Clamp, which is installed to clamp two modules together. The lower part is the cut section shows the installation of C-Clamp. The C-Clamp is placed over two square steel profiles and one bolt is fasten to squeeze the two modules together. The number of the C-Clamp required depends on the size of the modules.

#### 4.3.5 AHU components

The internally installed fan and drive system support structure are bolted onto the floor panel edge as same as concept 2. Drain Pan, Coil and other equipment can be installed on the post or on the floor. Drain Pan is located above the lower frame of the structure for sliding out. The Coil is the standard water coil range from 4 to 8 rows with variable tube heights and fin lengths.

#### 4.3.6 Miscellaneous

The lift hook can be installed on the roof due to the strength of the structure and the forklift access is at the base of the structure for moving in the plant. The filter section, lighting and other equipment can be mounted on the structure directly, on any position without putting all weight on the floor.

### 4.4 Concept 4

The "Concept 4" is the diversification design of the "Concept 3". In the "Concept 3" there is potential thermal bridges at the edges of wall and floor panels. From the QFD guideline, the thermal should be eliminated. The "Concept 4" is increased the thermal bridge free feature as well as the assembly of the AHU. Cost of production is also taken for consideration in this "Concept 4" development. The external appearance is not a major concern for the AHU so the "Concept 4" is designed to have rugged look. The structure is fully knocked downcapaility and very flexible in component configuration.

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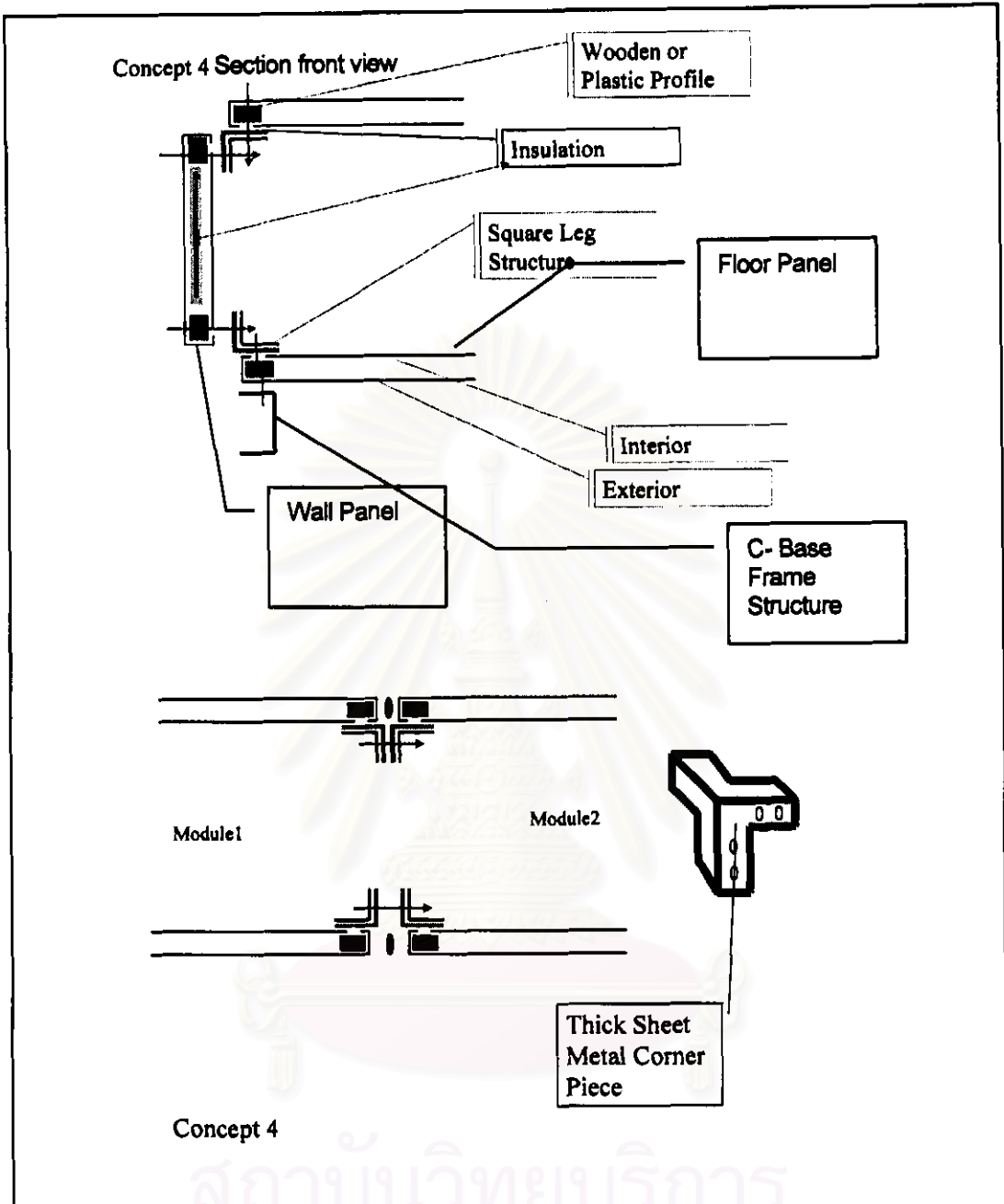


Figure 4.22: The sketch of the section of "Concept 4"

From figure 4.22, three section of drawing is shown. The top drawing is the cut section of the "Concept 4" which show the major components of the structure. The main structure of the "Concept 4" is the L-shape equal leg steel sheet metal profile. The profiles is held together to form the AHU box by the corner piece. The corner pieces are made with the thick sheet metal folded and welded, which is shown in the lower right of the figure 4.22. The lower left part of the figure 4.22 is the top view cross-section of "Concept 4". This drawing illustrate the connection method of two "Concept 4" module together.

#### 4.4.1 Construction

The square leg folded sheet metal is unit structure. The thick sheet metal corner piece served as the corner holder to align and secure the structure. The structure is color coated for clean look. The exterior is covered with the neoprene gasket. The gasket served as the frame insulation and airtight seal for the panel installation as shown in figure 4.23

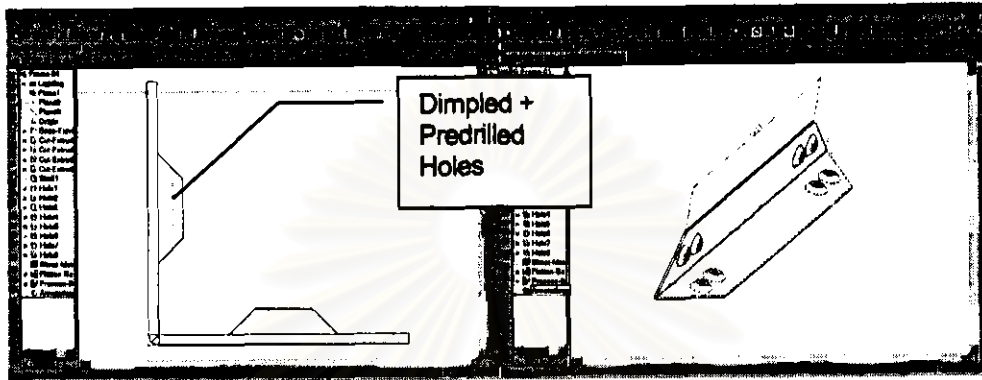


Figure 4.22: The L-shape equal leg post structure.

Figure 4.22 illustrate the main post of the "Concept 4". The post end have pre-drilled and dimpled holes for guiding the post to the guide dimple on the corner pieces. The corner pieces of the "Concept 4" is shown in figure 4.24

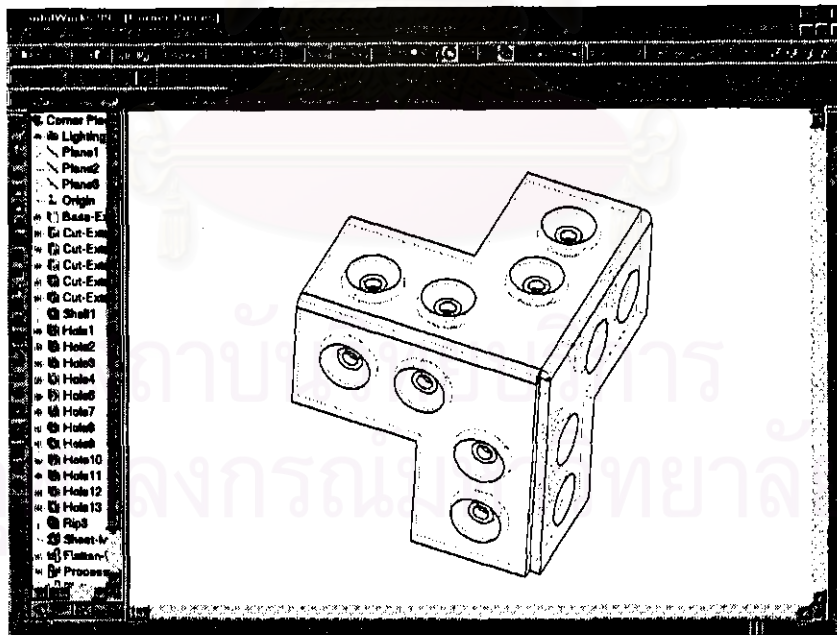


Figure 4.23: The "Concept 4" corner piece

Figure 4.23 illustrate the "Concept 4" corner piece that has the pre-drilled dimpled holes. These holes serve as guide for the L-shape post to properly installed.

#### 4.4.2 Floor & Panel

The floor and wall panels share same platform. The exterior shell is looked like the rectangular tray with the folded in rim as shown in figure 4.24

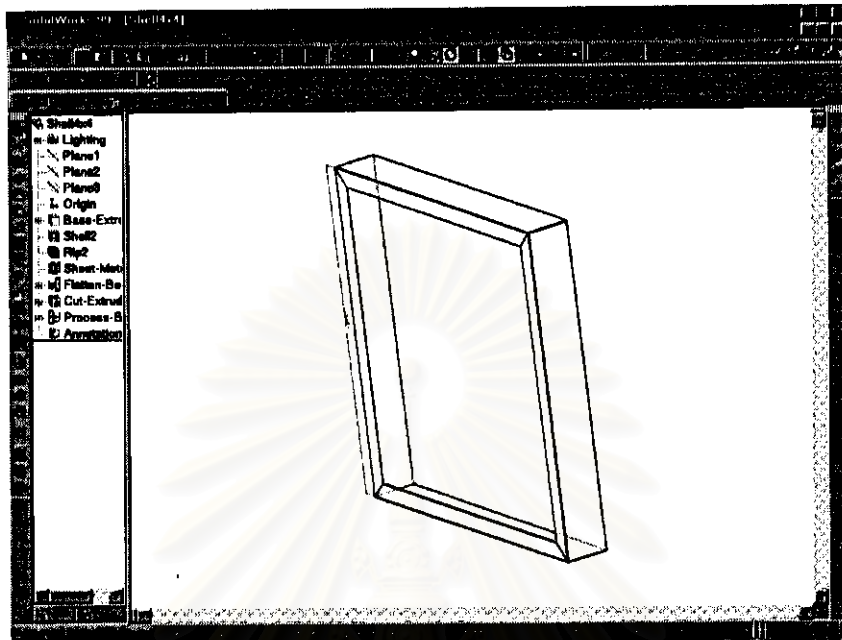


Figure 4.24: External shell of the "Concept 4" wall and floor panel

The plastic or wood profile is inserted into the rim and the internal sheet metal is riveted to the plastic or wood profile. This structure provides no metal contact of the structure. The insulation can be made of any insulation material, without limitation. This AHU design makes wall panel thickness be able to extended or reduced to the required thickness of the panel to meet the design specification. Figure 4.25 shows the exploded assembly of the "Concept 4" wall panel.

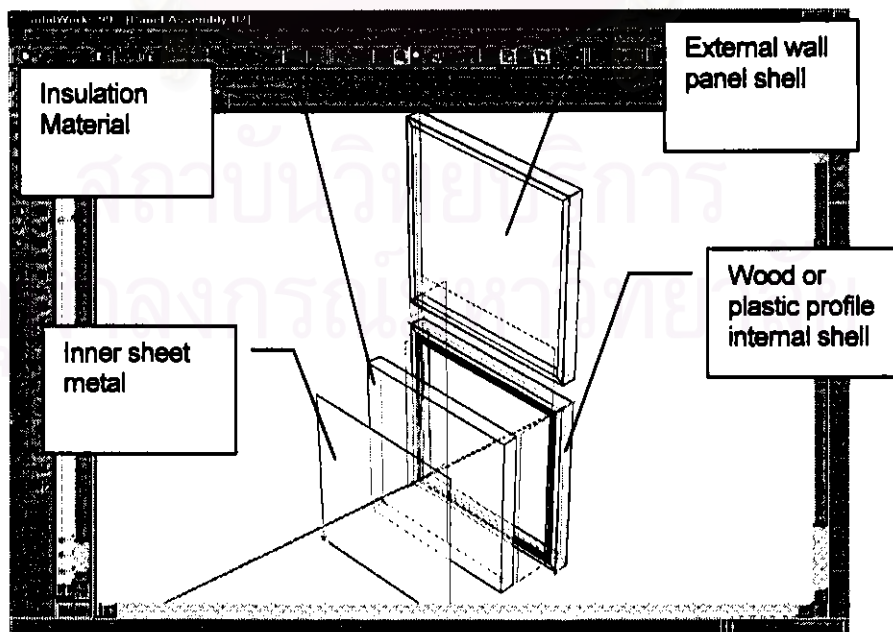


Figure 4.25: Exploded assembly of "Concept 4" wall panel

The figure 4.25 illustrates the assembly of the wall panel. The external shell is inserted with the wood or plastic profiles, filled with insulation and closed with the inner sheet metal to form the double skin construction. The insulation and gasket neoprene material cover the gap between two sheet metals. The neoprene work as both thermal insulation and the wall panel gasket.

To secure the panel to the structure, bolts are used to secure the panel to the structure, through the gap between sheet metal, as shown in figure 4.26

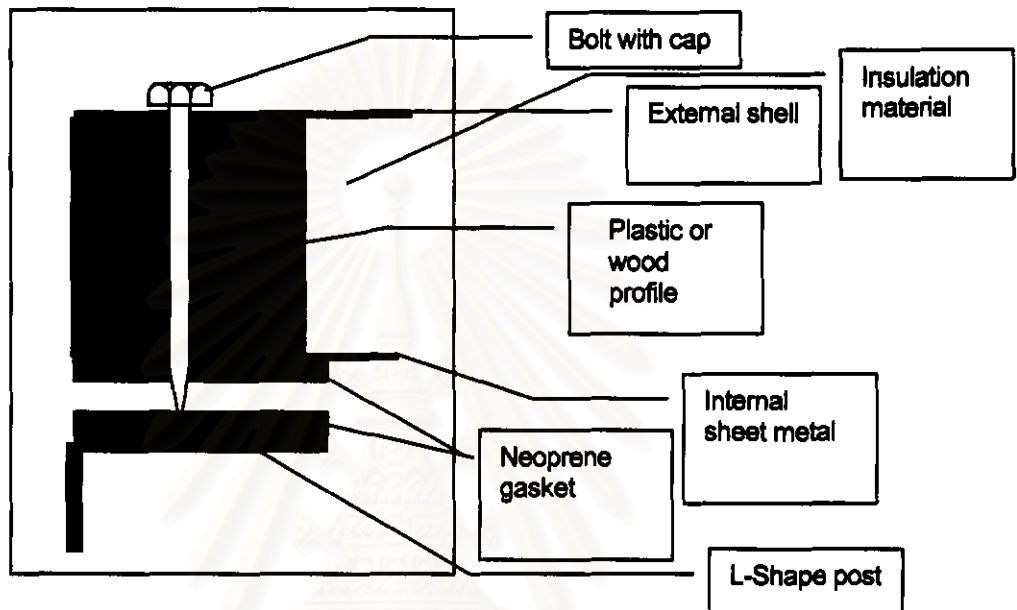


Figure 4.26: Panel Fastening, Concept-4

Figure 4.26 illustrates the method of holding the floor and wall panel to the L-shape structure. The wall and floor panel is bolted to the insulated L-shape post structure. The bolts are drilled through the panel between the gap of external shell and internal sheet to prevent metal contact. The sealed neoprene gasket forms the airtight. The bolt cap is covered with the plastic cap to prevent the condensation

#### 4.4.3 Service Door Service Panel

The service panel is the standard option, the self-taper bolt is easily removed and re tightened so the access to internal parts is easy. For the frequent access, the service door air tight is the option to choose for. Figure 4.27 illustrate the new design service door for "Concept 4"



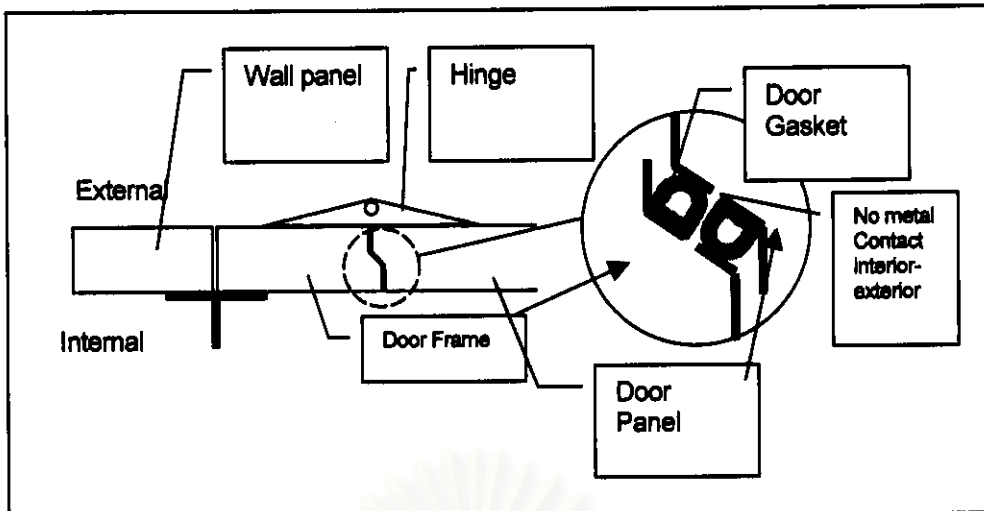


Figure 4.27: 45 degree door panel

From the figure 4.27: The 45-degree-service door edges increase the airtight capability of the service door. Integrated with the half round double rows door gasket. The door hinges is removable. Special plastic or wood profile is used to form the 45-degree edges of the doorframe and the door panel.

#### 4.4.4 Module Connection

To connect two concept-4 modules together, the simple fastening operation is taken place. The module is aligned by the pre-drilled hole and the bolt and nut are used to fasten two modules together. The end of the square leg works as the flange and the insulation works as the gasket. The compression force of the bolt forms perfect seal between two modules.

#### 4.4.5 Fan Section

With the same approach as other concepts, the concept-4 fan mounting is simple and can work with any orientation. The main fan structure is secure to the square leg sheet metal while the rubber and spring isolate the sub-frame vibration.

#### 4.4.6 Drain Pan, Coil

The condensation drain pan and coil are placed in the split-level. The drain pan locate under the coil can be slid out for the cleaning. The coil structure is secured to the base frame and the vertical structure and the coil can slide out or lift off the unit easily.

#### 4.4.7 Miscellaneous

The additional equipment such as heating coil, heat recovery unit can be installed to the machine. The internal modular size is expected to be the multiple size of 305 mm. The unit transporting lift hook is located on the base of the module. The forklift access is also at the base of the module that has one side long enough for the forklift. The unit is equipped with standard wire guide and power connecting terminal. The sight glass at the access panel or access door is optional.

#### 4.5 QFD Table E4: New Concept Selection Summary

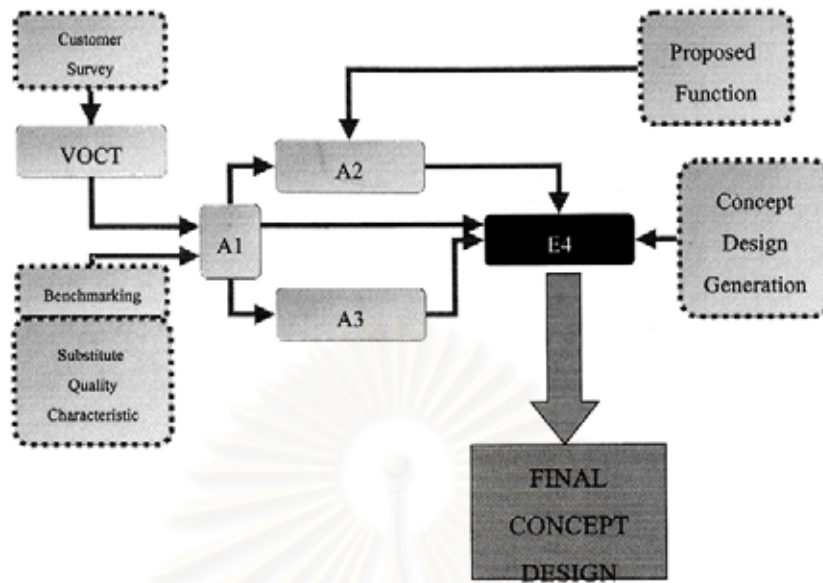


Figure 4.28: Quality Function Deployment (QFD) Process Flow: E4

Figure 4.28 illustrates the current step of the QFD. The dark shaded block of E4 shows that this section will work on the QFD matrix E4 step, which is the final step of the Quality Function Deployment (QFD) process for this Air Handling Unit (AHU) design development. Matrix E-4 or "PUGH Table" is used to select concept designs that are generated by the researcher and design team. The "best in the class" concept is selected from the multiple comparisons between the candidate concepts. The "best in the class" concept will show the best score and should be selected for further detail design.

##### 4.5.1 How the Matrix E4 works

The QFD matrix E4 is the comparison of each concept design to the "Substituted Quality Characteristics", "Customer Demands" and "Proposed Function" that were developed by AHU researcher and design team in earlier QFD Matrix A1, A2 and A3. This QFD Matrix E4 is composed of four parts which will be discussed in detail. In each comparison trial, one concept design is selected as the "DATUM". "DATUM" is the reference that other concept design is compared with on each "Substituted Quality Characteristics", "Customer Demands" and "Proposed Function". The figure 4.29 shows the general look of the QFD Matrix E4.

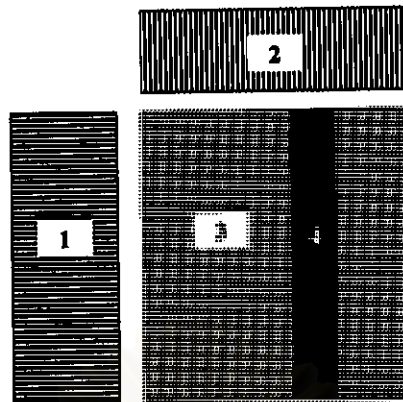


Figure 4.29, The Quality Function Deployment (QFD) Matrix E4

The table E4 is composed with four parts as shown in figure 4.29. The first part (Part-1) is the column listed of "Customer Demands", Proposed Functions and "Substituted Quality Characteristics". Part-2 is the column contains New Concept Designs of AHU, which generated by researcher and design team. Part-3 is the comparison level scoring area that the + "Plus" and – "Minus" indicator shall be filled by researcher and design team. The comparison is made between the "Datum" and other concept designs. Part-4 is the "Datum", which is one of the concept designs that randomly selected to use as reference.

In this AHU concept design selection, four concept designs are the candidate; "Concept 1", "Concept 2", "Concept 3" and "Concept 4". The AHU researcher and design team decided to give a chance to all concept to be the "Datum", so the matrix E4 need to be completed four time. Each time different AHU concept design is used as "Datum".

This QFD E4 matrix use the comparison value of (+) and (-) as the score. In Matrix E4 scoring process, the researcher and design team has to pick one concept design as "Datum". The comparison is made by researcher and design team, considering the satisfaction level of each concept design on each row of "Matrix E4 Part-1". The comparison is made on the basis of comparing the concept design and "Datum". If concept design is better than datum on particular row of "Matrix E4 Part-1", the (+) Plus sign is given to that concept design. If compared concept design is worse than "Datum" (-) minus sign is given instead. If the compared concept design is perform at the equal level to "Datum" no sign is given.

After the researcher and design team complete the task of concept design comparison, the total sum of the "Plus" and "Minus" obtained will indicate the strength and

weakness of each concept design. The score of each concept design is the number of the Plus deducted by number of Minus.

From the repeating assessments of the Matrix E-4, the researcher and design team will set the accumulated scores of each concept design and the highest score shall be the best concept design. The researcher and design team also gets the runner up concept designs, which can be further developed to be better concept design in the future.

#### 4.5.2 The Complete Matrix E4

Four trials are taken for comparing the "Concept 1", "Concept 2", "Concept 3" and "Concept 4" of Air Handling Unit (AHU). The Matrix E4 Part-1 input are the list of "Substituted Quality Characteristics", "Customer Demands" and "Purposed Function" that developed from the QFD Matrix A1, A2, and A3. The detail list of Matrix E4 Part-1 is shown in following table 4.1.

0,90,180,270/ L-R degree blow outlet
180 Removable Pin Hinge for Access Door
305mm Base Dimension Modular (Internal)
Access to the internal components
Accurate Air Volume
Air Cleanliness Control
Air Humidity Control
Air Mixer
Air Volume Control
Air Washer Section
Anti Trap-in
Appearance
Assembly Fool Proof
Belt Guard
Build Close loop air circuit
Build Static Pressure
Centrifugal Fan Installation
Clean Air
Clean internal construction
Clean Internal Structure
Coil Sliding
Coil velocity up to 700 fpm
Color Finished Exterior
Color Finished Interior
Connected to Air Distribution Systems
Control Connector Terminal
Controlling equipment installable
Cooling Capacity
Delivery Air to Distribution System
Dehumify
Door and Service Panel Removal in 1 min
Double Skin Construction 2", Thermal transmission insulation 1-1.4 W/m <sup>2</sup> /K
Droplet Eliminator after coil
Dry Drain Pan
Easy to remove & install wall panel
Fan Inlet Guard
Fan Set Vibration Isolator
Flexible Configuration
Fool Proof For Connection

Table 4.1: List of QFD Matrix E4 Part-1

Continue from previous page

Forklift Access From Side
Guide Hole-Guide Pin for Installation
Heating
Height Variable Base Structure 10cm-20cm
High Performance Fan & Drive
High Static Operation
Humidifying
Inlet Flange, Duct Bolt Connect
Insulated Drained Floor( With Expanded metal cat walk, on large unit)
Insulated Sight Glass
Internal Inlet Damper @ Mixing Box
Internal Lighting Switch
Knock Down Structure
Lift Hook
Lighting IP55
Long Maintenance Life
Low Vibration
Maintainability, Serviceability and Installation
Mixing Box
Modular Equipment Section
Modular Filter Section 305x305
Monitoring equipment installable
Multi-Choice Insulation (PU, PS, Rockwool, Fiberglass)
Multi-Choice Internal Skin
Multi-Stages, selectable modular component
Multi-Type-Fan Configuration
No Thermal bridge and internal-external condensation
Non-Corrosive
On Floor Installation
On Hanging Plat Form Installation
Out Let Flange
Perfect Sealed Gasket
Easy to maintenance
Powder Coated Exterior
Protection of Water Carry Over from Coil
Quiet operation
Rigid-Tough Construction
Safety
Section Labeling Indicator
Service Door Air Tight 100%
Service Panel-Air Tight 100%
Shaft Guard
Side Access Pre Filter & Medium Filter Housing
Small Foot Print
Stackable Unit 2 level
Trap In alarm
V Grooved Elevated Drain Pan
Walkable Unit Top: 400 kg
Water Pipe Header
Wire Guide-Wire Way
Wiring Terminal for Power Connector

Table 4.1 (Continue): List of QFD Matrix E4 Part-1

The list of the double skin AHU "Substituted Quality Characteristics", "Customer Demands" and "Purposed Function" in the table 6.1 will be used in QFD matrix comparison. The researcher and design team will start working on the Matrix E4 by first selecting the "Concept 1" as the "Datum". The "Concept 2", "Concept 3" and "Concept 4" are compared to the "Datum". The result of the matrix is shown in figure 4.12

Second trial, researcher and design team select "Concept 2" as the "Datum". The "Concept 1", "Concept 3" and "Concept 4" are compared to the "Datum". The result of the comparison is shown in figure 4.13. Third trial, researcher and design team select "Concept 3" as the "Datum". The "Concept 1", "Concept 2" and "Concept 4" are compared to the "Datum". The result of the comparison is shown in figure 4.14. Fourth trial, researcher and design team select "Concept 4" as the "Datum". The "Concept 2", "Concept 3" and "Concept 4" are compared to the "Datum". The result of the comparison is shown in figure 4.15. After four trial, the total summary score of the four matrix E4 is shown in the table 4.3.

In this AHU design, the researcher and design team compares the concept design over the "Datum" for almost 400 comparison on four trials of QFD Matrix E4. Example of the comparison of the concept design over the "Datum" is shown in Table 4.2

Trial Number	1			
Concept	1	2	3	4
Multi-Choice Insulation (PU, PS, Rockwool, Fiberglass)		+	+	+

Table 4.2: Sample of the Matrix E4 Comparison

From table 4.1a, the sample of the comparison of the Matrix E4 is shown. This sample is taken from the first trial of the Matrix E4. The "Concept 1" is selected as the "Datum" and will be used as the comparison reference for "Concept 2", "Concept 3" and "Concept 4".

The subject that the design concept is compared in the example is the ability of the designed double skin wall panel to use variety of thermal insulation materials. In concept design "Concept 1" can use only the sheet PU, sheet PS, Rockwool and Fiberglass. The "Concept 2", "Concept 3", and "Concept 4" can use the injection PU, injection PS, sheet PU, sheet PS, Rockwool and Fiberglass. In the comparison score, the "Concept 2", "Concept 3", and "Concept 4" is perform better so the score is ( + ).

When each matrix E4 is completed the researcher and design team have to count the number of each ( + ) and ( - ). The total sum of ( + ) and ( - ) is displayed at the bottom of matrix and will be used for scoring.

4.5.3 Quality Function Deployment (QFD) Matrix E4 First Trail: Concept-1 = DATUM

QFD-Matrix E-4 Chart New Concept Selection Summary					
	Trial Number	1	2	3	4
Concept	1	2	3	4	
0, 90, 180, 270° L-R degree blow outlet					
180 Removable Pin Hinge for Access Door		+	+	+	
305mm Base Dimension Moduler (Internal)		-			
Access to the internal components		-			
Accurate Air Volume					
Air Cleanliness Control			-		
Air Humidity Control					
Air Mixer					
Air Volume Control					
Air Washer Section					
Anti Trap-in		-			
Appearance					
Assembly Foot Proof					+
Belt Guard					
Built Close top air circuit					
Built Static Pressure					
Centrifugal Fan Installation					
Clean Air					
Clean internal construction					
Clean Internal Structure					
Coil Sliding		+			+
Coil velocity up to 100 fpm					
Color Finished Exterior					
Color Finished Interior					
Connected to Air Distribution Systems					
Control Connector Terminal					
Controlling equipment installation					
Cooling Capacity					
Delivery Air to Distribution System					
Demunking					
Door and Service Panel Removal in 1 min					+
Double Skin Construction 2", Thermal transmission insulation 5-14 & W/m2K		+	-		+
Dropout Eliminator after coil					
Dry Drain Pan		+	-		
Easy to remove & install wall panel		+			+
Fan Inlet Guard					
Fan Set Vibration Isolator					
Flexible Configuration		+			+
Foot Proof For Connection			-		
Footst Access Firm Side					
Guide Hole-Guide Pin for Installation					+
Heating					
Height Variable Base Structure 10cm-20cm					
High Performance Fan & Drive					
High Static Operation			-		+
Humidifying					
Inlet Flange, Duct Bolt Connect					
Insulated Drained Floor (With Expanded metal cat walk, on large unit)					
Insulated Sight Glass					
Internal Inlet Damper @ Mixing Box		+			+
Internal Lighting Switch					
Knock Down Structure		+			+
Lift Hook				+	
Lighting IP55					
Long Maintenance Life					
Low Vibration					
Maintainability, Servicability and Installation		+			+
Mixing Box					
Modular Equipment Section					
Modular Filter Section 30x305					+
Monitoring equipment installable					
Multi-Choice Insulation (PU, PS, Rockwool, Fiberglass)		+	+		+
Multi-Choice Internal Skin					
Multi-Stage, selectable moduler component					
Multi-Type Fan Configuration					
No Thermal bridge and internal-external condensation		+	+		+
Non-Corrosive					
On Floor Installation					
On Hanging Plat Form Installation					
Out Let Flange					
Perfect Sealed Gasket		+			+
Easy to maintenance					+
Powder Coated Interior					
Protection of Water Carry Over from Coil					
Quiet operation					
Rigid-Tough Construction			-	+	+
Salty					
Section Labeling Indicator					
Service Door Air Tight 100%					+
Service Panel-Air Tight 100%					+
Shaft Guard					
Side Access Pre Filter & Medium Filter Housing					
Small Foot Print					
Stackable Unit 2 level					
Trap In alarm					
V Grooved Elevated Drain Pan				+	+
Walkable Unit Top 400 kg			-	+	+
Water Pipe Header					
Wire Guide-Wire Way					
Wiring Terminal for Power Connector					
Number of Plus	0	12	7	22	
Number of Minus	0	7	4	1	
Score Plus-Minus	0	6	3	21	

Figure 4.30: First Trial Matrix E4 for AHU Concept Selection

The result: Concept-1 = Datum; Concept-2 = 12 Plus, 7 Minus, Score 5; Concept-3 = 7 Plus, 4 Minus, Score 3; Concept-4 = 22 Plus, 1 Minus, Score 21. The Best in Class for this trail is Concept-4.

4.5.4 Quality Function Deployment (QFD) Matrix E4 Second Trail: Concept-2 = DATUM

QFD-Matrix E-4 Chart New Concept Selection Summary					
	Trial Number	2			
	Concept	1	3	4	
0.90 180 270° L-R degree blow outlet					
180 Removable Pin Hinge for Access Door		-			
305mm Base Dimension Modular (Internal)		+		+	
Access to the internal components		+		+	
Accurate Air Volume					
Air Cleanliness Control					
Air Humidity Control					
Air Mixer					
Air Volume Control					
Air Washer Section			-		
Anti Trap-in		+			
Appearance		-		-	
Assembly Fool Proof			-	+	
Ball Guard					
Blow Close stop air circuit					
Build Static Pressure					
Centrifugal Fan Installation					
Clean Air					
Clean internal construction					
Clean internal structure					
Coil Sliding		-	-		
Coil velocity up to 700 fpm					
Color Finished Exterior					
Color Finished Interior					
Connected to Air Distribution Systems					
Control Connector Terminal					
Controlling equipment in-statable					
Cooling Capacity					
Delivery Air to Distribution System					
Demisting					
Door and Service Panel Removal in 1 min				+	
Double Skin Construction 2", Thermal transmission insulation 1-1.4 W/m2K		-	-		
Droplet Eliminator after coil					
Dry Drain Pan		-	-		
Easy to remove & install wet panel		-	-	+	
Fan Inlet Guard					
Fan Set Vibration Isolator					
Flexible Configuration		-	-		
Fool Proof For Connection			-		
Forklift Access From Side					
Guide Hole Guide Pin for Installation				+	
Heating					
Height Variable Base Structure 10cm-20cm					
High Performance Fan & Drive					
High Static Operation		+	+	+	
Humidifying					
Inlet Flange Duct Bolt Connect					
Insulated Drained Floor( With Expanded metal cat walk, on large unit)					
Insulated Sight Glass					
Internal Inlet Damper @ Mixing Box		-	-		
Internal Lighting Switch					
Knock Down Structure		-	-	+	
Lift Hook			+		
Lighting IP55					
Long Maintenance Life					
Low Vibration					
Maintainability, Servicability and Installation		-	-		
Mixing Box					
Modular Equipment Section					
Modular Filter Section 30x30x5				+	
Monitoring equipment in-statable					
Multi-Choice Insulation (PU, PS, Rockwool, Fiberglass)		-			
Multi-Choice Internal Skin					
Multi-Stage, selectable modular component					
Multi-Type Fan Configuration					
No Thermal bridge and internal-external condensation		-			
Non-Corrosive					
On Floor Installation					
On Hanging Flat Form Installation					
Out Let Flange					
Perfect Sealed Gasket		-			
Easy to maintenance				+	
Powder Coated Exterior					
Protection of Water Carry Over from Coil					
Quiet operation				-	
Rigid-Tough Construction		+	+	+	
Safe					
Section Labeling Indicator					
Service Door Air Tight 100%				+	
Service Panel-Air Tight 100%				+	
Shaft Guard					
Side Access Pre Filter & Medium Filter Housing					
Small Foot Print					
Stackable Unit 2 level		+			
Trap In alarm					
V Grooved Elevated Drain Pan					
Walkable Unit Top: 400 kg		+	+	+	
Water Pipe Header					
Wire Guide-Wire Way					
Wiring Terminal for Power Connector					
	Number of Plus	7	0	5	14
	Number of Minus	13	0	10	2
	Score Plus-Minus	-6	0	-6	12

Figure 4.31: Second Trial Matrix E4 for AHU Concept Selection

The result: Concept-2 = Datum; Concept-1 = 7 Plus, 13 Minus, Score -6; Concept-3 = 5 Plus, 10 Minus, Score -5; Concept-4 = 15 Plus, 2 Minus, Score 12. The Best in Class for this trail is Concept-4.



4.5.5 Quality Function Deployment (QFD) Matrix E4 Third Trail: Concept-3 = DATUM

QFD-Matrix E-4 Chart New Concept Selection Summary	Trial Number			
	1	2	3	4
0.90, 180, 270° L-R degree blow outlet				
180 Removable Pin Hinge for Access Door	-			
305mm Base Dimension Modular (Internal)		-		
Access to the internal components				*
Accurate Air Volume				
Air Cleanliness Control	*			
Air Humidity Control				
Air Mixer				
Air Volume Control				
Air Washer Section				
Anti Trap-in				*
Appearance				
Assembly Fool Proof		*		
Belt Guard				*
Build Close loop air circuit				
Build Static Pressure				
Centrifugal Fan Installation				
Clean Air				
Clean internal construction				
Clean internal structure				
Coil Sliding		*		*
Coil velocity up to 700 fpm				
Color Finished Exterior				
Color Finished Interior				
Connected to Air Distribution Systems				
Control Connector Terminal				
Controlling equipment installable				
Cooling Capacity				
Delivery Air to Distribution System				
Demounting				
Door and Service Panel Removal in 1 min				*
Double Skin Construction 2", Thermal transmission insulation 1-1.4 W/m <sup>2</sup> K	*	*		*
Droplet Eliminator after coil				
Dry Drain Pan	*	*		*
Easy to remove & install wall panel		*		*
Fan Inlet Guard				
Fan Set Vibration Isolator				
Flexible Configuration		*		*
Fool Proof Fan Connection	*	*		*
Front Access From Side				
Guide Hole Guide Pin for installation				*
Heating				
Height Variable Base Structure 10cm-20cm				
High Performance Fan & Drive				
High Static Operation		-		*
Humidifying				
Inlet Flange, Dust Bolt Connect				
Insulated Drained Floor (With Expanded metal cat walk, on large unit)				
Insulated Sight Glass				
Internal Inlet Damper @ Mixing Box		*		*
Internal Lighting Switch				
Knock Down Structure		*		*
Lift Hook	-	-		-
Lighting IP55				
Long Maintenance Life				
Low Vibration				
Maintainability, Serviceability and Installation		*		*
Mixing Box				
Modular Equipment Section				
Modular Filter Section 305x305				*
Monitoring equipment installable				
Multi-Choice Insulation (PU, PS, Rockwool, Fiberglass)	-			
Multi-Choice Internal Skin				
Multi-Stage, selectable modular component				
Multi-Type-Fan Configuration				
No Thermal bridge and internal-external condensation	-			
Non-Corrosive				
On Floor Installation				
On Hinging Flat Form Installation				
Out Let Flange				*
Perfect Sealed Gasket				*
Easy to maintenance				
Powder Coated Exterior				
Protection of Water Carry Over from Coil				
Quiet operation				
Rigid-Tough Construction	-	-		-
Safety				
Section Labeling Indicator				*
Service Door Air Tight 100%				*
Service Panel-Air Tight 100%				*
Shaft Guard				
Side Access Pre Filter & Medium Filter Housing				
Small Foot Print				
Stackable Unit 2 level				
Trap In alarm				
V Grooved Elevated Drain Pan	-			
Walkable Unit Top, 400 kg	-	-		-
Water Pipe Header				
Wire Guide-Wire Way				
Wiring Terminal for Power Connector				
Number of Plus	4	10	0	18
Number of Minus	7	5	0	5
Score Plus-Minus	-3	5	0	13

Figure 4.32: Third Trial Matrix E4 for AHU Concept Selection

The result: Concept-3 = Datum; Concept-1 = 4 Plus, 7 Minus, Score -3; Concept-2 = 10 Plus, 5 Minus, Score 5; Concept-4 = 18 Plus, 5 Min, Score 13. The Best in Class for this trail is Concept-4.

4.5.6 Quality Function Deployment (QFD) Matrix E4 Fourth Trail: Concept-4 = DATUM

QFD-Matrix E-4 Chart New Concept Selection Summary	Trial Number			
	1	2	3	4
0.90, 180, 270 L-R degree blow outlet				
180 Removable Pin Hinge for Access Door				
305mm Base Dimension Modular (Internal)				
Access to the internal components				
Accurate Air Volume				
Air Cleanliness Control				
Air Humidity Control				
Air Mixer				
Air Volume Control				
Air Washer Section				
AVB Trap-in				
Appearance	+	+	+	
Assembly Foot Proof	-	-	-	
Belt Guard				
Build Close loop air circuit				
Build Static Pressure				
Centrifugal Fan Installation				
Clean Air				
Clean internal construction				
Clean Internal Structure				
Coil Siding	+		+	
Coil velocity up to 700 fpm				
Color Finished Exterior				
Color Finished Interior				
Connected to Air Distribution Systems				
Control Connector Terminal				
Controlling equipment installable				
Cooking Capacity				
Delivery Air to Distribution System				
Demounting				
Door and Service Panel Removal in 1 min	-	-	-	
Double Skin Construction 2", Thermal transmission insulation 1-1.4 W/m <sup>2</sup> K	-	-	-	
Droplet Eliminator after coil				
Dry Drain Pan				
Easy to remove & install wall panel	-	-	-	
Fan Inlet Guard				
Fan Set Vibration Isolator				
Flexible Configuration	-	-	-	
Foot Proof for Connection				
Front Access from side				
Guide Hose-Guide Pin for Installation	-	-	-	
Heating				
Height variable (Steel Structure 10m-20m)				
High Performance Fan & Drive				
High Static Operation	-	-	-	
Humidifying				
Inlet Flange, Duct Bolt Connect				
Insulated Drained Floor( With Expanded metal cat walk, on large unit)				
Insulated Sight Glass				
Internal Inlet Damper @ Mixing Box	-	-	-	
Internal Lighting Switch				
Knock Down Structure	-	-	-	
Lift Hook				
Lighting IP55				
Long Maintenance Life				
Low Vibration				
Maintainability, Serviceability and Installation	+		+	
Mixing Box				
Modular Equipment Section				
Modular Filter Section 30x30x5	-	-	-	
Monitoring equipment installable				
Multi-Choice Insulation (PU, PS, Rockwool, Fiberglass)	-			
Multi-Choice Internal Skin				
Multi-Steps, selectable modular component				
Multi-Type-Fan Configuration				
No Thermal bridge and internal-external condensation	-			
Non-Corrosive				
On Floor Installation				
On Hinging Plat Form Installation				
Out Let Flange				
Perfect Sealed Gasket	+		+	
Easy to maintenance	-	-	-	
Powder Coated Exterior				
Protection of Water Carry Over from Coil				
Quiet operation		+	+	
Rigid-Tough Construction	-	-	-	
Safety				
Section Labeling Indicator				
Service Door Air Tight 100%	-	-	-	
Service Panel-Air Tight 100%	-	-	-	
Shaft Guard				
Side Access Pre Filter & Medium Filter Housing				
Small Foot Print				
Stackable Unit 2 level				
Trap in alarm				
V Grooved Elevated Drain Pan	-	-	-	
Walkable Unit Top 400 kg	+	+	+	
Water Pipe Insulator				
Wire Guide-Wire Way				
Wiring Terminal for Power Connector				
<b>Number of Plus</b>	<b>1</b>	<b>2</b>	<b>5</b>	<b>0</b>
<b>Number of Minus</b>	<b>22</b>	<b>14</b>	<b>18</b>	<b>0</b>
<b>Score Plus-Minus</b>	<b>-21</b>	<b>-12</b>	<b>-13</b>	<b>0</b>

Figure 4.33: Fourth Trial Matrix E4 for AHU Concept Selection

The result: Concept-4 = Datum; Concept-1 = 1 Pluses, 22 Minuses, Score - 21; Concept-2 = 2 Pluses, 14 Minuses, Score -12; Concept-3 = 5 Pluses, 18 Minus, Score -13. The Best in Class for this trail is Concept-4.

#### 4.6 Quality Function Deployment (QFD) Matrix E4 Score Summary

The final scores from comparison between different concept design as illustrated in the Figure 4.30–4.33 are summarized and shown in the table 4.3

Concept	Trial	1	2	3	4	Total
1	Plus	0	7	4	1	12
	Minus	0	13	7	22	42
	Total	0	-6	-3	-21	-30
2	Plus	12	0	10	2	24
	Minus	7	0	5	14	26
	Total	5	0	5	-12	-2
3	Plus	7	5	0	5	17
	Minus	4	10	0	18	32
	Total	3	-5	0	-13	-15
4	Plus	22	14	18	0	54
	Minus	1	2	5	0	8
	Total	21	12	13	0	46

Table 4.3: The Quality Function Deployment (QFD) Matrix E4 Score Summary

The table 4.3 shows the summary of the four QFD Matrix E4 for AHU. The four concept design are showing each "PLUS" and "MINUS" scores and the total scores. The total scores are obtained from the number of "PLUS" deducted by "MINUS". In the summary, the Concept-4 is considered as the "Best in the Class" concept design with the maximum score of 46. The runner-up is the Concept-2 with the total score of -2. Concept-2 can be further developed and improved to meet more customer demands and can be the candidate in the product improvement project.

"The Concept-4" is selected as core concept design for Air Handling Unit (AHU) design improvement detail design.

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