Chapter 3

AHU Design Improvement Using QFD Approach Part-1

The Quality Function Deployment (QFD) is the quality approach design process, which is first used by the Mitsubishi Heavy Industries in the shipyard for large vessel construction. Later, this process is further developed and expanded throughout the world class Japanese companies for designing the products, services and process. In the success histories of using the Quality Function Deployment (QFD) in the Japanese Automobile Industries, TOYOTA, HONDA and others Japanese carmaker can compete with the competitors in the world market by the state of the arts products which meet the demands of the customers.

Further more, the western country industries are adapting the Quality Function Deployment (QFD) approach in their design processes. QFD process integrated with other design tools such as concurrent engineering, robust design and etc. shall make the design of products, services, and process more effective. The strength of Quality Function Deployment (QFD) process is its ability to work with any design processes that involve the voice of customers, internally and externally, in any industries.

The Quality Function Deployment (QFD) methodology is the process that bridging the gap between customer demands and the designer. The customers could be the end-users, people who use the product, the person who maintenance the product or the person who selecting the product. The designer can be the concept designer, engineering designer and etc. The bridged gap lead to the state of the art end product or process design that meets the customer demands and expectations.

First introduced Quality Function Deployment (QFD) table/Matrix is the Japanese version "House of Quality", which illustrated in Figure 3.1, which work on translating the customer demand quality to the engineering specification, benchmarking technical quality and benchmarking competitors. In further expanding usage of the Quality Function Deployment (QFD) in the industries, tables and matrix are added to the Quality Function Deployment (QFD) process, which help to create the dynamic, flexible design process. The expanding of tables, matrices also generate the confusion in implementing the Quality Function Deployment (QFD).

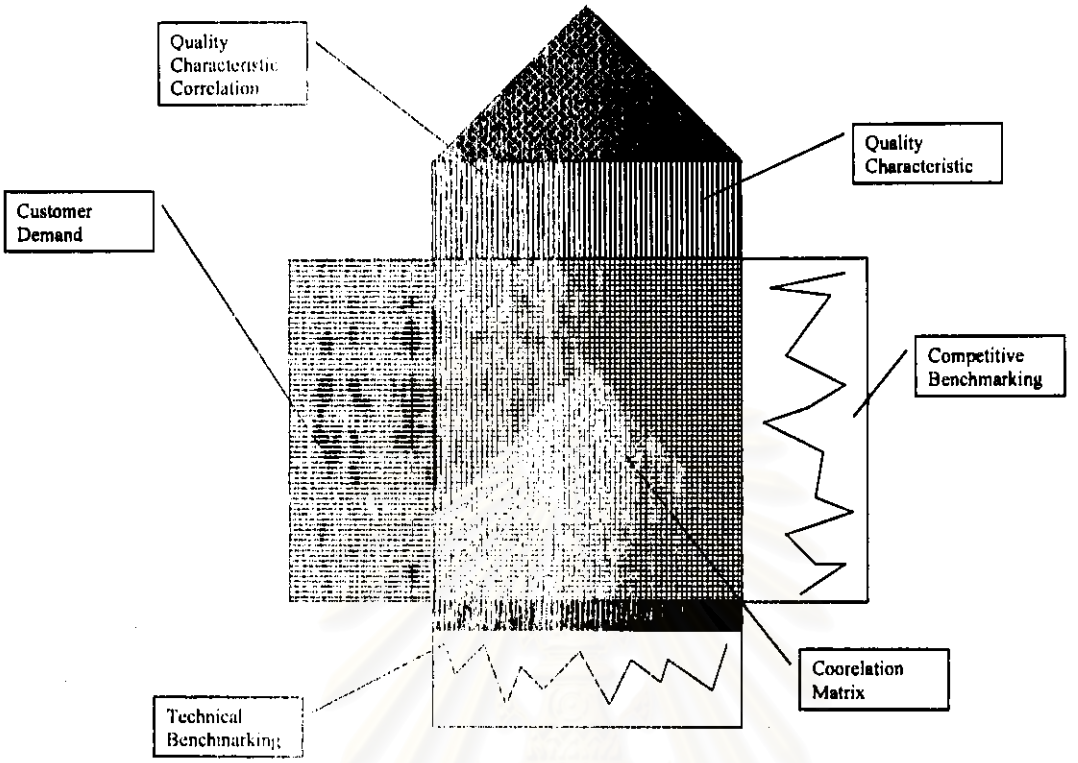

Figure 3.1: The House of Quality

In figure 3.1. the Japanese version "House of Quality" is illustrated. The "House of Quality" comprised of six major parts. Customer Demand on the left side and the quality characteristics on the middle-top of the matrix are used as the in put of the matrix. At the middle the correlation matrix is used to show the correlation of demands and quality. The benchmarking on the right and on the bottom, as well as the correlation among the quality characteristics is used as the references.

In further developed QFD matrices from original "House of Quality", there are two downstream approaches of the Quality Function Deployment (QFD) processes one is *the American Supplier Institute (ASI) Four Phase Approaches* and another is *GOAL/QPC Research Committee Metrix of Matrices Approach*. Also upstream development from the original "House of Quality" is *the Voice of Customers Table (VOCT)*. The VOCT is the expanded table that increases the Quality Function Deployment (QFD) process capability to translate and arrange the voice of the customers.

The American Supplier Institute's "Four Phase Approaches", shown in Figure 3.2, is the four levels of the Quality Function Deployment (QFD) implementation in the product design to manufacturing process.

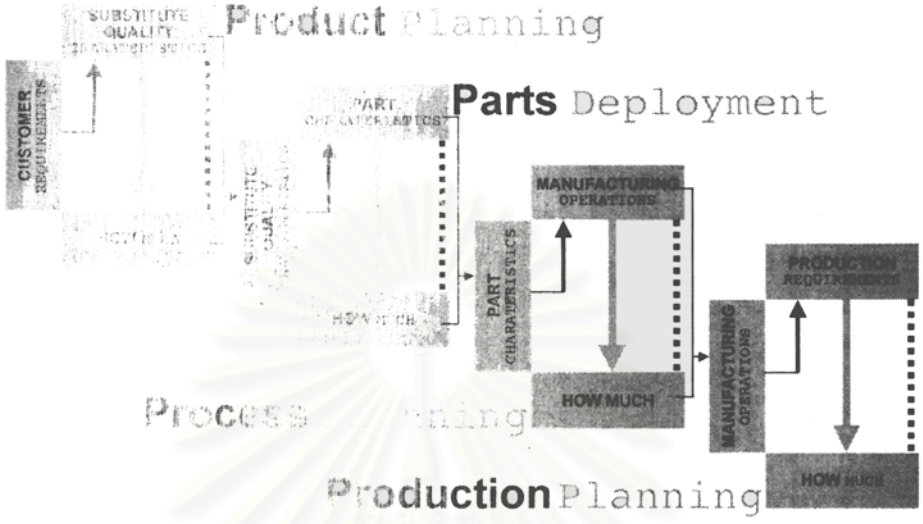

Figure 3.2: American Supplier Institute's Four Phase Approach of Quality Function Deployment (QFD)

From the figure 3.2, The Four Phase Approach start from the Phase-1 *Product Planning* where the customer requirement and the substitute quality characteristic are the input of the matrix (the traditional house of quality). The output of this matrix is the "How Much" is "Substitute Quality Characteristics". The qualitative and quantitative values of the "Substitute Quality Characteristics" are derived from the correlation of the customer requirement and the substitute characteristic. The researcher and researcher and design team will justify the proper value and decide the values of the output.

The phase-1 output then works as the input of the phase-2 *the Parts Deployment* where the "Substituted Quality Characteristics" and the part characteristics are addressed. By using the same methodology as the phase-1, the detail and specification of the parts can be derived from phase-2.

Phase-3: The *Process Planning* is the matrix that use the Manufacturing Operation and the Parts Characteristics output from phase 2 for the phase-3 matrix input, the researcher and researcher and design team will manage and assess the matrix to get the proper manufacturing operation requirement for the parts. This phase will provide the researcher and researcher and design team the idea of the workflow and the process requirement.

Final phase is the *production planning* where the manufacturing requirement is work as the input. Along with the production requirement of the manufacturing facility

this phase will identify manufacturing facility, the proper production steps, work load, production planing, labor, material and quality control for the production of the design product. The complete approach of the ASI four phases Quality Function Deployment (QFD) will provide the company to work systematically on design to production.

Another approach of QFD process is the GOAL/QPC approach, which the "Matrix of Matrices" is illustrated in figure 3.3.

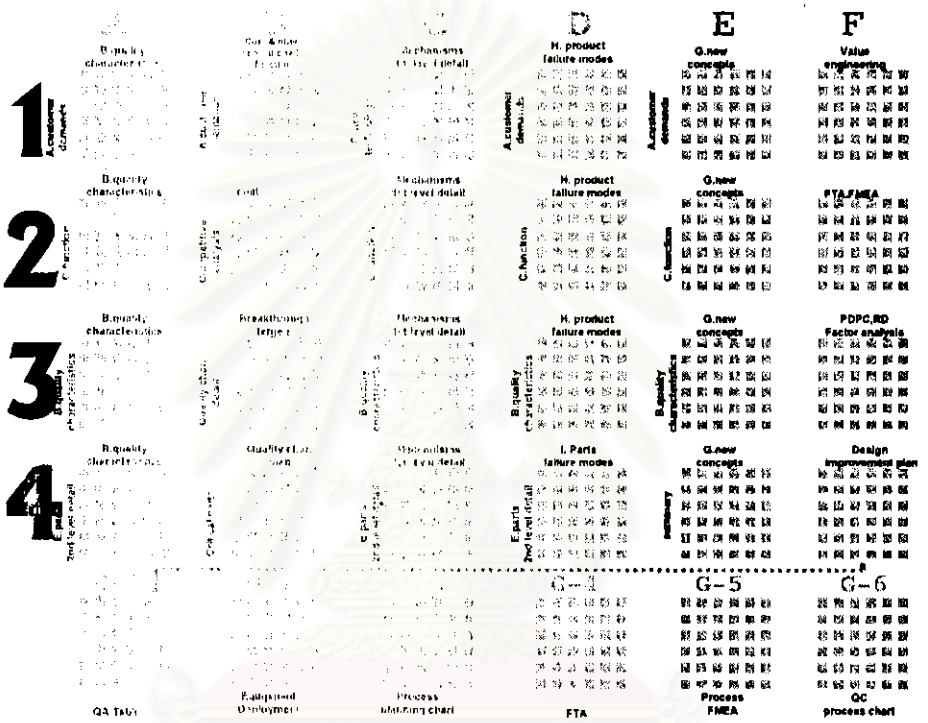

Figure 3.3: GOAL/QPC Research Committee, Quality Function Deployment (QFD) Approach: Matrix of Matrices

Figure 3.3 Ilustrate the 30 matrices that put into one large matrix, the matrices referenced are A-F horizontal coordinate and 1-4 Vertical coordinate. At the last row of the matrices the G1 to G6 matrix are the additional matrices that not put into the coordinate. Each matrix serves individual task in QFD approach and will be discussed later.

The GOAL/QPC Research Committee Quality Function Deployment (QFD) approach composes of 30 matrices called "Matrix of Matrices" (Figure 3.3) by King Robert, in Better Design in Half the Time published by GOAL/QPC[1]. Figure 3.3, 3.4, 3.5 and tables 3.1 represent all GOAL/QPC Approaches from the book "From Concept to Customers"[2]. The Matrix of Matrices is the derivative of the ranges of QFD matrices that

[1] King Robert, Better Design in Half the Time, Methuen, MA: GOAL/QPC, 1987

[2] J. B. ReVelle, N. L. Frigon Sr. and H. K. Jackson Jr., From Concept to Customer: The Practical Guide to Integrated Product and Process Development and Business Process Reengineering, USA, Van Nostrand Reinhold, 1995, pp. 137-150

used in the design process. These 30 matrices are flexible and can be rearrange to fit each specific design objective. This innovative Quality Function Deployment (QFD) to complete the processes of the complex design task that large number of stakeholder and constrain being involved. The relationship between GOAL/QPC matrices is in the flowchart Figure 3.4.

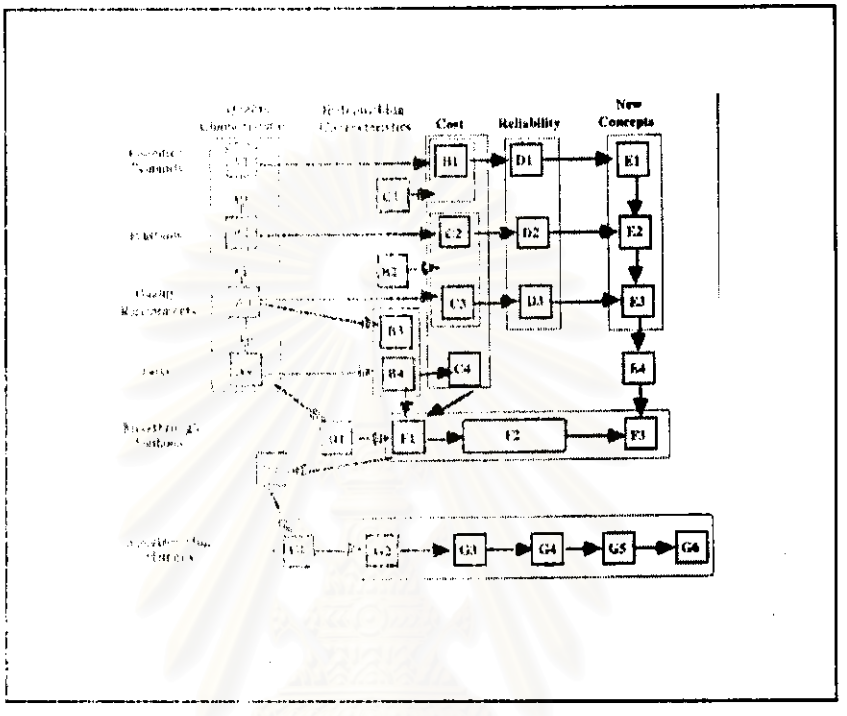

Figure 3.4: GOAL/QPC Quality Function Deployment (QFD) Approach: Matrix of Matrices Relationship.

In figure 3.4 the relationships of the matrices are represented into groups. The matrices are laid in the coordinate of two input, the arrows show the path of the output on one matrix that will served as the input to others.

From the matrices relationship various flows are indicated and each flow path is serving the different QFD objective. Table 3.1 is the description of the GOAL/QPC matrices required to work through for the different objective of QFD process. And Figure 3.5 is the matrices flow paths used in the GOAL/QPC Approaches.

Purpose to be achieved	**Matrices to be used**
Analyze Customer Demand	A1,B1,D1,E1
Critique Functions	A2,C2,D2,E2
Set Quality Characteristics	A1,A2,A3,A4,B3,B4,C3,D3,E3
Identify Critical Parts	A4,B4,C4,E4
Set Breakthrough Targets	C1,B2,B3,B4
Set Reliability Targets	D1,D2,D3,D4
Select New Concepts	E1,E2,E3,E4
Identify Breakthrough Methods	D4,F1,F2,F3

Identify Manufacturing Method	G1,G2,G3,G4,G5,G6

Table 3.1: GOAL/QPC Quality Function Deployment (QFD) Approach, Matrix of Matrices Relationship: Purpose to be achieved and Matrix required

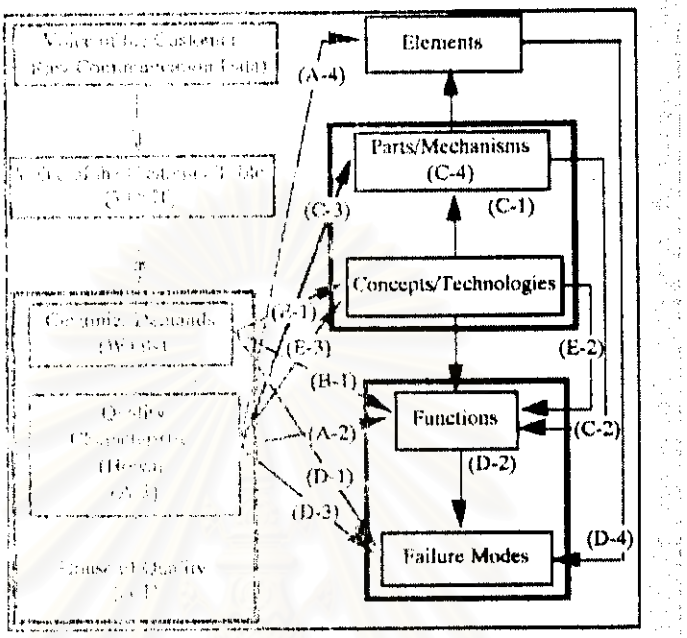

Figure 3.5: GOAL/QPC Quality Function Deployment (QFD) Approach, Matrix Flow

From the figure 3.5, the GOAL/QPC QFD Approach process is shown. Each box indicate the function that need to work through while the arrows show the matrices that needed to complete the QFD process.

The GOAL/QPC Quality Function Deployment (QFD) approach is complex but yet systematic and flexible. The matrices can be selected and can be adjusted to fit the individual requirement of the design product and process. This approach can be very useful for improving the product design and process development methodology.

The major problem that exists in the inexperienced researcher and researcher and design teams who trying to use the ASI and GOAL/QPC Quality Function Deployment (QFD) approaches is the complexity. Selecting the proper matrices and the proper sequences to reach the goal are very confusing. By the help of a software program QFD/Pathway™, developed by J. B. ReVelle and Alan Kemerling in 1997, the program output will give the researcher and researcher and design team adequate details for Quality Function Deployment (QFD) process. The QFD/Pathway™ outputs are:

- ✓ Matrices required to accomplish the design objective

- ✓ Sequence of Matrices
- ✓ Concurrent Engineering Opportunity
- ✓ Procedures of each Matrix

3.1 QFD/Pathway for design Air Handling Unit (AHU) in Thailand

Since the Quality Function Deployment (QFD) is a new design process to the Thailand air conditioning industries, all the processes, methods and the interpretation of the Quality Function Deployment Matrices will be further described. All steps are displayed in the Quality Function Deployment (QFD) Process Flow flowchart that generates from the output of the QFD/Pathway™.

When starting the software, the QFD/Pathway will show the welcome screen as illustrated in figure 3.6

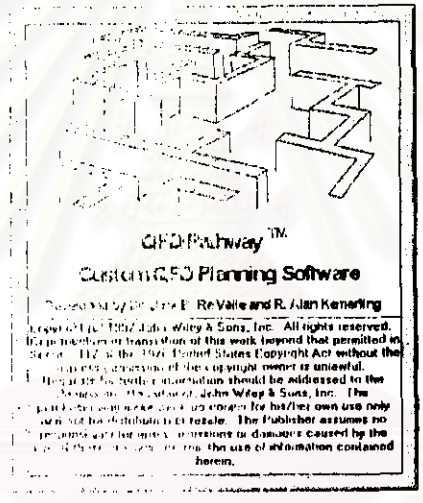

Figure 3.6 QFD/Pathway™ Welcome Screen

Figure 3.6 is the welcome screen of QFD/Pathway™. After start the program this welcome screen will appear for 3 seconds and then it move to the selection screen, which is illustrated in figure 3.7

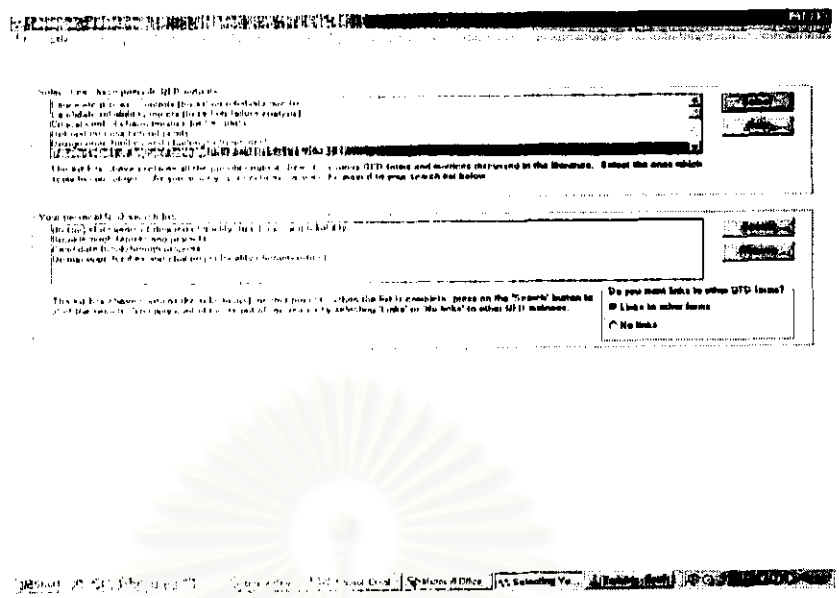

Figure 3.7 QFD/Pathway™ Selection Screen

The selection screen in figure 3.7 is the main screen of input the requirement of QFD process to the QFD/Pathway™. There are two sections of the screen; top section is the input part by selecting the "possible QFD output" that the item need for QFD process requirement. Lower section shows the selected QFD process output. When the selection is completed user can click at the search button as shown in figure 5.7 and the software is begin to work and generate the proper QFD output base on selected QFD possible output.

The List of the design objectives available in the software QFD/Pathway™ is as follow:

- (Better) statements of demanded quality, functions, and reliability
- Key substitute quality characteristics related to customer demands
- Key design priorities related to customer demands
- Key product or service functions
- Functions with little or no customer need
- Value of new concepts relative to functions
- Substitute quality characteristic interrelationships
- Design opportunities and challenges (quality characteristics)
- Quality system support for better parts
- Potential process failure modes and causes at all process levels
- Process corrective action information
- Guidance on the best supplier (internal or external)
- Defined process control points
- Detailed plans of process controls
- Value of new concepts relative to quality characteristics
- Value of new concepts relative to customer demands, functions and quality characteristics
- Function interrelationships
- Design opportunities and challenges (functions)
- Key parts for special controls and optimization
- Functions targeted for cost reduction

The List of the design objectives available in the software QFD/Pathway, continue from previous page:

- Targeted manufacturing cost
- Targeted service delivery cost
- Breakthrough targets and projects
- Value of new concepts relative to customer demands
- Missing data on key parts
- Opportunities for improvement on key parts
- Potential new technologies to introduce
- Potential new materials to introduce
- Mechanism opportunities for cost reduction
- Mechanisms targeted for breakthrough
- Parts targeted for value engineering
- Prioritized value analysis (value engineering) projects
- Key failure modes (prioritized by customer demand)
- Key failure modes (prioritized by product functions)
- Key failure modes (prioritized by substitute quality characteristics)
- Prioritized FMEA projects (prioritized by key parts)
- Candidate reduction controls (based on reliability needs)
- Candidate reliability projects (based on failure analysis)
- Candidate breakthrough projects
- Table of design improvement projects and considerations

In improving the current Air Handling Unit (AHU) design the following design objective shall be chosen

- (Better) Statements of demanded quality, functions and reliability
- Design opportunities and challenges (quality characteristics)
- Key design priorities related to customer demands
- Key substitute quality characteristic interrelationship, and
- Value of new concepts relative to customer demands, function and quality characteristics.

This thesis will focus only on the Air Handling Unit (AHU) application design and equipment selections for a rubber skin AHU. The design of detail design and manufacturing process shall not be considered. Thus, design objective shall focus only on retrieving customer demand and concept design evaluation.

The output generated from QFD/Pathway™ has two parts. First part is the "Planning Summary" and another part is the "Detailed of each matrix". The *Planning Summary* will display the matrices that required for completing the selected QFD output in selection screen. *Planning Summary* will show researcher and researcher and design team which matrices can directly take the result and which step can concurrently work to reduce process time.

Additional report generated from QFD/Pathway™ is "Detail of each matrix". All of the matrices that listed in the "Planning Summary" will be detailed in each process, procedure to complete the matrix

For this Air Handling Unit (AHU) design improvement, the QFD/Pathway™ generates following output:

Planning summary -
You selected the following QFD outputs for your project:
- (Voice) statements of demanded quality, functions, and reliability
- Design opportunities and challenges (quality characteristics)
- Key design priorities related to customer demands
- Key substitute quality characteristics related to customer demands
- Substitute quality characteristic interrelationships
- Value of new concepts relative to customer demands, functions and quality characteristics
The following QFD matrices:
VOCT * Voice of the Customer Table
A1 * Demanded Quality and Substitute Quality Characteristics
A2 Functions and Substitute Quality Characteristics
A3 * Substitute Quality Characteristics Compared
E4 * New Concept Selection Summary
An asterisk beside the matrix name indicates that you directly selected its output. No asterisk beside a chart symbol indicates that it is required to provide an input to another chart.
Select DETAILS from the menu above for more information on these charts.
The following QFD charts offer an opportunity for concurrent QFD activity. This may reduce overall project cycle time. Each row introduces a combination with common inputs.
A2 A3
Select the Details option in the menu above for information on each QFD chart above.

From the output the following matrices need to work through:

VOCT *	Voice of the Customer Table
A1 *	Demanded Quality and Substitute Quality Characteristics
A2	Functions and Substitute Quality Characteristics
A3 *	Substitute Quality Characteristics Compared
E4 *	New Concept Selection Summary

The detailed of each matrix procedures are shown in the Appendix 1.

The QFD/Pathway™ shows the five steps that needed to work through for achieving the Air Handling Unit (AHU) design improvement the flowcharted is developed to represent the flow of the matrices and illustrated in Figure 3.8

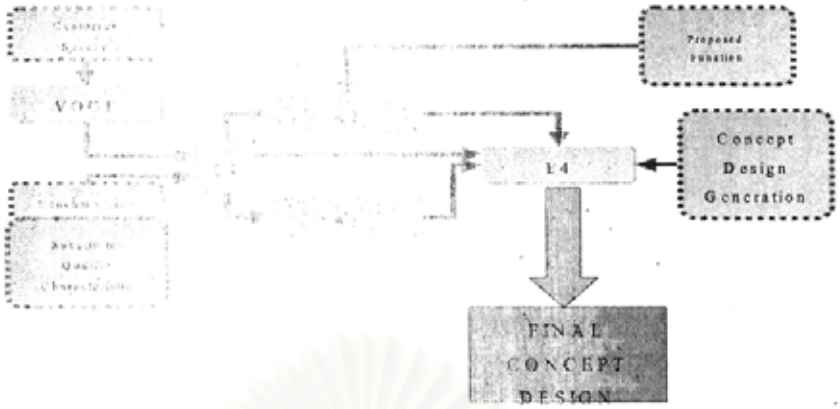

Figure 3.3. Quality Function Deployment (QFD) Process Flow for Air Handling Unit (AHU) design improvement

The Quality Function Deployment (QFD) process Step-1 for the design improvement of double skin Air Handling Unit (AHU) for production in Thailand will start at finding the customer demand through the customer survey. The customers verbatim is put into the Voice of Customer Table (VOCT) for clarify stratify and arranging. The result of the VOCT will be the better customer demand quality, function, reliability and unacceptable failure mode statements.

Step 2 is the analysis the "House of Quality" matrix A1 which the input are:

- Better Statements of Customer Demand Quality, Function, Reliability and Unacceptable Failure Mode from the VOCT
- Substitute Quality Characteristic
- Competitive Benchmarking on the Customer Demands and
- Technical Benchmarking

The output of the Matrix A1 are

- Key Substitute quality characteristics related to customer demands
- Key design priorities related to customer demands
- Identification of customer reliability expectation

Step-3 and Step-4. The concurrent Matrix A2-A3 . The A2 Chart will use the proposed functions by the new author and researcher and design team and the output of the "House of Quality" as the input to assess the relation of the function and "Substitute Quality Characteristics" in the Matrix A2. Matrix A3 is the interrelationship between the "Substitute Quality Characteristics". The Matrix A-3 provides the relationship and effect of one "Substitute Quality Characteristics" to other "Substitute Quality Characteristics". The

output of the Matrix A2 will be then used as the input of the Matrix E4 for the concept selection phase. The output of the Matrix A3 will set aside and use for design reference.

The Step-5: the Concept Selection Summary, which works by using the Customer Demand of Quality, Function and Reliability in Matrix A1, the Key Product Functions in Matrix A2 and the concept generated by the researcher and researcher and design team as inputs. The Matrix E4 will compare the concepts generated by researcher and researcher and design team and the output will be the selected "best in the class" design concept for further product design. The selected concept from the Matrix E4 is used as the master product concept for detail design in ongoing sections.

3.2 QFD Team Setup

In implementing the QFD to the design process the researcher and researcher and design team must be setup. QFD approach is the team process that the number of expertise in various fields e.g product designer, marketing, manufacturing engineers, and finance staffs are involved in the process. To successfully implementing the QFD to the product development process following field of expertise is required for the team.

The team member should have following qualification:

1. Understand the process of QFD
2. Have background knowledge of the focused product or relevant filed
3. Ability to work in team not individualist
4. Innovative thinking

In this AHU design improvements following is the list of the team members:

1. QFD project leader, design engineer (the researcher)
2. HVAC engineer
3. Production Engineer
4. Marketing Staff
5. Service Engineer

Addition members that party involved in the QFD process are:

- ✓ Suppliers
- ✓ Customers
- ✓ Finance Staff

The five main members are directly involved in the project in full-time basis, the variety of team expertise broaden the ideas of the researcher and researcher and design team and increase the effectiveness of the design improvement of the AHU. Team working also extended the team member knowledge and point of view in product development process. Additional part-time members are invited to provide specific opinions from specific point of view. The involvement of the external expertise increase the design improvements to be better and right to the objective.

3.3 Retrieving the customers demands in market

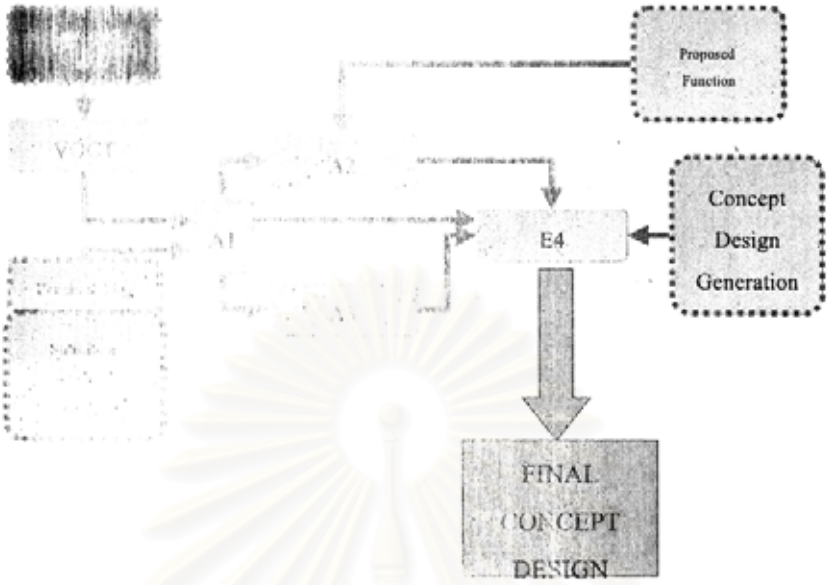

Figure 3.2 Quality Function Deployment (QFD) Process Flow: Customer Survey

Figure 3.2 illustrate the step that currently discussed in the QFD process. The dark shaded [illegible] process.

In order to get the actual voice of the customers, proper marketing survey must be prepared and conducted. The key customers in the focus group will be individually interviewed, to get the variations demands. The demand obtained will be the input for Voice of Customers Table (VOCT).

3.3.1 *Focus Group*

- [illegible] Engineering Consultant Company

The engineering consultants are playing key role in design and selecting the Air Handling Unit (AHU) for the customers. This group generates the engineering specification demand in the industries and controlling the direction of the engineering trend of the system design. With the in-depth understanding of design and installation of the Air Handling Unit (AHU), including the commissioning the installed AHU the Mechanical Engineering Consultant can provide broad range and actual demand of the Air Handling Unit (AHU) in system design and equipment selection.

- Semiconductor Factory

The semiconductor factory are the largest customers of the double skin air handling unit, which require the large amount of air volume, high static pressure and the endurance operation. Most of the factories in Thailand are operated on twenty-four hours,

and three-shift basis. The Air Handling Unit (AHU) is operated almost whole year with the minimum shutdown for maintenance. Engineers, technicians and the staffs who involved in using the Air Handling Unit (AHU) in this type of facility will be the great source and good representative of the end users of the Air Handling Unit (AHU).

- Pharmaceutical & Health Care Product Factory

Same as the semiconductor industries, the Pharmaceutical Factory is another segment of Air Handling Unit (AHU)'s customers that have a high selection criteria. The air cleanliness requirement and the endurance usage of the Air Handling Unit (AHU) in the facility will be another important factor effect the design. The information from this segment shall be another good source for the AHU requirements.

- Air Handling Unit (AHU) Manufacturer

The Air Handling Unit (AHU) manufacturer is a very good source to verifying the design and retrieving the problems of the current design for production. The involvement of the manufacturing side in the design process is vital. The designer can share the manufacturing experience for robust design.

- Engineering Contractor

The contractors are the one who installing the Air Handling Unit (AHU) on the customer sites. Since they are installing many brand of AHU, the engineering contractor perceived a lot of product information in all aspect. The experiences and the knowledge on the products that they used to work with are the vital information for the AHU researcher and researcher and design team. They are good sources of information for the serviceability, installation and maintainability of various brands of the Air Handling Unit (AHU) in the market.

3.3.2 Conducting the Customer Survey

In the customer survey process, the researcher successfully arrange the meeting with 7 key senior engineers in the focused group, three from the engineering consultant company: EEC Co., LTD., ARTR CO., LTD and W & ASSOCIATE, one from the semiconductor factory: AMD (Thailand) Co., LTD, one from AHU manufacturer (reference company) and two from the engineering contractor: Electrowatt Co., Ltd., Thao Obayashi Co. LTD. The verbatim of the interview is interpreted and concludes into the English Language for reference and used in the VOCT as shown in the Appendix 2. Unfortunately, the researcher cannot arrange the meeting with the facility manager of pharmaceutical segment. But the information obtain from those seven contributors is enough to start the VOCT.

This small group of the interview meeting is very vital to the research, since all the contributors are the key engineers in Thailand HVAC industries and have strong influence in the using, designing and selecting the Air Handling Unit (AHU) for their projects and facilities. The information obtained from the contributors, many are the new ideas and the hidden demands of the function that existing designs of the Air Handling Unit (AHU) do not contain.

3.4 VOCT: Generating The Voice of customer Table

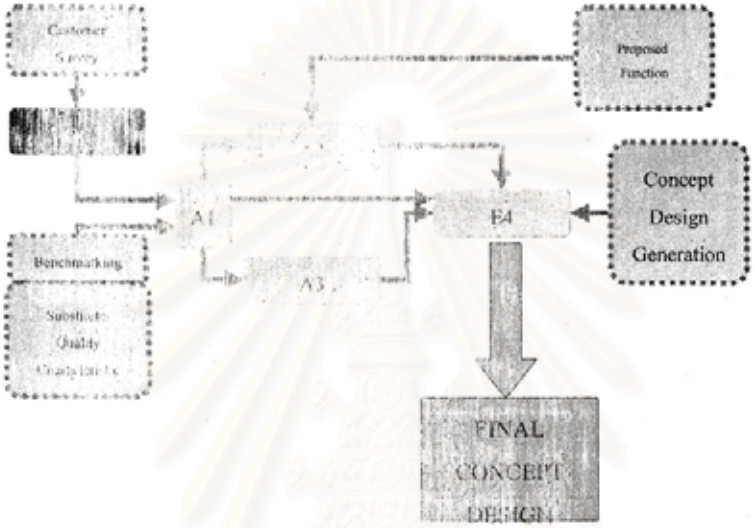

Figure 3.9: Quality Function Deployment (QFD) process flow: VOCT

Figure 3.9 illustrate the current step of AHU design improvement. Shaded VOCT block indicated the current step. The AHU customers surveyed will be input of this step. The customer's verbatim will be arranged and stratified for used in QFD matrix A1.

3.4.1 Voice of Customer Table

The Voice of Customer Table (VOCT) is the first step of the Quality Function Deployment (QFD) approach. This VOCT will arrange the verbatim of the customers into the designer understandable language. The customer verbatim will be re-arranged, re-worded, stratified and grouped into following categories:

- The Statements of Customer Demand Quality
- The Statements of Customer Demand Function
- The Statements of Customer Demand Reliability and
- The Statements of Unacceptable Failure Modes

Those four categories are the outputs of the VOCT and will be used in the Matrix A1 "House of Quality" in the next step.

Also included in the VOCT is the marketing data that related to the source of information that used to verify the importance of the customer's verbatim. The data will be stated in the customer demographics. In general the customers demographic will be the sex, age, occupation, income and etc. For Air Handling Unit (AHU) design improvement, the customer demographic will be focused on the job position of the customers, their usage of the Air Handling Unit (AHU), and their experience background.

The example of the VOCT for this Air Handling Unit (AHU) design improvement is shown in table 3.2. The complete VOCT of seven contributors are shown in the Appendix 2 for references.

3.4.2 How The VOCT works

This section will discuss background of VOCT. First Column of the VOCT is the customer verbatim, the data should be undistorted customer verbatim that the customer discussed about the Air Handling Unit (AHU), their requirement, experience on working with the Air Handling Unit (AHU), their comments and ideas. The necessary customer demographics is then put into the second column where the job function, the usage of the Air Handling Unit (AHU) and the experience about the Air Handling Unit (AHU) are described.

The designer has to re-state the verbatim into the usable form of the data and categorized into another two columns:

- Customer Demand Function

The customer demand function is the basic function of the Air Handling Unit (AHU) that the customer is expecting. The function is not the special feature or the expectation of quality of the Air Handling Unit (AHU).

- Customer Demand Reliability

The customer demand reliability is the point that the customer addresses on the reliability of the Air Handling Unit (AHU). The demand reliability can be both quantitative and qualitative value.

Then the researcher and researcher and design team is responsible to re-address the Verbatim, Demand Function and Demand Quality into the usable format that the designer can perfectly understand.

The re-written statements will than categorized in four columns on the right:

- The Statements of Customer Demand Quality
- The Statements of Customer Demand Function
- The Statements of Customer Demand Reliability and
- The Statements of unacceptable failure modes

The result of each customer VOCT then put together for further used. The duplicated meaning of the demand is deleted. And re-arrange for use in other Quality Function Deployment (QFD) matrices. Example of the completed VOCT is shown in Table 5.2.

Verbatim	Customer Demographics	Customer Expectation of Function	Customer Expectation of Reliability	Statement of Customer Demanded Quality	Statement of Customer Demanded Function	Statement of Customer Demanded Reliability	Statement of Unacceptable Failure Modes
No Sweating and condensation at the external AHU surface when operation on the normal condition. The AHU should be able to use multi stages, variable position of equipment. The drain pan must be clean, easy flow. The vibration and noise should be low. The size of the AHU should be modular. Easy to access the major equipment for services, such as motor, fan, pulleys, baring, coil and filter. The Construction must be rugged and rigid. Able to install on floor or hanging platform. Good Price performance/ total investment trade off.	Senior Design Mechanical Engineer. Selecting and Recommend the AHU to customers.	• Deliver Cooled/Heated Air. • Humidity Control • Dust Control • Duct Connected • Connectable to monitoring and control* equipment	• No Condensation • Accurate Air Volume • Quality of Assembly • Air Tight Service Door • Baring Life • Low vibration during running	• Air Humidity Control • Air Volume Control • No Thermal Bridge • Air Tight at the operating Pressure • Access to the internal components • On Floor Installation • On Hanging Plat Form Installation • Strong Construction • Modularity Sizing • Low Vibration • Low Noise Generation • Dry Drain Pan • Good Value for Money • Multi-Stages, selectable modular component	• Deliver Cooled Air • Deliver Hot Air • Air Cleanliness Control • Connected to Air Distribution Systems • Monitoring equipment installable • Controlling equipment installable	• Workmanship • No Thermal Bridge • Long Baring Life • Air Tight Service Door • Low Vibration	• Leakage Service Door • Thermal Bridge • Vibration during operation • Loud Operating Noise • Leakage air from the unit

Table 3.2: Example of the VOCT

In this Air Handling Unit (AHU) product design improvement, the seven VOCTs are completed by the QFD team. The references of the completed VOCTs are shown in Appendix 2. In order to used the VOCT for further customer surveys, the output of each AHU customer's VOCT table is put together, all customer demanded quality, function, reliability and unacceptable failure mode are listed in table 3.3. Further usage of this data will be discussed in next section.

Statement of Customer Demanded Quality	Statement of Customer Demanded Function	Statement of Customer Demanded Reliability	Statement of Unacceptable Failure Modes
• Flexible Configuration • Modular in cross section size • Modular in equipment • Knock down • Clean internal construction • Pipe Connection • Wiring Terminal • Duct Connection • Color Finished Exterior • Multi Material Interior • Sufficient Insulation • Easy to remove & install wall panel • East to Assembly • Easy to install	• Deliver Constant Air • Conditioned the Air • Modular Section Size • Modular Equipment Section • Safety Protection for moving and dangerous part • Knock Down • Protection of Water Carry Over from Coil • Dry Drain Pan • Lighting Equipment	• Thermal Insulation • Thermal Bridge • Low Vibration • Low Noise • Non-Corrosive • Good Fan Performance • 100000hr. service life	• Air Leakage of the Unit and Access Door • Condensation at Exterior • Load Noise • High Vibration • Generate dust

Table 3.3: The VOCT output of the Air Handling Unit (AHU) design improvement

3.4.3 *Managing the Statements of Demanded Quality, Function and Reliability*

The output of the VOCT is not yet ready to be used in the "House of Quality" the Matrix A1. The Customer Demanded Quality, Function and Reliability should be weighed to identify the importance level of each demand. In order to obtain the voice of the customer on the importance level of each demand, customer survey is a good methodology to complete the weighing. The researcher decided to use two phases of the survey to obtain the better feedback from the customers.

The first phase, researcher use the output of the VOCT as the start demand and include five blank demand for fill in, the customer is given the important of each demand in weight scale range of 0 to 9 from the least importance demand to the most importance demand. The customers are allowed to fill-in additional demand, which they think it should be added and give weight. The first stages score is then calculated and averaged each demand weight and rounded the decimal to the nearest integer. The additional demands form the customer are grouped, stratified and selected for use in the second phase survey.

The second phase survey, same selected demand from first phase is used in the questionnaires. Customers who already completed the first phase surveys are the survey focused group without allowing the customers to add any further demands. The completed weighting scores will return to researcher and averaged demand weights are calculated, rounded to the nearest integer. The completed weight scores will be used in other Quality Function Deployment (QFD) matrices, especially Matrix A1 for Air Handling Unit (AHU) design improvement.

3.4.4 *Final Survey Result*

From the 100 surveys taken, first phase 50 surveys and second phase 50 surveys, the table 3.4 shows the final result and the weight of the Customer Demanded Quality, Functions, Reliabilities and Unacceptable Failure Modes. The detail scoring and weight calculation is shown in the Appendix 3 for references.

From now on the "Customer Demanded Quality, Functions, Reliabilities and Unacceptable Failure Modes" will be called as "Customer Demands".

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Table 3.4: The final result and weight of the customer demands

The table 3.4 shows the unsorted list of the weighted customer demands that gathered from the customer surveys.

3.5 QFD Matrix A1: Demanded Quality and Substitute Quality

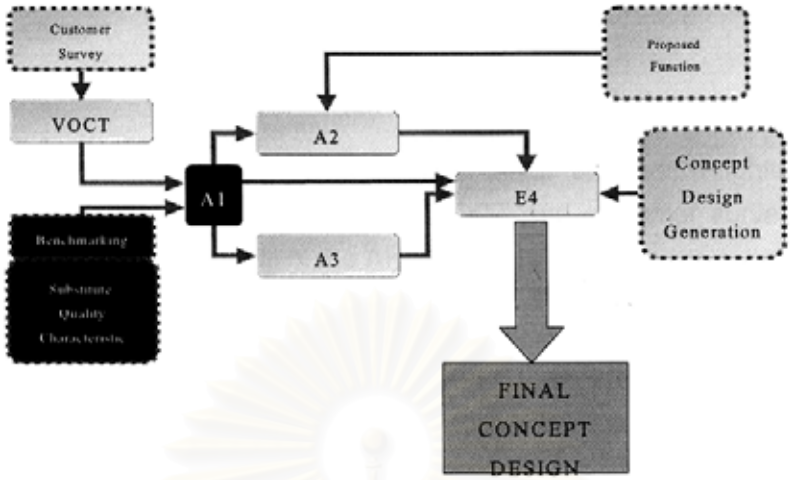

Figure 3.11: Quality Function Deployment (QFD) Process Flow: Matrix A1

The Figure 3.11 illustrates the current step of AHU design improvement. At this step, there are three major works need to be done for completing the QFD matrix A1. Those three major works are 1) The Technical Benchmarking of competitors over the "Substitute Quality Characteristics" 2) Competitive Benchmarking of competitors over the "Customer Demands " and 3) the Correlation Scoring of the "Customer Demands" and the "Substitute Quality Characteristics"

The Quality Function Deployment (QFD) Matrix A1 or the "House of Quality" is the origin of the Quality Function Deployment (QFD) process. This key matrix begin with the input from the VOCT: the Customer Demanded Quality, Customer Demanded Functions and Customers Demanded Reliability along with their weighting and priority. The A1 Matrix is composed with six important areas as shown in Figure 3.12

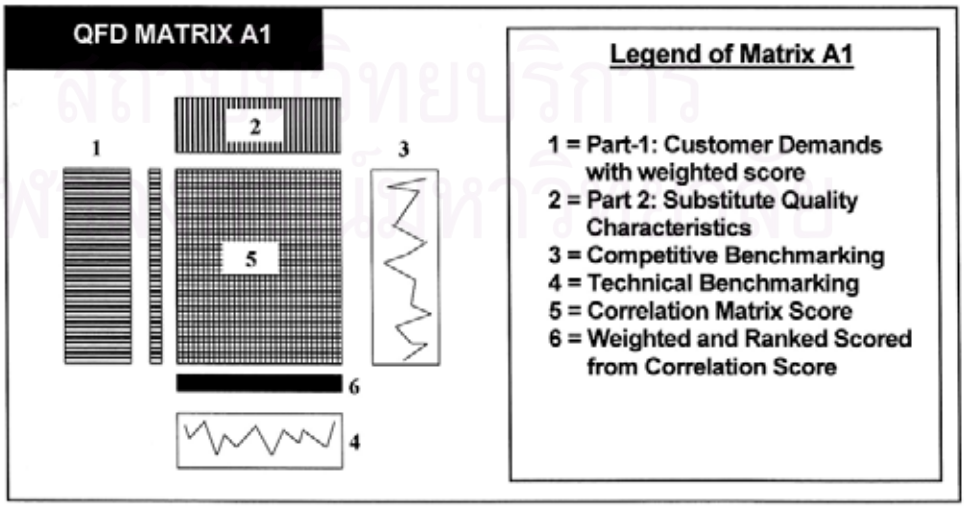

Figure 3.12: The Quality Function Deployment (QFD) Matrix A1

The figure 3.12 illustrates the split section of the QFD Matrix A1, each section definition is shown in the legend and the usage of each split section will be discussed in next thesis section.

3.5.1 How the QFD Matrix A1 Works

The Part-1 is the list of "Customer Demands" and their weighted score, which can be obtained from the customers via the VOCT and customer survey. This section represents the customer demands of the AHU products

The Part-2 is the "Substitute Quality Characteristics". The substitute characteristics are obtained from the researcher and researcher and design team idea, brainstorming and group discussion on the focus product or process design. The Substitute Quality Characteristics are measurable design target for the focus product, service and process. This Substitute Quality Characteristics can be adjusted to meet the "Customer Demands".

Part-3 is the competitive benchmarking diagram. The key competitors in the market are benchmarked against the "Customer Demands". The detail of the benchmarking process will be discussed in section 3.5.1.2. The competitive benchmarking provide the status of the focus brand compared to competitors.

Part-4 is the technical benchmarking diagram. The key competitors in the market are benchmarked against the "Substitute Quality Characteristic". The detail of the benchmarking process will discussed in section 3.5.1.2. The technical benchmarking provide the status of the focused brand compare to the competitors in technical side.

Part-5 is the correlation matrix, the customer demands and the "Substituted Quality Characteristics" are given the correlation score which are 9, 3, 1 and 0 (In traditional Quality Function Deployment (QFD), symbols are used instead of number). The correlation score are as follow:

9 = High Correlation

3 = Medium Correlation

1 = Low Correlation and

0 = No Correlation.

Part-6 is the Weight and Ranked of the correlated "Substituted Quality Characteristics" , which will be discussed in section 3.5.1.1

3.5.1.1 The Correlation Score

The 9, 3, 1 and 0 score are working as the important number in this A1 Matrix. AHU researcher and researcher and design team members have to determine the effect of the "Substituted Quality Characteristics" to the "Customer Demands" and put the score in each coordinate of "Substituted Quality Characteristics" and "Customer Demands". After completed the correlation scoring, the researcher and researcher and design team must calculate the total score of each "Substituted Quality Characteristics" by multiplying each correlation score with the "Customer Demands" weight on same row. The sum of multiplied correlation score in each "Substituted Quality Characteristics" column indicates the important value of each "Substituted Quality Characteristics". The sum of each column is the weight of the substitute characteristic, which is very useful for further analysis. In practical, the "Substituted Quality Characteristics" weight will be sorted into the ordered to determine the importance of each developed "Substituted Quality Characteristics".

3.5.1.2 The Benchmarking Process

There are two Benchmarking processes in the Matrix A1, the Competitive Benchmarking and the Technical Benchmarking. The Competitive Benchmarking is the process that compares the focused brand with the competitors in term of satisfaction levels to the "Customer Demands". This benchmarking is done across the rows of Matrix A1. The Technical Benchmarking is the process that compares the focused brand with the competitors in term of satisfaction levels to "Substituted Quality Characteristics". This benchmarking is done across the columns of Matrix A1.

The benchmarking will grade the competitors and the focused brand with the five satisfaction levels: Poor, Moderate-Poor, Moderate, Moderate-Good, and Good. Symbols represented the focused brand and the competitors are used to avoid benchmarking bias on the brand in this thesis. In the Benchmarking Diagrams in each benchmarking subject the symbols will be put in to the different levels of satisfactory and will be used to indicate focused brand compare to the competitors. It also suggest the important area that need to improve or already outstanding.

In this Air Handling Unit (AHU) design improvement the researcher and researcher and design team is responsible to work on the Technical Benchmarking by selecting the major AHU brands in to the benchmarking process. The technical benchmarking result is based on the judgement of the researcher and researcher and design team. For the Competitor Benchmarking, the AHU customer is asked in the surveys to compare each AHU brand on their demands. Those survey data is used to be the input for the Competitor Benchmarking.

3.5.2 *Analyzing the result*

There are three major areas of the Quality Function Deployment (QFD) Matrix A1 output, which is the important information for researcher and researcher and design team:

- Weight of the Substitute Quality Characteristic

The "Substituted Quality Characteristics" weights that obtained from each substitute column are ranked from the highest to the lowest. The high "Substituted Quality Characteristics" are the **Key Design Priorities** that the researcher and researcher and design team needs to focus on design and improvement. This high ranked "Substituted Quality Characteristics" is also represent the **Key "Substituted Quality Characteristics"** that related to customer demand.

- The Competitive Benchmarking related to Weight of "Customer Demands"

The competitive benchmarking will show the opportunity to improve the product. In comparing with the competitors, the designer can focus to improve the product in some specific areas to develop the competitive edges over the competitors to meet the "Customer Demands". On the other hand, the poor product quality from the customer's point of view can be noticed and the opportunities of product improvement on specific "Customer Demands" areas can be addressed.

- The Technical Benchmarking related to the Weight of "Substituted Quality Characteristics"

The technical benchmarking will show the opportunity "Substituted Quality Characteristics" that the researcher and researcher and design team can focus in design and improvement, especially for the high ranked "Substituted Quality Characteristics".

3.5.3 *The Completed QFD Matrix A1*

In this Air Handling Unit (AHU) design improvement, The Part-1 of the Matrix A1 is the "Customer Demands" that sorted by "Customer Demands" weight. The important issue is the development of "Substituted Quality Characteristics" for this new AHU. Researcher and researcher and design team innovative is needed to generate the new paradigm of the AHU design and improving the current identified problems.

The researcher and researcher and design team meeting is arranged for brainstorming the possible "Substituted Quality Characteristics". Cycles of brainstorming generate the tentative "Substituted Quality Characteristics" for AHU. The final list of the "Substituted Quality Characteristics" is shown in Table 3.5. This is the input to Part-2 of Quality Function Deployment (QFD) Matrix A-1.

Substitute Quality Characteristic
Double Skin Construction 2", Theimal transmission insulation 1-1.4 W/m2/K
Door and Service Panel Removal in 1 min
Rigid-Tough Construction
Centrifugal Fan Installation
Insulated Drained Floor(With Expanded metal cat walk, on large unit)
Knock Down Structure
High Performance Fan & Drive
Stackable Unit 2 level
4,6,8,10,12 roll Cooling Coil with various fin type
Internal Inlet Damper @ Mixing Box
Height Variable Base Structure 10cm-20cm
V Groved Elevated Drain Pan
Fan Set Vibration Isolator
Service Door Air Tight 100%
Service Panel-Air Tight 100%
Heating Element
Multi-Choise Internal Skin
Fool Proof For Conenction
Perfect Sealed Gasket
180 Removable Pin Hinge for Access Door
Modular Filter Section 305x305
Section Lebeling Indicator
305mm Base Dimension Modular (Internal)
Colour Coated Interior
Out Let Flange
Walkable Unit Top: 400 kg
Insulated Sight Glass
Water Pipe Header
Guide Hole-Guide Pin for Installation
Air Washer Section
Forklift Access From Side
Lift Hook
Coil velocity up to 700 fpm
Wiring Terminal for Power Connector
Multi-Choise Insulation (PU, PS, Rockwool, Fiberglass)
Powder Coated Exterior
Inlet Flange, Duct Bolt Connect
Side Access Pre Filter & Medium Filter Housing
Multi-Type-Fan Configuration
Wire Guide-Wire Way
Assembly Fool Proof
Droplet Eliminator after coil
Coil Sliding
Control Connector Terminal
Air Mixer
Mixing Box
Internal Lighting Switch
0,90,180,270/ L-R degree blow outlet
Fan Inlet Guard
Lighting IP55
Shaft Guard
Belt Guard
Trap In alarm

Table 3.5 Substitute Quality Characteristic of the Air Handling Unit (AHU)

The list of "Substituted Quality Characteristics" in the table 3.5 is put in the Part-2 of the QFD Matrix A1. This "Substituted Quality Characteristics" will be used for Technical Benchmarking for AHU product in Thailand market.

Another part that the researcher and researcher and design team used for QFD matrix A1 inputs is the competitive benchmarking. As mentioned, the competitive benchmarking is done by the customers in the customer surveys. The researcher and researcher and design team re-arranged the data from the surveys. The symbols represent focused brands and competitors are plotted on the competitive benchmarking chart. In this benchmarking the focused brand is represented by the "Star" symbols and the competitors are represented by the numbers (1 to 5) The completed plotted competitive benchmarking that derived from the customer surveys are shown in Table 3.6

"Customer Demands"	Average Score	Competitive Benchmarking				
		BAD		Moderate		Good
Air Humidity Control	9			★①②③⑤	④	⑥
Air Tight at the operating Pressure	9		★①③	⑤		②④
Connected to Air Distribution Systems	9	⑤			★①②③④	
Deliver Cooled Air	9				★①②③④⑤	
Multi-Stages, selectable modular component	9		⑤		★①②③④	
No Thermal Bridge	9		①	★③⑤	②④	
On Floor Installation	9				★①②③④⑤	
On Hanging Plat Form Installation	9		⑤	★①③④	②	
Easy to maintenance	9				★①③⑤	②④
Small Foot Print	9		⑤	★①②③④		
Access to the internal components	8			①③	★②④⑤	
Accurate Air Volume	8		★①②③⑤			④
Air Tight Service Door	8		★①③	⑤		②④
Clean internal construction	8	①⑤		★②③	④	
Color Finished Exterior	8	①③	⑤	★②	④	
Easy to remove & install wall panel	8	①③⑤	④	★	②	
Good Fan Performance	8	★①②③⑤			④	
Lighting Equipment	8	★①③⑤			②④	
Long Maintenance Life	8		★⑤	①③	②	④
Low Noise Generation	8	⑤	★①③		②④	
Low Vibration	8		①	★③⑤	②④	
Modularity Sizing	8	①②③	③	★④		
Monitoring equipment installable	8			★①②③④⑤		
Strong Construction	8			★①③	⑤	②④
Appearance	8		①	★③⑤	②④	
Air Volume Control	7			★①②③⑤	④	
Controlling equipment installable	7			★①②③④⑤		
Deliver Hot Air	7		⑤	★①②③	④	
Dry Drain Pan	7	⑤	★①	③	②	④
Flexible Configuration	7		⑤	★①③	②④	
Multi Material Insulation	7	★①②③④⑤				
Multi Material Interior	7		⑤	★①②③④		
Non-Corrosive	7		★①③⑤	②	④	
Protection of Water Carry Over from Coil	7			⑤	★①②③④	
Safety Protection for moving and dangerous part	7		★①②③⑤	④		
Anti Trap-in	7	★①②③④⑤				
Wiring Terminal	7	★①②③⑤			④	
Air Cleanliness Control	6		①③⑤	★⑤	④	
Knock down	6	⑤	①②④	★	③	
Color Finished Interior	5	★①③⑤			②④	

Table 3.6: Competitive benchmarking for the AHU

The completed competitive benchmarking will be placed in the Part-3 of the QFD Matrix A1. The analysis of the result of the competitive benchmarking will be discussed later.

The researcher and researcher and design team must complete the correlation scores of the "Customer Demands" and the "Substituted Quality Characteristics". Brainstorming among the researcher and design team generated the correlation score of each "Customer Demands" and "Substituted Quality Characteristics" coordinate. Then the total score is calculated by sum over the column of each "Substituted Quality Characteristics". The completed ranked of the "Substituted Quality Characteristics" is listed in table 3.7a and 3.7b. The completed ranked of "Substituted Quality Characteristics" is used for working on technical benchmarking.

Substitute Quality Characteristics		Rank
	Average Score	
Double Skin Construction 2", Theimal transmission insulation 1-1.4 W/m2/K	885	1
Door and Service Panel Removal in 1 min	858	2
Rigid-Tough Construction, 50kg/ cubic module	843	3
Centrifugal Fan Installation	784	4
Insulated Drained Floor(With Expanded metal cat walk, on large unit)	705	5
Knock Down Structure	690	6
High Performance Fan & Drive	685	7
Stackable Unit 3 level	684	8
4,6,8,10,12 roll Cooling Coil with various fin type	680	9
Internal Inlet Damper @ Mixing Box	613	10
Height Variable Base Structure 10cm-20cm	612	11
V Groved Elevated Drain Pan	597	12
Fan Set Vibration Isolator	537	13
Service Door Air Tight 100%	532	14
Service Panel-Air Tight 100%	532	15
Heating Element	510	16
Multi-Choise Internal Skin	473	17
Fool Proof For Conenction	438	18
Perfect Sealed Gasket	412	19
180 Removable Pin Hinge for Access Door	396	20
Modular Filter Section 305x305	393	21
Section Lebeling Indicator	389	22
305mm Base Dimension Modular (Internal)	385	23
Colour Coated Interior	378	24
Out Let Flange	373	25
Walkable Unit Top: 400 kg	365	26
Insulated Sight Glass	357	27
Water Pipe Header	354	28
Guide Hole-Guide Pin for Installation	351	29
Air Washer Section	346	30

Table 3.7a: Completed Ranked Scored "Substituted Quality Characteristics" for Double Skin AHU rank 1-30

Substitute Quality Characteristics	Average Score	Rank
Forklift Access From Side	346	31
Lift Hook	336	32
Coil velocity up to 700 fpm	332	33
Wiring Terminal for Power Connector	332	34
Multi-Choise Insulation (PU, PS, Rockwool, Fiberglass)	329	35
Powder Coated Exterior	312	36
Inlet Flange, Duct Bolt Connect	308	37
Side Access Pre Filter & Medium Filter Housing	306	38
Multi-Type-Fan Configuration	292	39
Wire Guide-Wire Way	257	40
Assembly Fool Proof	255	41
Droplet Eliminator after coil	246	42
Coil Sliding	217	43
Control Connector Terminal	210	44
Air Mixer	207	45
Mixing Box	143	46
Internal Lighting Switch	137	47
0,90,180,270/ L-R degree blow outlet	123	48
Fan Inlet Guard	114	49
Lighting IP55	108	50
Shaft Guard	108	51
Belt Guard	101	52
Trap In alarm	100	53

Table 3.7b:Completed Ranked Scored "Substituted Quality Characteristics" for Double Skin AHU rank 31-53

After the Part-5 is finished, the researcher and design team is moved forward to working on the Part-4 "Technical benchmarking" of the QFD Matrix A1. The technical benchmarking process is based on the work and judgement of the researcher and design team on each brand technical performances over the ranked "Substituted Quality Characteristics". To complete this technical benchmarking, the researcher and design team used the space for meeting at the warehouse where all competitors AHU that purchased for competitor's product study are kept side by side. All of the researcher and design team can see all AHU that are going to be benchmarked. Data can be obtained directly from the AHU to ensure that there is the minimum tolerance on technical benchmarking.

Large technical benchmarking chart is set on the wall. Brainstorming and discussions on each competitor AHU performances related to the developed "Substituted Quality Characteristics" generate the scoring level. The score and the symbols used are based on the same criteria of the competitor benchmarking. The focused brand is represented by the "Star" symbols and the numbers (1 to 5) represents the competitors. The symbols are plotted on the chart for each brand satisfactory level upon each "Substituted Quality Characteristics". The completed technical benchmarking is shown in Table 3.7.

Substitute Quality Characteristics		Technical Benchmarking				
	Average Score	Poor		Moderate		Good
Double Skin Construction 2", Thermal transmission insulation 1-1.4 W/m2/K	885		①	○③⑤	②④	
Door and Service Panel Removal in 1 min	858	⑤	○①③		②④	
Rigid-Tough Construction, 50kg/ cubic module	843			○①④	⑤	②④
Centrifugal Fan Installation	784			○①②④⑤		
Insulated Drained Floor(With Expanded metal cat walk, on large unit)	705	○①②④⑤				③
Knock Down Structure	690	①②③④⑤		○		
High Performance Fan & Drive	685	○①②⑤	②			③
Stackable Unit 3 level	684			⑤	○①②④⑤	
4,6,8,10,12 roll Cooling Coil with various fin type	680				○①②④⑤	
Internal Inlet Damper @ Mixing Box	613	○①②③④⑤				
Height Variable Base Structure 10cm-20cm	612		⑤		○①②④⑤	
V Groved Elevated Drain Pan	597				○①②③④⑤	
Fan Set Vibration Isolator	537				○①②③④⑤	
Service Door Air Tight 100%	532	○①③④⑤			②④	
Service Panel-Air Tight 100%	532				○①②③④⑤	
Heating Element	510			○①②③④⑤		
Multi-Choise Internal Skin	473			○①②③④⑤		
Fool Proof For Conenction	438	○①②③④⑤				
Perfect Sealed Gasket	412			○①③④⑤	②④	
180 Removable Pin Hinge for Access Door	396		①	③④⑤	○②④	
Modular Filter Section 305x305	393	①			○②③④⑤	
Section Labeling Indicator	389	○①②③④⑤				
305mm Base Dimension Modular (internal)	385	②④	①	○②④		
Colour Coated Interior	378	○①③		⑤	②④	
Out Let Flange	373					○①②③④⑤
Walkable Unit Top: 400 kg	365	①②④⑤	○		②④	
Insulated Sight Glass	357	○①②③④⑤				
Water Pipe Header	354	○①②③④⑤	④			
Guide Hole-Guide Pin for Installation	351	○①②③④⑤				
Air Washer Section	348	①②③④⑤		○④		
Forklift Access From Side	346		⑤		○①②③④	
Lift Hook	336		○⑤	①③④	②	
Coil velocity up to 700 fpm	332	○①④	②③④			
Wiring Terminal for Power Connector	332	○①②③④⑤				
Multi-Choise Insulation (PU, PS, Rockwool, Fiberglass)	329	○①②③④⑤				
Powder Coated Exterior	312	③	⑤		○①②④	
Inlet Flange, Duct Bolt Connect	308					○①②③④⑤
Side Access Pre Filter & Medium Filter Housing	306			○①②③④⑤		
Multi-Type-Fan Configuration	292				○①②③④⑤	
Wire Guide-Wire Way	257	○①②③④⑤				
Assembly Fool Proof	255	○①②③④⑤				
Droplet Eliminator after coil	246	①②③④⑤		○	③	
Coil Sliding	217	①②③④⑤	○④			
Control Connector Terminal	210	○①②③④⑤				
Air Mixer	207	○①②③④		④		
Mixing Box	143				○①②③④⑤	
Internal Lighting Switch	137	○①②③④⑤				
0,90,180,270/ L-R degree blow outlet	123		○①②③④⑤			④
Fan Inlet Guard	114	○①②③④⑤				
Lighting IP55	108	○①②③④			④	
Shaft Guard	108	○①②③④⑤				
Belt Guard	101	○①②③④	①			
Trap in alarm	100	○①②③④⑤				

Table 3.8: Completed technical Benchmarking for AHU

The completed technical benchmarking will be placed into the Part-4 of QFD Matrix A1. The result of the technical benchmarking will be discussed later.

From the work of researcher and design team on the Quality Function Deployment (QFD) Matrix A1, the completed Matrix is shown in Appendix 4. Figure 3.12 is the minimized version of the A1.

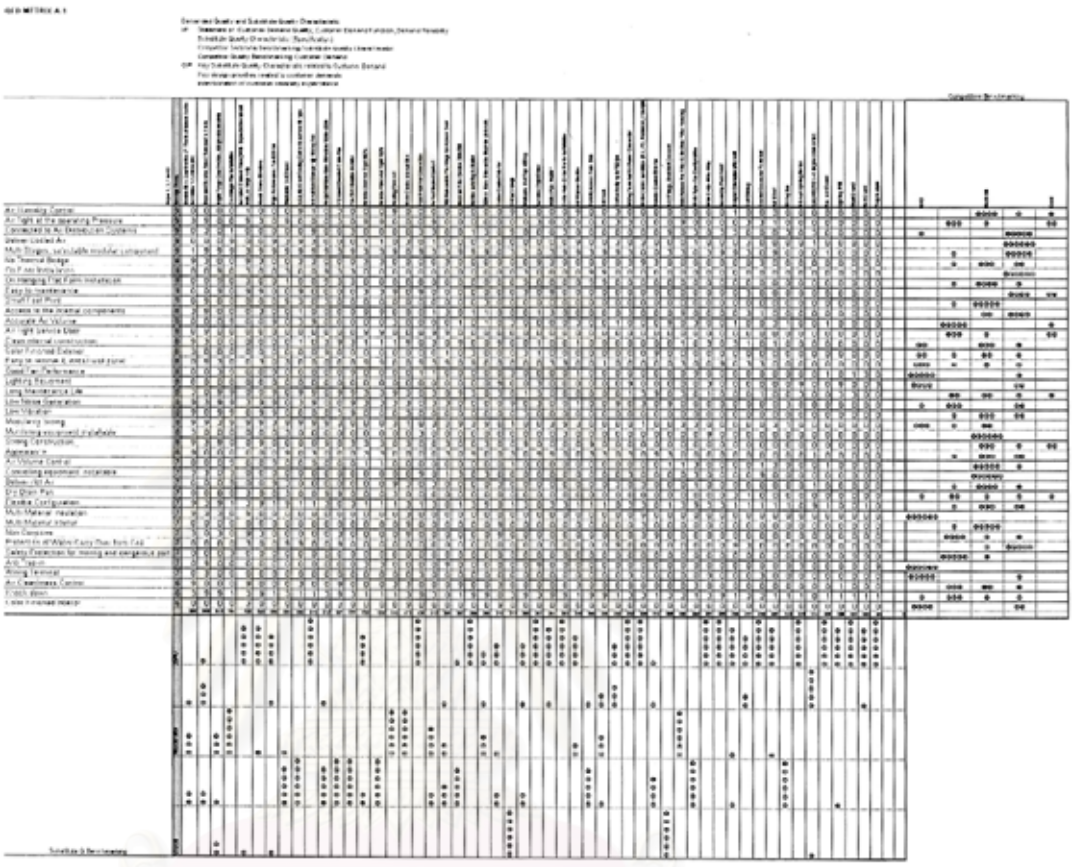

Figure 3.13: Completed Quality Function Deployment (QFD) Matrix A1 for Air Handling Unit (AHU) design improvement

3.5.4 *The Result of QFD Matrix A1*

From the Quality Function Deployment (QFD) matrix A1 assessment, the following results are obtained

- Key Substitute Quality Characteristic & Key Design Priority

The top ranked "Substituted Quality Characteristics" is considered as the key "Substituted Quality Characteristics" and key design priority. The 53 "Substituted Quality Characteristics" must be filtered to get the key design priority group. Researcher and design team decided to focus on the top 80% of the accumulated score on the "Substituted Quality Characteristics". The stratified weight scored and the focused

"Substituted Quality Characteristics" that selected as key design priority is shown in Table 3.8.

Substitute Quality Characteristic	Weight
Double Skin Construction 2", Theirnal transmission insulation 1-1.4 Wm2/K	865
Door and Service Panel Removal in 1 min	858
Rigid-Tough Construction	843
Centrifugal Fan Installation	784
Insulated Drained Floor(With Expanded metal cat walk, on large unit)	705
Knock Down Structure	690
High Performance Fan & Drive	685
Stackable Unit 2 level	684
4,6,8,10,12 roll Cooling Coil with various fin type	680
Internal Inlet Damper @Mixing Box	613
Height Variable Base Structure 10cm-20cm	612
V Groved Elevated Drain Pan	597
Fan Set Vibration Isolator	537
Service Door Air Tight 100%	532
Service Panel-Air Tight 100%	532
Heating Element	510
Multi-Choise Internal Skin	473
Fool Proof For Connection	438
Perfect Sealed Gasket	412
180 Removable Pin Hinge for Access Door	396
Modular Filter Section 305x305	393
Section Lebeling Indicator	369
305mm Base Dimension Modular (Internal)	365
Colour Coated Interior	378
Out Let Flange	373
Walkable Unit Top 400 kg	365
Insulated Sight Glass	357
Water Pipe Header	354
Guide Hole-Guide Pin for Installation	351
Air Washer Section	346
Forklift Access From Side	346
Lift Hook	336
Coil velocity up to 700 fpm	332

Table 3.8: The Key Substitute Quality Characteristics and Design Priorities for the Air Handling Unit (AHU) design improvement

From the table 3.8 the most important feature with weight score of 885is *Double Skin Construction that provide the range of thermal conductivity of 1-1.4 W/m²/K* This quality characteristic is the first priority that the designer should focus on designing. Other key qualities are the removable access door and access panels of the Air Handling Unit (AHU) (858) and the Rigid-Tough construction (843). This is the top three rank "Substituted Quality Characteristics" that weight score gap are narrow.

For further assessment of the Matrix A1 to get the design references, The Technical Benchmarking and the Competitive Benchmarking results will be discussed.

In competitive benchmarking researcher and design team found that some areas of the key "Customer Demands" are in the incompetence and unsatisfied range. Illustrated in the table 3.9 the dark shaded areas show the design opportunities that the AHU should be designed to increase the customer satisfaction.

	Average Score	BAD		Moderate		Good
Air Humidity Control	9					
Air Tight at the operating Pressure	9					
Connected to Air Distribution Systems	9					
Deliver Cooled Air	9					
Multi-Stages, selectable modular component	9					
No Thermal Bridge	9					
On Floor Installation	9					
On Hanging Plat Form Installation	9					
Easy to maintenance	9					
Small Foot Print	9					
Access to the internal components	8					
Accurate Air Volume	8					
Air Tight Service Door	8					
Clean internal construction	8					
Color Finished Exterior	8					
Easy to remove & install wall panel	8					
Good Fan Performance	8					
Lighting Equipment	8					
Long Maintenance Life	8					
Low Noise Generation	8					
Low Vibration	8					
Modularity Sizing	8					
Monitoring equipment installable	8					
Strong Construction	8					
Appearance	8					
Air Volume Control	7					
Controlling equipment installable	7					
Deliver Hot Air	7					
Dry Drain Pan	7					
Flexible Configuration	7					
Multi Material Insulation	7					
Multi Material Interior	7					
Non-Corrosive	7					
Protection of Water Carry Over from Coil	7					
Safety Protection for moving and dangerous part	7					
Anti Trap-in	7					
Wiring Terminal	7					
Air Cleanliness Control	6					
Knock down	6					
Color Finished Interior	5					

Table 3.9: Key design opportunity from AHU competitive benchmarking

From the table 3.9 following points are the design opportunities: Air tight, No thermal Bridge, Hanging Plat Form installation, Small foot print, Accurate air volume, Air tight service door, Clean internal construction, Fan performance, Lighting, Low noise, Low vibration, Dry drain pan, Flexible equipment configuration and Multi-insulation material. The listed "Customer Demands" should be taken for account in AHU design improvement for increasing the customer satisfactory level.

For technical benchmarking, the key design priority is focused for the benchmarking assessment. The key "Substituted Quality Characteristics" that the researcher and design team should focus to increase the AHU competitive edge is shaded in the table 3.10.

Substitute Quality Characteristics	Average Score	Rank	al Benchmarking				
			Poor		Moderate		Good
Double Skin Construction 2 : Thermal transmission insulation 1-1.4 W/m2/K	685	1		1	❶ 2 3	2 1	
Door and Service Panel Removal in 1 min	658	2	5	❶ 1 3		2 1	
Rigid-Tough Construction, 50kg/ cubic module	649	3			❶ 1 3	5	2 1
Centrifugal Fan Installation	784	4			❶①②③④⑤		
Insulated Drained Floor(With Expanded metal cat walk, on large unit)	705	5	❶ 1 2 3 5				1
Knock Down Structure	690	6	①②③④⑤		❶		
High Performance Fan & Drive	685	7	❶ 1 3 5	2			1
Stackable Unit 3 level	684	8			⑤	❶①②③④	
4,6,8,10,12 roll Cooling Coil with various fin type	680	9				❶①②③④⑤	
Internal Inlet Damper @ Mixing Box	613	10	❶ 1 2 3 1 5				
Height Variable Base Structure 10cm-20cm	612	11		⑤		❶①②③④	
V Groved Elevated Drain Pan	597	12				❶①②③④⑤	
Fan Set Vibration Isolator	537	13				❶①②③④⑤	
Service Door Air Tight 100%	532	14	❶ 1 3 5			2 1	
Service Panel-Air Tight 100%	532	15				❶①②③④⑤	
Heating Element	510	16			❶①②③④⑤		
Multi-Choise Internal Skin	473	17			❶①②③④⑤		
Fool Proof For Connection	426	18	❶ 1 2 3 1 5				
Perfect Sealed Gasket	412	19			❶ 1 3 5	2 1	
180 Removable Pin Hinge for Access Door	396	20		①	①⑤	❶①④	
Modular Filter Section 305x305	393	21	①			❶②③④⑤	
Section Labeling Indicator	389	22	❶ 1 2 3 1 5				
305mm Base Dimension Modular (Internal)	385	23	②⑤	①	❶②④		
Colour Coated Interior	378	24	❶ 1 3		⑤	2 1	
Out Let Flange	373	25					❶①②③④⑤
Walkable Unit Top: 400 kg	365	26	①②⑤	❶		②④	
Insulated Sight Glass	357	27	❶①②③④⑤				
Water Pipe Header	354	28	❶①②③⑤	④			
Guide Hole-Guide Pin for Installation	351	29	❶①②③④⑤				
Air Washer Section	346	30	①②③⑤		❶④		
Forklift Access From Side	346	31		⑤		❶①②③④	
Lift Hook	336	32		❶⑤	①③④	②	
Coil velocity up to 700 fpm	332	33	❶①⑤	②③④			

Table 3.10: Opportunity for improving existing AHU design on from technical benchmarking assessment.

From the table 3.10 the current focused brand AHU design should be improved in following areas to increase the AHU competitive edge over competitors: Double skin panel thermal transmission resistance, Service door and service panels, Strength of construction, Fan performance, Drain floor, Air tight, Fool proof assembly, Door and wall panel gasket.

After combining the competitive benchmarking and the technical benchmarking, there are some repeated design-opportunities. This repeated design

opportunities are key design competitive edges for double skin AHU, which the designer should focus in design improvement.

The QFD matrix A1 for AHU design improvement is completed. The outputs of this matrix will be directly used in other matrices A2, A3 and E4. In concept designs generation the outputs from this QFD Matrix A1 are used as the design guidelines.

3.6 QFD Matrix A2: Functions and Substitute Quality Characteristics

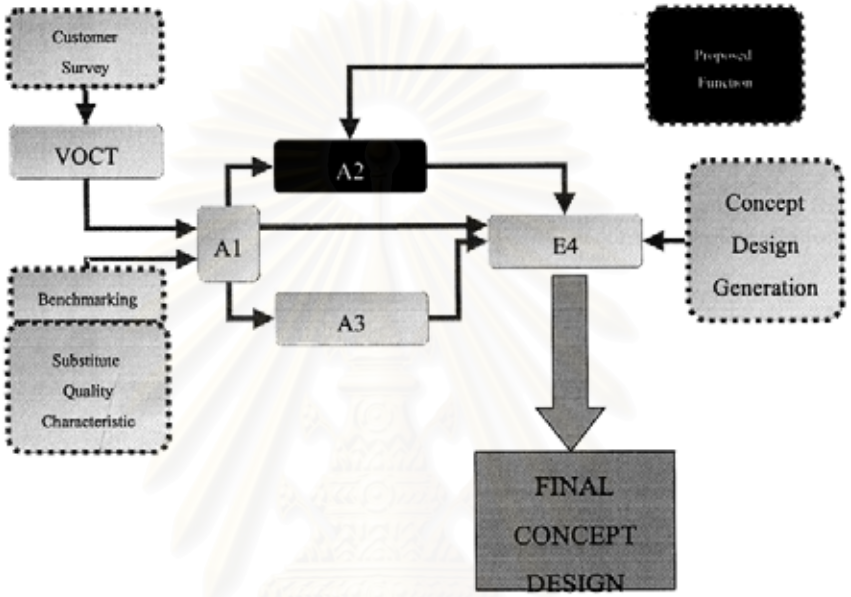

Figure 3.14: Quality Function Deployment (QFD) process flow: Matrix A2

Figure 3.14 illustrate the current step of AHU design improvement process. Dark shaded block indicated that in this step the researcher and design team is proposing functions of AHU. The proposed functions are then put into the QFD matrix A2 to find the correlation between the proposed function and the key "Substituted Quality Characteristics".

This QFD Matrix A2 is working on identifying the key "Substituted Quality Characteristics" that related to the proposed function of the AHU. The correlation of the key substitute characteristic and the function are weight using the same approach of the Matrix A1. The result of the matrix is the function weight score that will identify which area of the function needed to focus and put afford on design. Also the result will show the opportunity function that can be the candidates for cost reduction in future.

3.6.1 How QFD Matrix A2 Works

The Quality Function Deployment (QFD) Matrix A2 is very simple and easier to assess than the Quality Function Deployment (QFD) Matrix A1. The matrix has four parts, the Substitute Quality Characteristics and its Weight on the vertical axis, the

proposed for the new product or services is then listed in the horizontal axis. The correlation scoring part is in the middle. The accumulated weight of function and the functions ranking are on the bottom of the matrix as shown in the Figure 3.15.

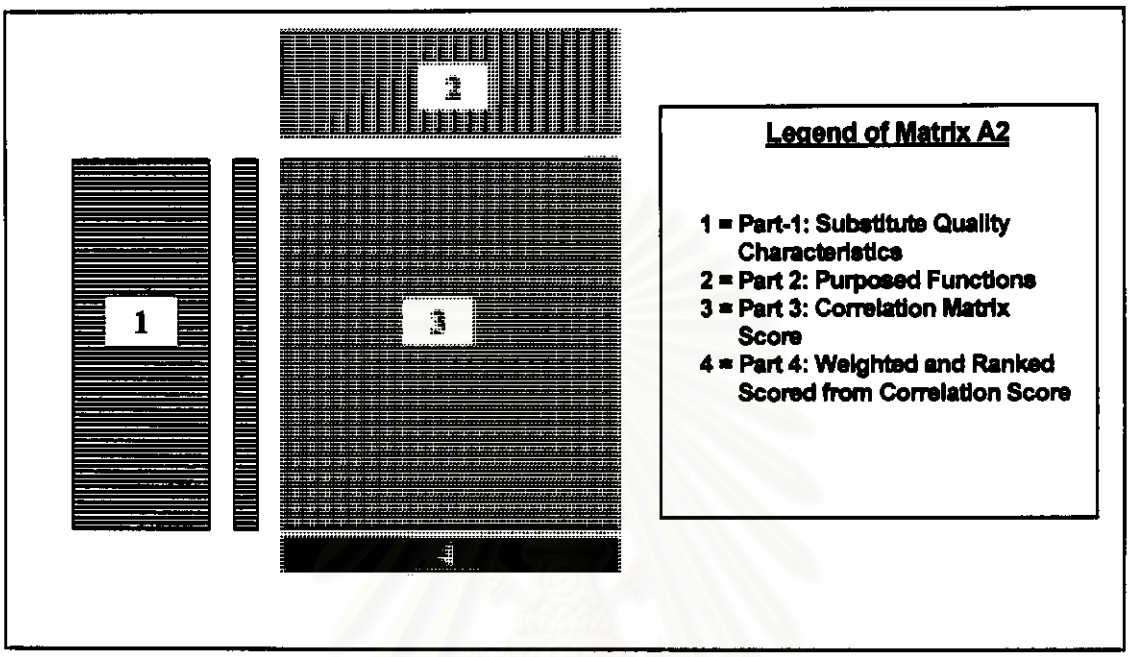

Figure 3.15 Quality Function Deployment (QFD) Matrix A2

The Substitute Quality Characteristic and its weight are taken from the result of the Quality Function Deployment (QFD) matrix A1 which the researcher and design team already assessed in previous section. The Part-2 the proposed function is the new product function that developed by the researcher and design team, during the meeting, brainstorming and ideas generation. This function will be the second guide for researcher and design team to generate the concepts of new product.

In the Part-3: The correlation scores 9, 3, 1 and 0 are used to identify the correlation of the new proposed function to the substitute quality characteristic, which will then multiply to the weight of each respective substitute quality characteristic and sum over the column to the Part 4. The Part 4 will contain the sum over column weight of each new proposed function that developed by the researcher and design team. The weight of the proposed function will be ranked from the highest weight to the least weight.

The ranked proposed AHU function is the key indicator on the important of the function on new AHU design improvement. The high ranked functions are important for marketing focus and key subjects for design improvement. The proper AHU functions focus will generate the effective product designs that meet customer expectation.

The low ranked function or no-correlation functions are representing the functions that do not relate to the customer needs, which will be latter candidate for cost reduction. On the other hand, it may show that the substitute quality characteristics are not yet identified, and the researcher and design team should carefully considered on the customer demand survey process.

In generating the new proposed function, the researcher and design team has to study the current function of each competitor in the market for references. Then the list of the new AHU functions is developed in the researcher and design team meeting. The new purposed function are listed in the table 3.11

NEW AHU PROPOSED FUNCTION
Thermal insulation
Build Static Pressure
Clean Air
Clean Internal Structure
Controlling equipment installable
Cooling
Deliver Constant Air
Delivery Air to Distributioln System
Demunifuing
Dry Drain Pan
Heating
High Static Operation
Humidifying
Knock-Down system
Lighting Equipment
Maintainability, Servic ability and Installation
Minimum Vibration
Modular Equipment Section
Modular Cross Section Size
Monitoring equipment installable
No Thermal bridge and internal-external condensation
Quiet operation
Safty

Table 3.11 New purposed function of double skin AHU

From the table 3.11 proposed function will be used as the input of the Part-2 QFD Matrix A2. These functions will be weighted and ranked. Result will be the importance function of AHU

The researcher and design team is working on scoring the correlation between the proposed function and the "Substituted Quality Characteristics" from the QFD Matrix A1. The 9, 3, 1 and 0 scores are used. After the correlation is scored, the researcher and design team has to fine the weight of each function by multiplying the "Substituted Quality Characteristics" weight to each correlation score and sum over the column. The sum of each proposed function is ranked and displayed in the completed QFD Matrix A2.

3.6.2 The Complete QFD Matrix A2

QFD METRIX A2: Customer Demand Function and the Substitute Characteristic fram A1 Substitute Quality Characteristic	Function Weight	Thermal Insulation	Build Static Pressure	Clean Air	Clean Internal Structure	Controlling equipment installable	Cooling	Deliver Constant Air	Delivery Air to Distribution System	Demumifying	Dry Drain Pan	Heating	High Static Operation	Humidifying	Knock-Down system	Lighting Equipment	Maintainability, Servic ability and Installation	Minimum Vibration	Modular Equipment Section	Modular Cross Section Size	Monitoring equipment installable	No Thermal bridge and internal-external condensation	Quiet operation	Safty
Double Skin Construction 2", Thelmal transmission insulation 1-1.4 W/m2/K	885	9	9	3	9	9	9	0	3	1	0	1	3	1	3	0	3	3	9	9	3	9	9	3
Door and Service Panel Removal in 1 min	858	3	0	0	9	3	0	0	0	0	3	0	1	0	9	0	3	0	3	3	3	0	0	9
Rigid-Tough Construction	843	0	9	0	0	0	0	0	3	0	3	0	9	0	9	0	1	9	9	9	0	0	9	9
Centrifugal Fan Installation	784	0	9	0	0	0	0	9	9	0	0	0	9	0	3	0	9	9	9	3	3	0	9	9
Insulated Drained Floor(With Expanded metal cat walk, on large unit)	705	0	0	3	9	0	9	0	0	3	9	0	0	0	9	0	3	0	0	0	0	9	0	3
Knock Down Structure	690	1	0	0	0	0	0	0	0	0	0	0	9	0	9	0	3	9	3	3	0	3	3	3
High Performance Fan & Drive	685	0	9	0	0	0	0	9	9	0	0	0	9	0	0	0	9	9	3	3	3	0	9	9
Stackable Unit 2 level	684	3	3	0	0	0	3	0	3	0	0	0	3	0	3	0	1	0	3	3	0	1	0	0
4,6,8,10,12 roll Cooling Coil with various fin type	680	0	0	3	0	0	9	0	0	9	3	0	0	9	3	0	3	0	3	3	0	0	0	0
Internal Inlet Damper @ Mixing Box	613	9	3	0	0	3	3	9	9	3	0	0	9	0	3	0	3	0	3	3	0	3	3	0
Height Variable Base Structure 10cm-20cm	612	0	0	0	0	0	0	0	0	0	3	0	0	0	9	0	0	3	3	3	0	0	3	0
V Groved Elevated Drain Pan	597	0	0	1	9	0	1	0	0	0	9	0	3	0	3	0	0	0	1	1	0	3	0	0
Fan Set Vibration Isolator	537	0	1	0	0	0	0	0	0	0	0	0	3	0	3	0	3	9	0	0	0	0	3	0
Service Door Air Tight 100%	532	9	9	3	3	0	1	1	0	3	0	1	9	0	9	0	9	1	3	3	0	3	1	0
Service Panel-Air Tight 100%	532	9	9	3	3	0	1	1	0	3	0	0	9	0	9	0	9	1	3	3	0	3	1	0
Heating Element	510	0	0	1	0	3	0	0	0	9	0	9	0	3	0	0	3	0	0	0	0	0	0	3
Multi-Choise Internal Skin	473	3	1	1	9	1	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	9	3	0
Fool Proof For Conenction	438	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	9	0	0	0	0	0	0	9
Perfect Sealed Gasket	412	9	1	3	3	0	3	0	0	3	1	0	0	0	9	0	0	0	0	0	0	0	0	0
180 Removable Pin Hinge for Access Door	396	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	3	9	0	9	0	9
Modular Filter Section 305x305	393	0	0	9	3	3	0	0	9	0	0	0	0	0	3	0	3	0	3	3	0	0	0	0
Section Lebeling Indicator	389	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	9	9	0	0	0	3
305mm Base Dimension Modular (Internal)	385	0	0	0	0	0	3	0	0	0	0	0	0	0	3	0	0	0	9	9	0	0	0	0
Colour Coated Interior	378	0	0	3	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Out Let Flange	373	0	0	0	0	0	0	1	9	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
Walkable Unit Top: 400 kg	365	0	0	0	0	0	0	0	0	0	0	0	3	0	9	0	3	0	0	0	0	3	0	3
Insulated Sight Glass	357	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3
Water Pipe Header	354	0	0	0	0	0	9	0	0	1	0	1	0	0	3	0	9	0	0	0	0	0	0	0
Guide Hole-Guide Pin for Installation	351	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	3
Air Washer Section	346	0	0	9	0	0	9	0	0	1	3	3	0	9	0	0	0	0	0	0	0	0	0	0
Forklift Access From Side	346	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	3
Lift Hook	336	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	3
Coil velocity up to 700 fpm	332	0	3	0	0	0	9	0	0	9	0	0	0	0	9	0	0	0	0	0	0	0	0	0
Wiring Terminal for Power Connector	332	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	9
Multi-Choise Insulation (PU, PS, Rockwool, Fiberglass)	329	0	0	3	0	0	9	0	0	0	0	0	0	0	3	0	0	0	1	1	0	9	0	0
Powder Coated Exterior	312	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inlet Flange, Duct Bolt Connect	308	0	0	0	0	9	0	3	3	0	0	0	0	0	3	0	0	0	0	0	0	0	3	0
Side Access Pre Filter & Medium Filter Housing	306	0	0	3	0	0	0	0	0	0	0	0	3	0	3	0	9	0	3	0	0	0	0	0
Multi-Type-Fan Configuration	292	0	3	3	0	0	0	3	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Wire Guide-Wire Way	257	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	9
Assembly Fool Proof	255	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	3	0	0	0	0	0	0	0
Droplet Eliminator after coil	246	0	0	3	0	0	9	0	0	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Coil Sliding	217	0	0	0	0	0	9	0	0	0	0	0	0	0	9	0	3	0	0	0	0	0	0	0
Control Connector Terminal	210	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	3
Air Mixer	207	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mixing Box	143	0	0	0	0	0	3	3	3	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0
Internal Lighting Switch	123	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	9
0,90,180,270/ L-R degree blow outlet	114	0	3	0	0	0	0	9	9	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Fan Inlet Guard	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Lighting IP55	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	3
Shaft Guard	101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Belt Guard	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Trap in alarm	93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Score		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 3.12: The Quality Function Deployment (QFD) Matrix A2 for Air Handling Unit (AHU) design improvement

The complete Quality Function Deployment (QFD) matrix A2 shown in the table 3.12 is the minimized version. The enlarged version is in the Appendix 5 for further reference. Please refer to the appendix 5 for easy reading the table.

3.6.3 The Result of QFD Matrix A2

From the assessment of the Quality Function Deployment (QFD) Matrix A2 we obtain following:

- Key product functions are the high ranked functions. The task of the researcher and design team is to find the key design functions, which will be used as the scope of AHU design improvement. For this Air Handling Unit (AHU) design improvement, following functions are needed to be carefully focused:
    - ✓ Knock Down System
    - ✓ Easy Maintainability, Serviceability and Installation
    - ✓ Safety
    - ✓ High Static Operation
    - ✓ Modular Equipment Section
    - ✓ Modular Cross Section Size
    - ✓ Cooling Capacity
    - ✓ Delivery High Static Pressure
    - ✓ Quiet and Low Vibration
    - ✓ Clean Internal Structure
    - ✓ No Thermal Bridge
    - ✓ Air Cleaning
    - ✓ Humidify and De-Humidifying
- The functions with little customer need are the low rank function from the matrix A2. The low rank function is listed to remind the researcher and design team that these functions can be put as the last priority for design.
    - ✓ Lighting equipment
    - ✓ Heating
    - ✓ Drain Floor
    - ✓ Control and Monitoring Equipment

The output of QFD Matrix A2 is also used as the further reference for the researcher and design team to develop the concept design in next chapter. This guideline will help the designer focus on proper functions.

3.7 QFD Matrix A3: Substitute Characteristics

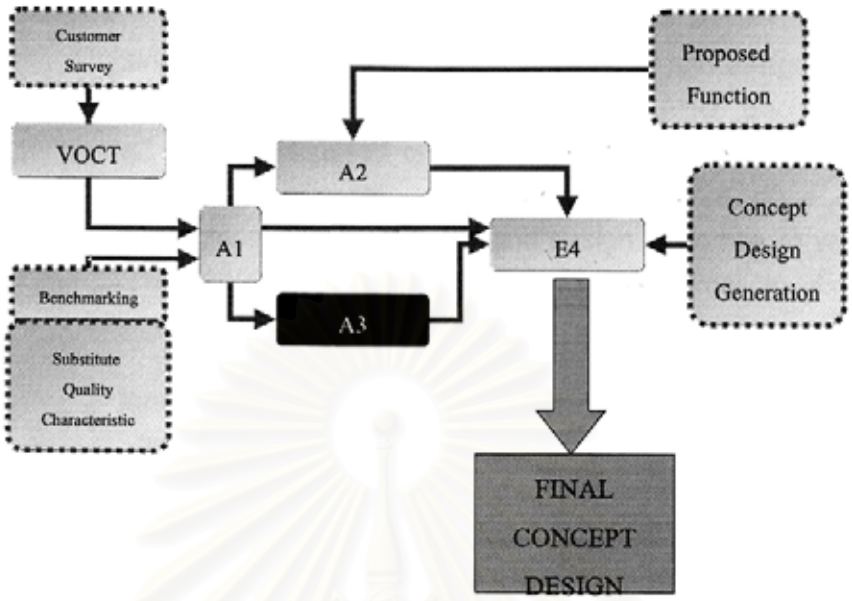

Figure 3.16: Quality Function Deployment (QFD) process flow: Matrix A3

Figure 3.16 illustrates the shaded current step, the QFD Matrix A3. This Matrix A3 is showing the correlation between "Substituted Quality Characteristics". The output of this matrix will be used in the "Concept Design Generation and used in the QFD Matrix E4.

The interrelationship between "Substituted Quality Characteristics" is the necessary information that the researcher and design team needs to be acquainted with. In generating the design improvement of AHU, there may be some specification trade-off or changing the value of the specification. The researcher and design team should know the effect of changing one "Substituted Quality Characteristics" to another. This QFD Matrix A3 is design to generate the relationship between "Substituted Quality Characteristics".

3.7.1 How QFD Matrix A3 Works

The substitute quality characteristic from the Quality Function Deployment (QFD) Matrix A1 is taken and put into both vertical and horizontal axis. This coordinate of the quality characteristic will generate duplicated correlation, so one correlation is block out to prevent confusion.

The interrelationship of the "Substituted Quality Characteristics" are representd by the, strong positive (++), Positive (+), no relationship ( ), negative (-) and strong negative (- -) effect to another "Substituted Quality Characteristics". The correlation between two-substitute characteristics are represented by those symbols and the

researcher and design team will be able to understand effect of the changing of each substitute quality characteristic to another.

In generating the relationship effect, the researcher and design team needs to understand all "Substituted Quality Characteristics" of the AHU. Each "Substituted Quality Characteristics" will be discussed on its effect over the other 52 "Substituted Quality Characteristics". The relationship effects discussions are done on all 53 "Substituted Quality Characteristics". Researcher and design team has to work on the relation between "Substituted Quality Characteristics" for 1378 times to complete the relationship.

The relationship effect is determined by asking the team member a simple question "If the Quality Characteristic A is increased in its value, what will other "Substituted Quality Characteristics" be?" For example, if the thickness of the wall panel is increased how it will effect the rest of the "Substituted Quality Characteristics". The wall thickness increased will negatively (-) effect the AHU structure since the weight is higher while strong positively (+ +) to the ability to varying the wall panel thickness.

The completed QFD Matrix A3 of the double skin AHU design improvement is shown in next section Figure 3.17, enlarged table is shown in Appendix 6

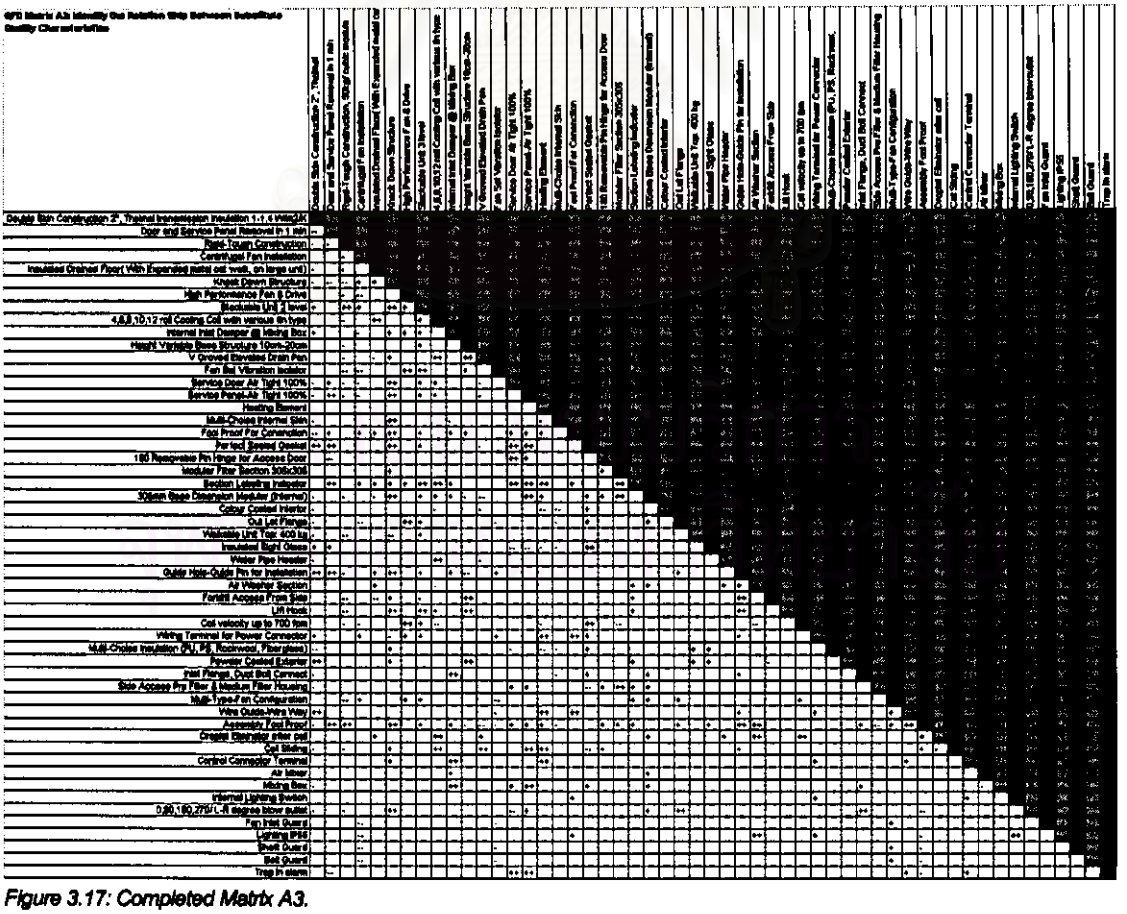

Figure 3.17: Completed Matrix A3.

Figure 3.17 illustrates the completed QFD matrix A3, which is done by the AHU researcher and design team. Both vertical and horizontal axes of the matrix are the "Substituted Quality Characteristics". The correlation between each pair of "Substituted Quality Characteristics" is displayed in the center of the matrix. The shaded color shows the blinded correlation area, which is repeated and not used.

3.7.2 The Result of QFD Matrix A3

We found that the developed "Substituted Quality Characteristics" in the Air Handling Unit (AHU) are related to each other. The changing in one "Substituted Quality Characteristics" value will effect the other "Substituted Quality Characteristics", both positively and negatively. If the adjustment of the "Substituted Quality Characteristics" is needed in AHU design process, researcher and design team need to carefully adjust the "Substituted Quality Characteristics" so there will be minimum effect to other "Substituted Quality Characteristics". Lack of considering to the effect of each "Substituted Quality Characteristics" on the other QFD Matrix A3 can create problems in AHU design. This Quality Function Deployment (QFD) Matrix A3 will be used as the guideline for the researcher and researcher and design team in generating the concepts for Air Handling Unit (AHU) design improvement.