

**DEVELOPMENT OF A MICROCOMPUTER BASED
DESIGN SYSTEM FOR
AIR MANAGEMENT OF BUILDINGS**

KASSEM AHMAD ALWAHBAN, B.Eng.

**The thesis submitted to Dublin City University in
Fulfilment of the requirement for the award degree of
*Master of Engineering***

Supervisor: Professor M.S.J. Hashmi

**School of Mechanical and Manufacturing Engineering
Dublin City University
JANUARY, 1993**



DEDICATION

I would like to dedicate this work to many people I love.

In particular

My

Father, Mother

Brothers, Sisters

Wife, Son


And friends:

KHALED, FATEHI

DECLARATION

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Master of Engineering is entirely my own work and has not been taken from the work of others save and the extent that such work has been cited and acknowledged within the text of my work.

Signed:



KASSEM AHMAD ALWAHBAN

I.D.No.: 89700210

Date: 5th of January 1993

ACKNOWLEDGMENT

I wish to express my gratitude to all those who helped me to produce this work. Especial gratitude is due to my supervisor Professor M. S. J. Hashmi, Head of the school of mechanical & manufacturing engineering (DCU), who originally conceived the project and who guided me in a very professional manner throughout the duration of the project. I would also like to express my sincere appreciation to Mr. Done Byren, for his guidance and assistance during the course of this research. I thank Dr.M.El-Baradie for his valuable advice and encouragement. Finally, I am indebted to the Scientific Studies & Research Center (SSRC) for providing the financial support towards this research.

ABSTRACT

DEVELOPMENT OF A MICROCOMPUTER BASED DESIGN SYSTEM FOR AIR MANAGEMENT OF BUILDINGS

KASSEM AHMAD AL-WAHBAN, (B.Eng.)

Expert systems are computer programs that seek to mimic human reasoning. Currently, expert systems are being used for the design of heating, ventilation, and air conditioning (HVAC) systems. The present work involves developing of several smaller expert systems known as knowledge bases, and integrating them in one simple package.

The aim of the research is to develop a such computer code for HVAC system designers which will considerably reduce man-hours during the whole design process, improve the productivity, increase the design quality, and give the customers more options to choose the best and optimum design. This thesis describes the development of a computer code, which has the ability to give all the design requirements for HVAC systems. This work which can be considered as a step towards HVAC Expert Systems, which outlines step by step calculation procedure to determine essential elements of heating and cooling loads such as U-value, air infiltration, solar heat gain, heat storage, psychrometric charts and the sunlit area of the exterior surfaces. The code (HVACSYS) consists of a main menu program and several auxiliary programs for gathering data, completing calculations, and printing project reports. The developed code is also connected with the AutoCAD package to give the final design of the HVAC systems. In the AutoCAD package, a special menu for HVAC systems design has been added (HVACCAD). This menu is developed for customizing the AutoCAD package in order to make the code interactive.

Finally, a case study has been considered in which solutions were obtained using an existing package and also the developed package. Comparison of the solutions illustrates the usefulness of the new package adequately.

CONTENTS

ACKNOWLEDGMENT	I
ABSTRACT	II
CONTENTS	III
CHAPTER ONE : A BASIS FOR HVAC EXPERT SYSTEMS	1
1.1 INTRODUCTION	1
1.2 BACKGROUND (LITERATURE SURVEY)	2
1.2.1 Expert system	2
1.2.2 HVAC Expert System Concept	3
1.2.3 Computer Aided Engineering (CAE) for HVAC systems design	7
1.2.4 HVAC Programs	11
1.3 THE NECESSITY OF A HVAC EXPERT SYSTEMS	15
1.4 OUTLINE OF THE THESIS	16
CHAPTER TWO : DESCRIPTION OF HVAC SYSTEM DESIGN SOFTWARE	17
2.1 INTRODUCTION	17
2.2 SYSTEM CONFIGURATION	19
2.2.1 Hardware Configuration	21
2.2.2 Software Configuration	22
2.3 HVACPRO PACKAGE DESCRIPTION	22
2.3.1 HVAC Main Menu	24
2.3.2 File Command Menu	24
2.3.3 Programs Command Menu	25
2.3.4 System Command Menu	30

2.3.5 Setup Command menu	31
2.3.6 Database Command Menu	33
2.3.7 Help Command Menu	34
2.4 HVACCAD PACKAGE DESCRIPTION	34
2.4.1 Customizing AutoCAD Menu	34
2.4.2 User Interface	35
2.4.3 PIPEWORK Programme	35
2.4.4 DUCTWORK Programme	36
2.4.5 PSYCHART Programme	37
CHAPTER THREE : THEORETICAL BASIS OF HVAC LOADS CALCULATION . .	38
3.1 INTRODUCTION	38
3.2 HEATING LOAD PROGRAM	39
3.2.1 Theoretical analysis of heat losses	41
3.2.2 Heating load program execution procedures	54
3.3 VENTILATION PROGRAMME	61
3.3.1 Ventilation programme formulation	61
3.3.2 Ventilation programme execution procedures	62
3.4 COOLING LOAD PROGRAMME	64
3.4.1 Cooling programme theoretical analyses	66
3.4.2 Cooling programme execution procedures	73
3.5 PSYCHROMETRIC CHART PROGRAMME	77
3.5.1 Thermodynamic properties of moist air	78
3.5.2 Formulation of psychrometric properties	89
3.5.3 Principal air conditioning processes	93
3.5.4 Psychrometric chart program execution procedures	100
3.6 U-VALUE PROGRAMME	113
3.6.1 U-Value programme execution procedures	113
CHAPTER FOUR: CUSTOMIZING A CAD SYSTEM FOR HVAC SYSTEMS DESIGN	
4.1 INTRODUCTION	123
4.2 HVACCAD USER INTERFACE	124

4.2.1 Bar (Pull-Down) Menu	126
4.2.2 Screen Menu	134
4.3 PIPE SIZE CALCULATION PROGRAMME	135
4.3.1 Pipe sizing theoretical analysis	137
4.3.2 Piping Layout Consideration	141
4.3.3 PIPEWORK program execution steps	142
4.4 DUCT SIZE CALCULATION PROGRAMME	143
4.4.1 Duct sizing theoretical analysis	145
4.4.2 DUCTWORK program execution steps	149
4.5 PSYCHROMETRIC CHART PROGRAMME	150
4.5.1 Psychart programme execution steps	150
4.6 COMPONENTS ALGORITHMS	151
CHAPTER FIVE : CASE STUDY AND VALIDATIONS	153
5.1 INTRODUCTION	153
5.2 CASE STUDY	153
5.2.1 Gneral project data input	155
5.2.2 Calculation U-Values	156
5.2.3 Heating lead programme results	161
5.2.4 Cooling load programme results	170
5.2.5 Psychrometric chart programme results	174
5.3 DISCUSSION	179
5.3.1 Heating Load	179
5.3.2 Cooling load	179
5.3.3 Psychrometric chart	180
CHAPTER SIX : CONCLUSIONS AND FURTHER WORK	181
6.1 CONCLUSIONS	181
6.2 FURTHER WORK	182
REFERENCES	183
APPENDIX: U-VALUE MATERIALS	

CHAPTER ONE

A BASIS FOR HVAC EXPERT SYSTEMS

1.1 INTRODUCTION:

The basic purpose of air conditioning is to control air flow, temperature and contaminant concentration in a room. To achieve these goals it is important to use advanced design methods which usually include numerical calculation of heating, ventilation, air conditioning (HVAC) loads, establishing air properties, room-air flows, pipe network, duct network, and selection and modelling of HVAC & Refrigeration systems.

The design process of HVAC systems involves adopting expert calculation procedures to give the optimum commercial design for all HVAC and refrigeration systems applications. Interest in computer aided analysis of the thermal performance of Buildings and HVAC systems has grown out of the need and desire to improve the effectiveness of the design process. This is influenced by technological changes in materials and equipment and by economic changes, such as the relative cost of different energy sources.

Methods of analysis for buildings have been developed to predict the energy demand of each zone of interest which enable the effects of architectural decisions on this demand to be studied. Peak loads may be identified from an analysis of the thermal performance of the building fabric together with any process loads for use in initial plant selection and thermal systems design. Most building energy analysis procedures which have been developed include implicit assumptions about idealised plant characteristics which maintain constant environmental conditions in the space.

1.2 BACKGROUND LITERATURE SURVEY:

1.2.1 EXPERT SYSTEM:

Expert systems are computer programs that are substantially different from the more conventional calculation programs commonly used in engineering. The most common form of the expert system is the knowledge-based system. Knowledge-based systems have been applied to various fields such as medicine, genetics, chemistry, geology, economics and engineering. Some literature concerning expert systems provide a thorough description of knowledge domains to which expert systems have been applied. These include discussions on the practical success of some of the systems developed. Brothers, et al. [1], Hamilton and Harrison [2], Katajamaki [3], Van Horn [4] put forward a number of criteria to describe the expert system as follows:

- I) In an expert system, all the decision rules in the program and all the data used to solve the problem need not to be reduced to numbers and algebraic equations.
- II) In an expert system, for any set of data there may be more than one solution computed.
- III) In an expert system, the program is capable of providing default data or otherwise continuing until a solution is reached even if the user does not have all the needed data. Missing data do not halt program execution.
- IV) In an expert system, the program assigns a certainty number to the solution or solutions it computes. For example, if much input data are missing, the expert system will provide a solution with low certainty.

An expert system can perhaps best be defined as a computer program that mimics a human expert in a given knowledge domain. The expert system asks questions to obtain pertinent data, uses conventional software to calculate other data, and mimics reason to reach its best solutions to a problem. A most important characteristic is that an expert system can explain its conclusions, its line of reasoning, and why it needs the inputs requested.

1.2.2 HVAC EXPERT SYSTEM CONCEPT:

Van Horn [4] lists several benefits of expert systems, of these the following three have been strongly considered in contemplating the practicality of expert systems in HVAC design:

- 1) The best expertise in the field is made available to as many people as possible. If the expert system is used as a learning tool, many more can learn what the teachers know.
- 2) Expert systems allow experts to handle even more complex problems rapidly and reliably.

Camejo and Hittle [5] put a new structure of HVAC expert system, in which the rules editor can be used to develop knowledge rules in many different domains without any programming changes to the user interface. The four main parts of the expert system shell are explained below;

1. The rules editor is used to develop the rules that make up the knowledge base. The rules are written in a structured syntax that is then converted into a form usable by the interface facility. In that sense the rules editor can be compared to a FORTRAN compiler, which takes fortran code and converts it into machine language code. One desired characteristic for the editor is that the rules' syntax should be easily understandable in natural language, for example English.
2. The user interface is the part of the expert system shell that allows the user to interact with the expert system . The key is that the interface must be user-friendly. It must be capable of communicating with both the user and other programs. The ideal interface would thus be one that uses natural language for input and output, but a menu-type interface can be acceptable . An early lesson in this research was that the user interface must be as flexible as possible.
3. The interface menu is the part of the shell that executes the reasoning algorithms of the expert system . The rules contain the knowledge and the inference facility applies the knowledge by asking for input through the user

interface and by making conclusions based on the rules.

4. The knowledge base is analogous to a data base except that the information in the knowledge base can be acted upon by a set of if-then-else rules. These rules contain the knowledge of the expert system. One or more knowledge bases can be developed using the rules editor, and all of the knowledge base can be interpreted by the interface facility.

Camejo and Hittle [5] divided the expert system to two important parts as shown in Fig.(1.1):

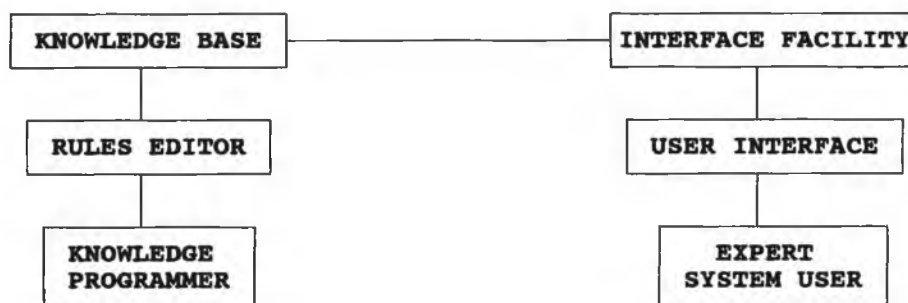


Fig.(1.1) Structure of expert system shells

HVAC User Interface:

Fig.(1.2) shows the first part which is the structure of the HVAC design expert system [5]. At the top level is the HVAC main user interface. This program was written specifically to interact with the selected shell and to serve several functions.

First, HVAC is an interactive menu that allows the user to work with the shell program and with some auxiliary programs by selecting options from the menu screen. HVAC's second and most important function is its project file manipulation. The objective is to have a data file for each active design project. Project file manipulation consists of three separate functions:

- a. Configuration of active project file.
- b. Removal of outdated data.

c. Conversion of choices.

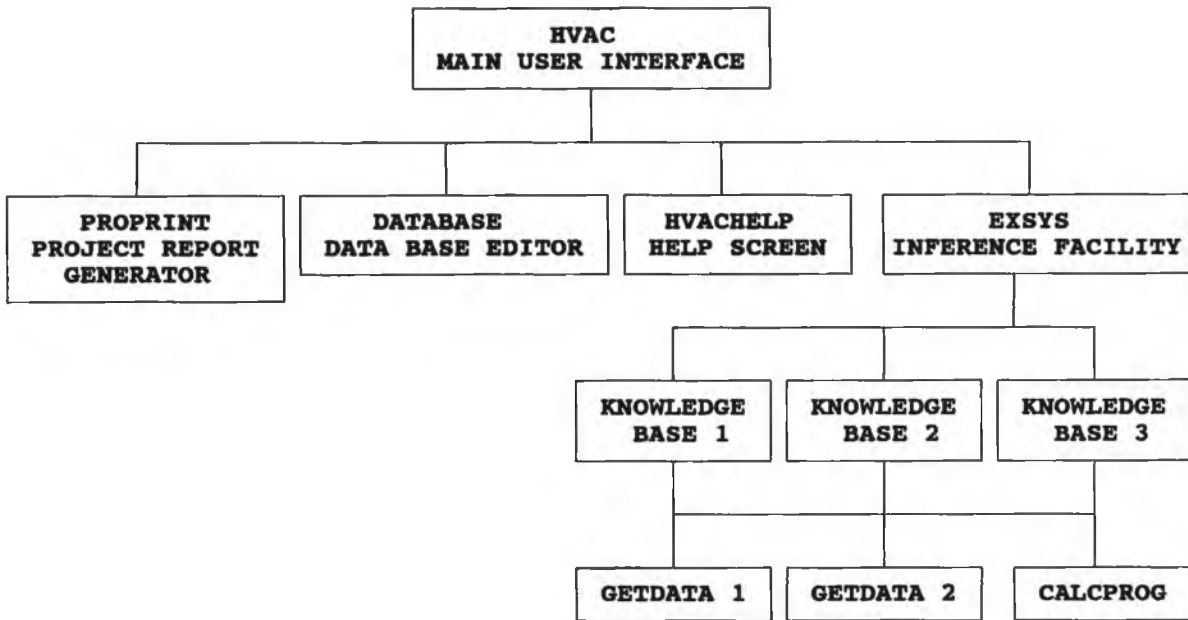


Fig.(1.2) Structure of HVAC expert system

Auxiliary Programs:

As was mentioned earlier, the HVAC program serves as a menu for working with the shell program and with some of the auxiliary programs. As shown in Fig.(1.2), HVAC also allows access to HVACHELP, PROPRINT, and DATABASE.

Knowledge Base:

The third element of the expert system is the knowledge base that contains all of the knowledge of the expert system. Fig.(1.3) shows the current structure of the knowledge bases in the expert system. Multiple knowledge bases are used in the expert system because several knowledge bases appear to be more suitable to HVAC design than one large knowledge base. System design can be viewed as a chronological process that requires interaction between architects, engineers, owners and users. The project

goes from pre-feasibility to pre-design to facility analysis, system selection, and so on. Invariably the results of one phase are inputs to the next phase. A further problem with a single knowledge base is that even minor changes in input data would require running the entire knowledge base, thus reconsidering every possible outcome and taking up valuable time.

The knowledge bases shown in Fig.(1.3) are arranged in the normal chronological order in which they would be used. The main menu of the HVAC user interface contains the pre-feasibility study knowledge base and the facility analysis knowledge base. The third knowledge selection option in the main menu is the system design menu. This second menu has the system selection knowledge base, the equipment selection knowledge base, and the controls selection knowledge base . The current chronological flow is, therefore, pre-feasibility study, facility analysis, system selection, equipment selection, and finally controls selection. The complete expert system will require several other knowledge bases, many of which will have to interface with design graphics. The purpose of the knowledge bases listed in Fig.(1.3) is to demonstrate the feasibility of the expert system.

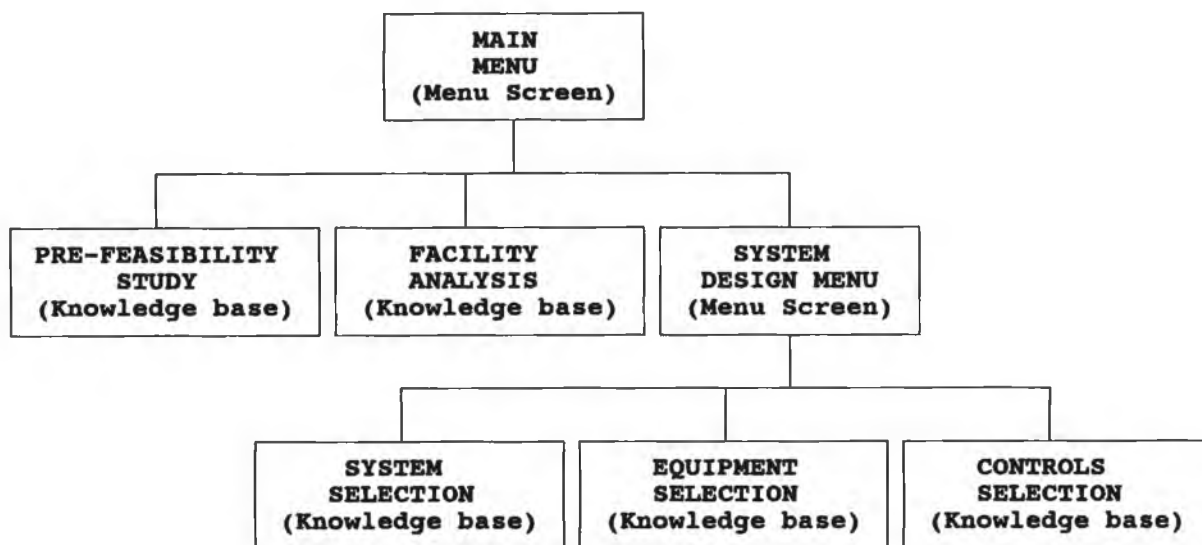


Fig.(1.3) Knowledge base structure

1.2.3 COMPUTER AIDED ENGINEERING (CAE) FOR HVAC SYSTEM DESIGN:

Many of the design tasks now done manually can be incorporated into an integrated and automated CAE program package. Lam [6] developed another HVAC expert system shell using Computer Aided Design (CAD) systems. The objectives of his work were to explore the possibility of a CAE package that would integrate and automate engineering and drafting for the HVAC industry and to develop a program flow chart for a generic process.

If the building process is examined, we find that from conceptual design to final building turnover to the clients a lot of tasks are done manually by the HVAC engineer. If the amount of time for these manual tasks is minimized during the design stages, the client can save money and the HVAC consulting engineer can make more profit. With this in mind, we can identify the tasks normally done manually or done independently on a PC by the HVAC design engineer. If we can provide a parallel CAE facility to replace these tasks, we can establish the criteria for a CAE program. The flow chart, in Fig.(1.4) shows the suggested flow chart for the entire CAE process by Lam [6]. The flow chart depicts an integrated and automated process, from scanning to final product (HVAC drawing), that is parallel to how a typical HVAC engineer would work normally. Development of the CAE package can be divided into three phases. Each phase should be able to function individually and should have hooks or interface left open for the next phase:

Translating CAD Graphics:

The translation of graphics using Initial Graphics Exchange Standard (IGES) or Drawing interchange format (DXF) between different CAD systems is limited to graphic data only. Any associated data or attributes may be lost during the translation process. It would probably take another research just to discuss the different types of CAD translation software and their pros and cons. However, we can summarize the current status of this topic as that there are a number of translation methods (IGES, DXF, etc.) [7], which are a standard for graphic data exchange which is imminent.

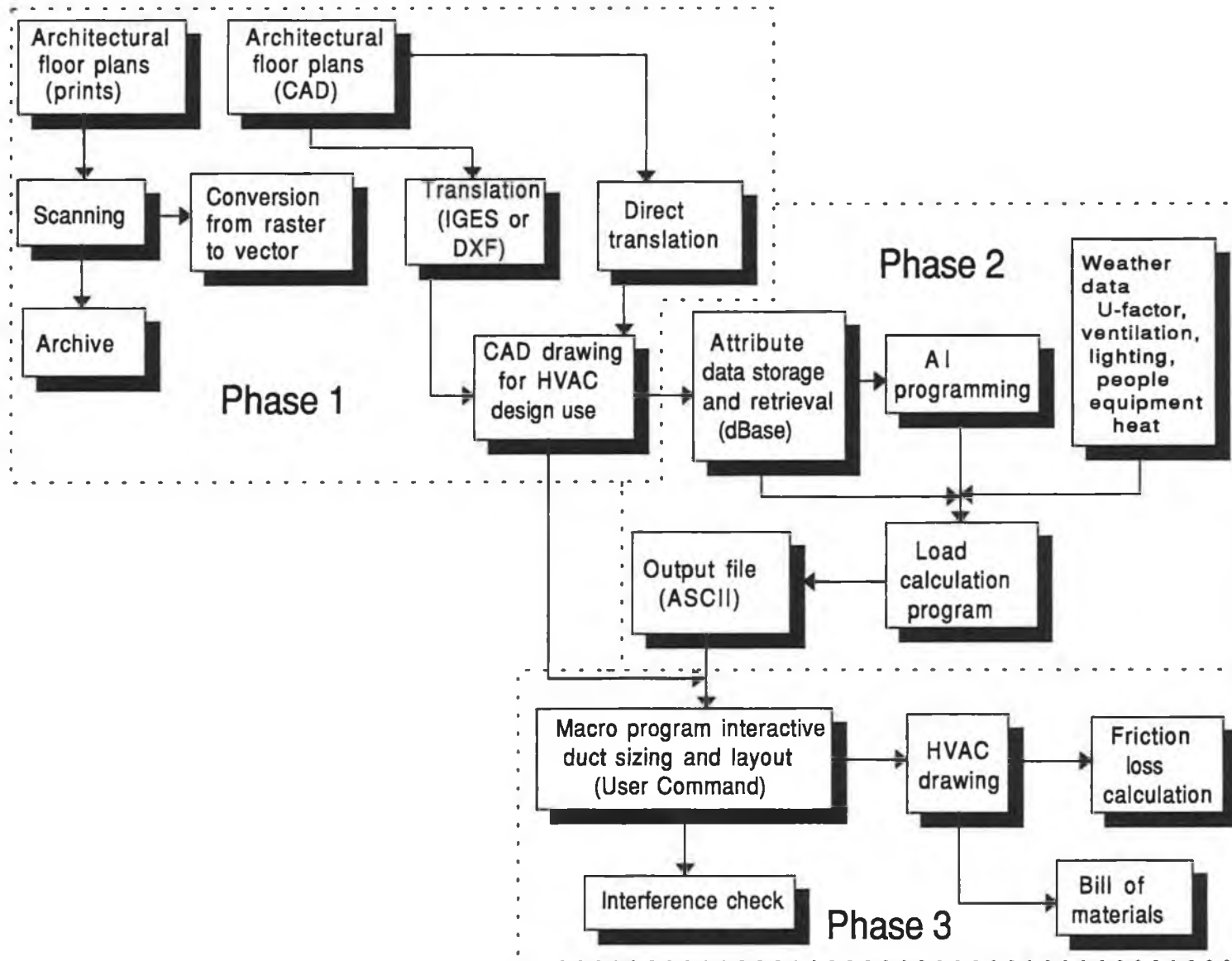


Fig.(1.4) Flow Chart illustrating a CAE package system design, [6].

The best way to accomplish this is to write short micro programs. Micro program languages, such as User Commands in Intergraph, Autolisp in AutoCAD [8] can be used. Using micro programs will automate some of the cleanup and editing required after an IGES transfer, such as graphic group regrouping or block "exploding" or reblocking. External FORTRAN programs are also supported by some CAD software, such as Intergraph and Autotrol.

Calculation of HVAC loads:

Assuming most of the graphics and associated data are intact after the translation, external or micro programs can be written to read, retrieve and store the necessary attributes (thickness of wall, window sizes, area, hight of building and building partitions, etc.) in a database. One can also use DATABase in AutoCAD [7] to accomplish data retrieval.

This database is then interpreted so that it can be understood and utilized by a third-party HVAC load calculation program from companies such as APEC, Elite, Carrier, Trane, or by a program that can be developed in-house.

The interpretation of the attribute database will require some programming in artificial intelligence (AI) language. Assumptions and Knowledge-bases should be developed and inputted automatically during this stage so that all the attributes of the building model can be understood and utilized in the load or energy calculation.

With a minimum of the input from HVAC engineer, the load calculation will be carried out automatically using the database and local weather data files. The program output will be stored in an output file, preferably an American Standard Code for Information Interchange (ASCII) file to facilitate the next automated task.

The duct program:

This program should also be written in the micro language that is provided with

the CAD software(e.g., User commands with Intergraph). An interactive approach is proposed in lieu of the batch-processing approach because it is more logical to set up the program so that it works the same way the HVAC engineer normally works. It Should be appropriately divided into the following sections:

- * Interactivity asking where the user identifies the starting and ending points of the sections of the duct system layout.
- * By using the Darcy-Weisbach and Colibbrook [7,8,9,10,11] equations and the ASCII files from the load calculation, the duct work will be sized automatically.
- * Friction loss in each section of the ductwork will be checked against the user input limiting velocity and allowable ceiling clearance.
- * Dimensions of each section of the ductwork will be stored in the database for material take-off purposes.

Here is how the program would work. The program would initially load the scanned and translated image of the architectural floor plan on the personal computer (PC) screen. It would prompt the user to input the friction loss factor per 100 ft of the duct, the limiting velocity, the roughness of the sheet metal used, and the allowable ceiling clearance dimension.

The program would then prompt the user for the start point of the duct system layout. As soon as this was entered, the output file from the load calculation would be read, and the air flow rate (cfm, m³/hr) would be used to calculate the duct size. It would then prompt the user for the end point to this section of the ductwork, and the ductwork would be drawn on the screen accordingly. Fittings such as elbows, transitions, dampers, and the turning vanes would be added automatically, based on the coordinates of the last option, the previous duct size, the direction of the next point, and the flow rate.

The initial inputs, such as the limiting velocity and the ceiling clearance, would act as check figures to round off the duct height/diameter to fit in the ceiling void. This

interaction would be carried out until the user entered quit or reset. All the necessary data for friction loss calculation and material takeoff would be saved in a database while the interaction was being carried out.

1.2.4 HVAC PROGRAMS:

There are mainly two sectors of development for HVAC systems design. The academic (research) sector, including ASHRAE, DOE, NBS, CIBSE companies [6,12], and numerous universities in the world who are actively involved in the development of HVAC load calculation and energy simulation programs. Established programs, such as BLAST, DOE2.1, TRAP, ESP, etc., have been available for many years. The commercial sector also has many engineering calculation programs available; Trane [13], Elite Software [14,15,16], Carrier [13], Hevacomp [17], and APEC have been in the market for years.

On the other hand, the CAD software industry, AutoCAD, has AEC (Architectural, Engineering and Construction) mechanical and architectural packages; however, they are basically drafting packages that use menus and symbol libraries. Intergraph has the PDS package that contains a HVAC module. PDS is an integrated plant design program that includes practically all engineering disciplines; however, it is a VAX-based system, and thus its cost is high. Computer vision has its Personal Architect and Personal Designer packages; again, they are basically drafting packages. Other CAD software vendors, such as Autotrol, CADAM, CADkey, CADvance, Drawbase, FastCAD, and VersaCAD, are most likely involved in the development of specialized packages for the AEC industry.

All of the programs mentioned above are excellent products of many years of development. However, they all work independently of each other. Integration of these programs into CAE is still in its infancy. Details of some of these packages are as follows;

Elite Software programs:

Elite Software developed various programs [14,15,16] for HVAC design, some of these programs are listed below:

QHvac - Simple Commercial HVAC Loads: This program [14] calculates the maximum heating and cooling loads for commercial buildings. QHVAC allows 50 zones which can be grouped into 10 air handlers. The program automatically looks up all cooling loads and correction factors necessary for computing loads.

DUCT SIZING: This program calculates duct sizes using either the static regain, equal friction, or constant velocity methods.

U-FACTOR: This program calculates the conductivity factor (U-factor) of walls and roofs.

PSYCHART: The PSYCHART [16] program displays the psychrometric chart on the computer screen. It displays numerical values of all properties of the moisture air for any selected point, and all the processes such as heating, cooling, humidification, dehumidification, and mixing are displayed on the screen.

SPIPE - Service Supply Pipe Sizing: calculates the pipe size for hot and cold water domestic water supply systems in both residential and commercial buildings using ASHRAE and ASPE procedures. It uses the Hazen-Williams equation to determine the pressure drop due to friction for a particular pipe size. Water velocity is calculated by first determining the expected gpm flow rate and then dividing by the pipe cross sectional area.

There are also other programs developed by Elite Software such as SHADOW, CHVAC, HTOOLS [15] , ENERGY, etc.).

TRANE Programs [13] :

The following summary describes the programs developed by TRANE using

Trane's TRACE and other CDS computer programs to calculate HVAC loads. They use network and personal computers, some of these programs are explained below:

Load Design: This program can be loaded on a microcomputer and is based entirely on ASHRAE algorithm and actual hour by hour weather tape data. All ASHRAE wall, floor, roof, and slab data are preloaded into the program. They put both of the ASHRAE [7] methods, total equivalent temperature difference (TETD), and the cooling load temperature difference (CLTD) for the calculation of the cooling load.

Energy Analysis program: This building energy analysis program is designed to calculate hourly loads throughout the year. It calculates the yearly energy consumption, operation costs, and equipment payback.

CAD Interface with Ultra Edition Design and Duct Design: This system integrates the entire computer-aided drafting and computer-aided design (CAD) processes. With the Trane CDS software and Sigma Design or AutoCAD system, the user can start with initial calculations and finish with final schedules. The user can begin with an architectural outline of the building, and the system measures lengths and areas of zones, generates reports, and provides input for the Ultra Edition Load Design program. This information is then fed into the Duct Design program, completing the duct design process.

Veratrine (Static Regain) Duct Design: With this duct-sizing program, the user inputs the duct layout in simple line-segment form with the cubic feet per minute for the zone, the supply fan value of cubic feet per minute, and the desired noise criteria (NC) level.

The program sizes all the ductwork based on an iterative static regain procedure and selects all variable air volume (VAV) boxes when desired. It identifies the critical path and downsizes the entire ductwork system to match the critical-path pressure drop without permitting zone NC levels to exceed design limits.

The output of this program is an efficient , self-balancing duct design. It gives

the designer a printout of the static pressure at every duct node, making troubleshooting on the job site easier. The program will estimate the duct system and print a complete bill of materials, including schedules.

Equal-Friction Duct Design: This program produces the total pressure as well as the pressure drop for each trunk section. The output also includes duct sizes, air velocity, and friction losses. The program can be used for fiberglass selection as well.

The program will calculate the metal gauges, sheet-metal requirement and total poundage and provide a complete bill of materials.

DOE-2 PROGRAMS [18]:

This program developed by the U.S. Department of Energy, is based upon the ASHRAE proposals and consists of four main programs:

LOADS, SYSTEMS, PLANT, and ECONOMIC [19]. The LOADS program computes the transient response of the building fabric to produce hourly thermal loads in each space. These thermal loads are then used by the SYSTEMS program, together with the characteristics of secondary systems to calculate the loads on the central plant. The secondary system which may be specified are drawn from a menu of approximately twenty-five options together with several control schemes and operating schedules. The energy load data is then used by the PLANT program to simulate the performance of the central plant, which may be selected from a menu of available options which includes conventional heating and cooling equipment together with the cogeneration and solar system. The ECONOMICS program provides a life cycle cost analysis to estimate the relative costs of the various options.

1.3 THE NECESSITY OF A HVAC EXPERT SYSTEMS:

The idea of the HVAC expert system is to help the designers in their work and help them in making decisions beginning from the preliminary phases to detailed design.

This work provides the procedure and the drawings for the design, it will considerably reduce man-hours during the whole design process. HVAC-design with this research will provide:

- a. improved productivity.
- b. increased design quality.
- c. design standard and regulations that are dynamically useable.
- d. design changes that can be controlled and managed.
- e. several quality/cost alternatives for customers to choose from.
- f. a system that accumulates design knowledge.

1.4 OUTLINE OF THE THESIS:

The objective of the current research is to develop a number of comprehensive packages which can be used to produce the HVAC systems design for scientific and commercial building. These packages are HVACSYS which are designed as a pull-down menu for calculating the HVAC loads, and to display the results and print them out. HVACCAD is designed by customizing AutoCAD Software to be used to give HVAC systems drawings. These packages should give the results for the building of HVAC systems.

The developed knowledge based system should be capable of achieving the optimum system design for all applications, and of being used efficiently by HVAC designers. It must therefore be relatively simple and straight forward to use and capable of running on a personal computer.

The research work carried out in accomplishing the above tasks has been laid out as follows;

- A review of various procedures for HVACSYS and HVACCAD package commands is given in chapter two. These procedures give an illustration of the two packages and their subroutines.

- Theoretical analysis and description of HVAC load calculation steps are presented in chapter three. Chapter three also includes a psychrometric chart subroutine to present the processes of air conditioning and get the properties of the moist air at any assumed case. The U-Value subroutine calculation steps are also presented in this chapter.
- Customizing AutoCAD menu for HVAC systems programs as "Pipework" to calculate the pipes sizing, "Ductwork" for calculating the duct size, and "Psychart" programme are described in chapter four.
- Case study of the developed package and discussion for comparing the results of the example with another commercial package are presented in chapter five.
- Finally the conclusion of the research and recommendations for further work are given in chapter six. The list of references and appendix of U-value materials data are presented at the end of this thesis.

CHAPTER TWO

DESCRIPTION OF HVAC SYSTEM DESIGN SOFTWARE

2.1 INTRODUCTION:

For a typical design process, the HVAC consulting engineer normally gets a set of prints from the architect. He then gets either a draftsman to trace the architectural floor plans on vellum or mylar or a CAD operator to copy the floor plans into a diskette with the help of CAD software such as AutoCAD or Computervision. If the architect happens to use CAD and his software is different from that of the HVAC engineer, the engineer must try to translate the architectural CAD drawings so that his CAD system can understand them. If the translation is not successful then the HVAC engineer pulls out his scale and starts calculating floor areas, window sizes, wall thicknesses, etc., from the architectural floor plans. He then refers to a handbook or the manufacturer's data and gets the weather data, U-values, ventilation rates, exhaust rates, equipment, appliance heat losses, lighting wattages, and so on. With these data on hand, he starts to do the load calculations, either manually or on a PC.

After completing the calculations, the HVAC engineer starts the duct sizing, pipe sizing, air, water friction loss calculation and equipment selections. If the examining of duct sizing process is limited, the HVAC engineer usually does it manually by sketching a one-line duct layout and using a ductulator or friction chart to size the ductwork. There are duct sizing computer programs on the market, but the data-input process is laborious. Most HVAC engineers prefer to use the old faithful Ductulator.

The HVAC engineer then passes the duct layout sketch to a draftsman and the draftsman tries to produce a proper, scaled, double-line drawing on a drawing board or a CAD workstation. Ordinarily, the draftsman does not or can not check whether the duct layout is correctly designed or check the interferences with other building services

facilities. An interference check is usually done manually by a facility peer-check or office-check within the consulting firm.

If the project requires it, the HVAC engineer may have to determine the material requirement for HVAC system. Again, this is normally done manually by using a scale to get the length and the size of the ductwork, and by counting the number of fittings, deffusers, dampers to come up with a tabulated bill of materials.

This chapter gives a general review of the development in the field of HVAC knowledge based (KB) system. This research attempts to introduce developing the computer package HVACSYS based on such developments. This generalized package will evaluate the performance of heating, ventilation and air conditioning design. The package is composed of a number of computer codes which are based on minimum input data by the user such as the information on buildings (uses, constructions, dimensions, occupants, etc.) and the weather.

HVACCAD is designed by customizing AutoCAD software, this gives the user the opportunity to work on AutoCAD as a HVAC drawing package. It is used to give all HVAC systems drawings (pipework, ductwork), and to workout all air conditioning processes on a psychrometric chart.

The output of the developed packages produce the final HVAC system design of the building which include:

- 1 - HVAC system engineering drawings.
- 2 - List of materials and their quantities.
- 3 - Individual and total component costs.
- 4 - Reports of the HVAC loads can be either viewed on the screen or printed together with the inputs entered by the user.

2.2 SYSTEM CONFIGURATION:

The function of this system, as mentioned above, is to design the HVAC system

starting from getting the architect's plans of the building until producing the final HVAC system drawings. The steps of using this system are shown in Fig.(2.1) and explained as follows;

1. Building drawings are received from the architectural engineer by electronic mail through computer network or on storage disk. These drawings contain the following information:

- a. Architect's plans of the building.
- b. The type and quantities of the material used in the building construction.
- c. The building furniture and the number of the people who are going to occupy the building.

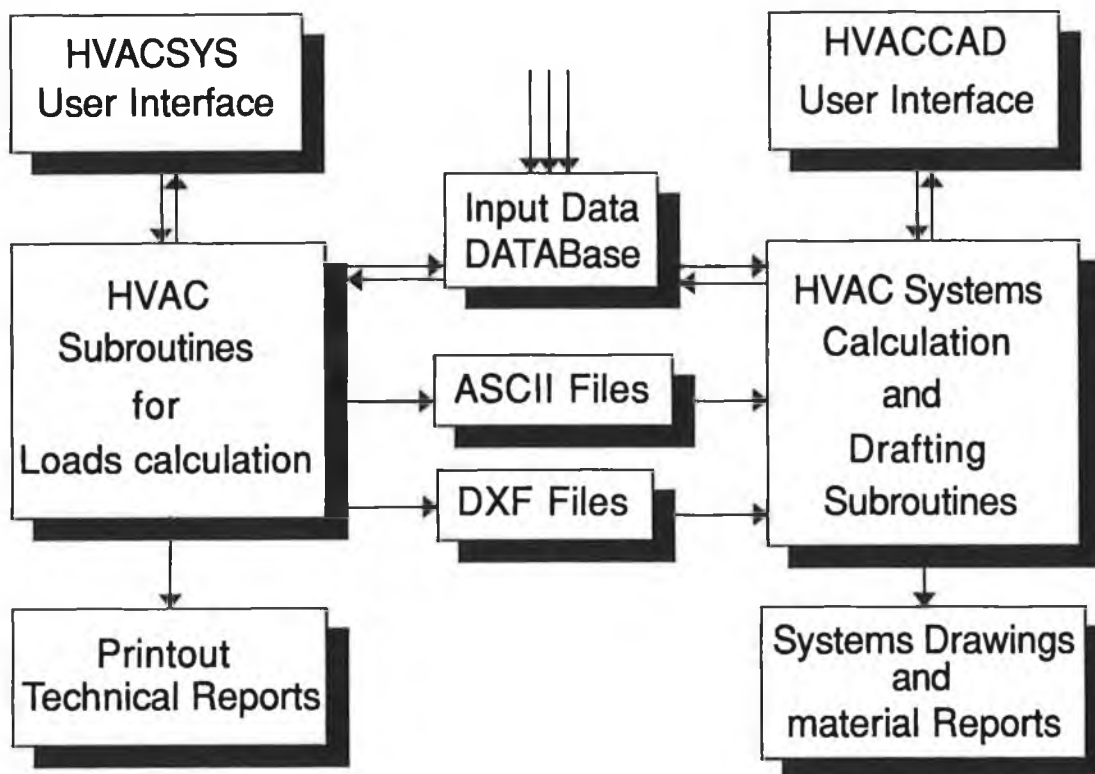


Fig.(2.1) *The structure of the developed knowledge based system*

2. Enquiries from the system user whether special conditions are required inside the building such as temperature, humidity or air purity.

3. Getting the weather data from DATABASE files (outside temperature, outside humidity, wind direction and magnitude, CLTD, Solar Heat Gain Factor (SHGF),)
for the calculation using HVACSYS package.
4. HVAC loads and system calculations are carried out by the routines developed within HVACSYS package to produce ASCII files and DXF files for HVACCAD package.
5. HVACCAD package access the material, standard components and equipment records in the DATABASE and retrieve information such as power, prices, volume, etc..
6. The data in the ASCII files produced by HVACSYS for calculation and drawing HVAC system, are accessed by routines in HVACCAD for further analysis and also for reading DXF files to display the drawings through HVACCAD routines.
7. Technical reports which may include input data for the HVAC loads can be displayed on the screen or printed out.
8. HVACCAD produces HVAC systems drawings which includes all the design information in detail such as piping, and ducting systems.

2.2.1 HARDWARE CONFIGURATION:

The research described in this thesis has been carried out using a microcomputer connected with complete hardware as follows;

1. A 286 personal computer with Math CoProcessor, 1.028MB of RAM, and storage consisting of a single 40MB hard disc, and floppy drives (5 1/2", 3 1/2"). A microcomputer was selected for this research because the intent is to develop a PC based system which will also permit the use of AutoCAD software for drawing. The selection of the hardware is very important for the ease of work, and the user can run more than one software at the same time. For example, in

this research the user working in AutoCAD package can run other software like the developed package (HVACSYS) and return to AutoCAD at any time.

2. A colour monitor with EGA graphic display.
3. A mouse (GM-F303) used as a digitizer for AutoCAD.
4. A printer (Star LC-10) for report printout.
5. A plotter (Hewlett Packard DraphPro DXL) for the drawing output.

2.2.2 SOFTWARE CONFIGURATION:

The software used in this development are divided into two categories;

1. *The commercial Package:*

- a. AutoCAD, 2D and 3D package release 10.
- b. Quick Basic Programming Software.

2. *Inhouse developed packages:*

- a. HVACSYS package.
- b. HVACCAD package by customizing AutoCAD.

2.3 HVACSYS PACKAGE DESCRIPTION

Fig.(2.2) shows the flow chart of the developed package (HVACSYS), which is totally pull-down menu driven, the master menu being the first and central menu that will branch to all other menus. These menus will make the program extremely user friendly even to the first time user. The input data is requested via a menu screen that is accessed through the master menu. The descriptive titles for input fields will appear on the monitor. The output from the programs are connected to the AutoCad Package by customizing its menu to HVAC system menu (HVACCAD) to perform the final engineering drawing.

The developed package (HVACSYS) is used to perform all the design of the HVAC system of Buildings. It contains a number of programs which the user can deal with easily to get the characteristics used by the HVAC designer.

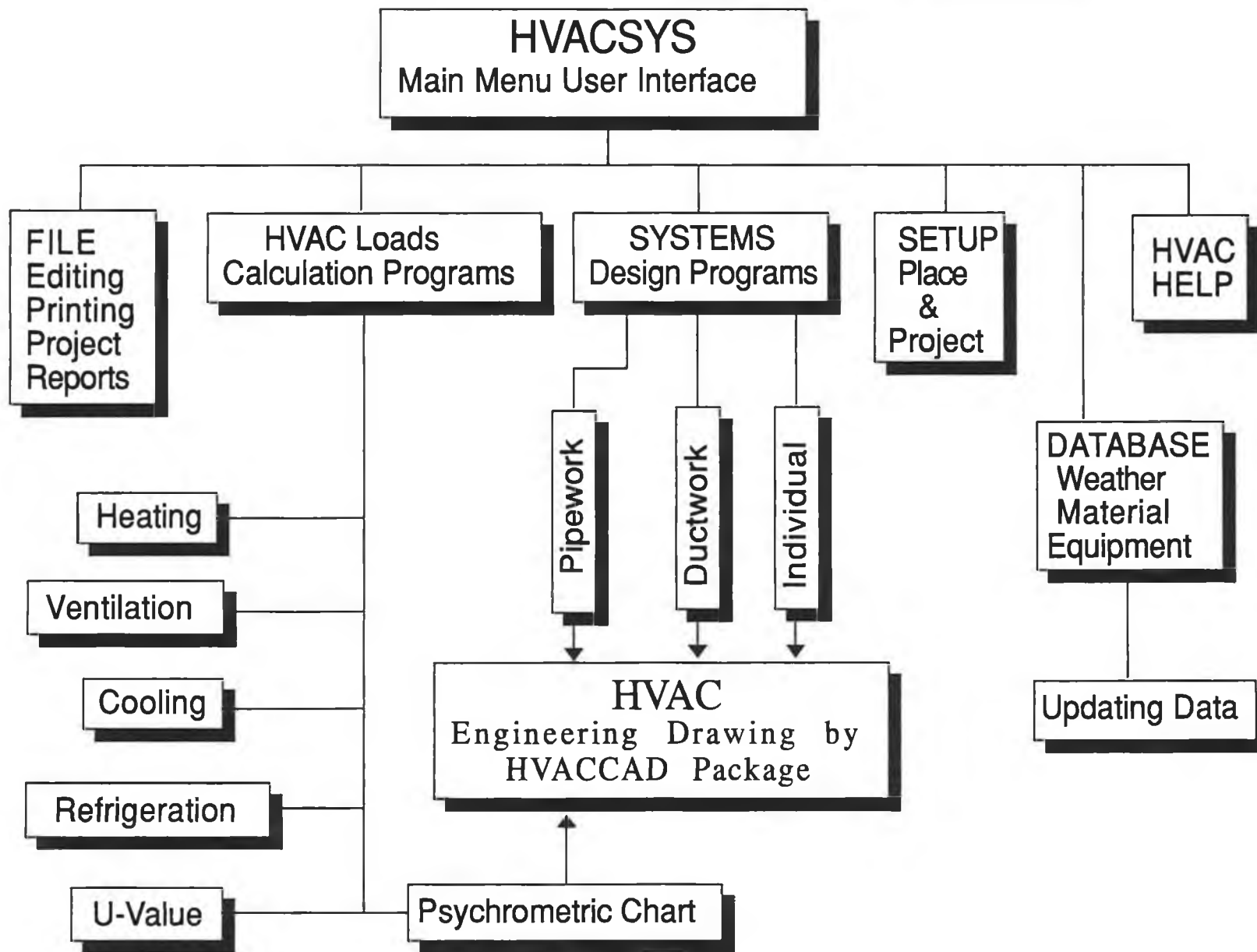


Fig.(2.1) Hierarchy chart for the developing package (HVACSYS).

2.3.1 HVACSYS MAIN MENU:

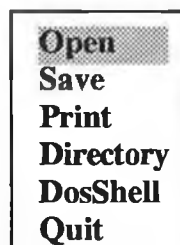
HVACSYS is an user interface which consists of six pull-down menus for easy use by any customer of the software. The interactive computer programs have been written in basic language using Quick Basic Compiler. It is displayed like any other software but with different command facility as follow;



To activate the menu bar, one can use the keyboard to select the desired option.

2.3.2 FILE COMMAND:

This option has a menu bar of five commands as follows:



Open command: This retrieves a document from the disk which represents a file of any HVAC project, and copies it on the screen for editing. The user can open several types of files by using the Open command on the File menu, Only ASCII files can be edited on the screen.

To open a file:

1. From the File menu, the user has to choose Open. Then the Open dialogue box appears.
2. The user then has to type the filename required and press the Enter key. If

the file he wants is not on the current drive or directory, he has to type the path as part of the filename.

Save command: This saves the current document on the screen to a hard disc or a floppy disc. The dos filenames can have up to eight characters plus an optional three-letter extension.

To save a file:

1. From the File menu, the user has to choose save command, then the Save dialogue box appears.
2. In the File name box, the user has to type a name for the file. If the user wants to save the file on a different drive or directory, he has to type the path as part of the filename.

Print Command: To print the current document on the printer, and put the printed document in paginated papers, the user must have a printer connected to or redirected through the LPT1 printer port

To print a file:

- From the File menu, the user has to choose the Print command, the print dialogue box appears, to allow the user to adjust the paper and to ensure the printer is on.

Directory command: This command displays a list of files, by selecting this option the screen will display a list of all the files that match the given filename template.

DosShell Command: This command allows the user to exit temporarily from the code and return back.

Quit Command: This command exits the package to dos prompt after giving the user a chance to save the current document. The ESC key can cancel the exit.

2.3.3 PROGRAM COMMAND:

This command takes the user through a submenu which contains many important programs to be used by any HVAC systems designer, this submenu has six options, as follows;

Heating
Ventilation
Cooling
Psychrometric chart
U-Value

Heating program:

This is a program to calculate the heating load (heat losses) of a building room by room according to ASHRAE method which is noted in ASHRAE Handbook, Fundamentals, 1989 [7]. The heating load is defined as the amount of kW or kcal/h or BTU/h that must be input by the HVAC equipment to maintain the structure at the indoor design temperature when the worst case winter design temperature is being experienced outside. Notice that people, lights, and equipment do not increase the heating load on the building and so are ignored. Heat losses occur through:

- 1) Glass Windows, glass doors, skylights.
- 2) Exterior walls or below grade walls.
- 3) Partition walls (that separate a heated zone from a cold zone).
- 4) Ceilings under a cold zone or attic.
- 5) Exterior roofs.
- 6) Floors over a basement or crawl space.
- 7) Floors on a concrete slab.
- 8) Air infiltration through cracks in the structure, doors, and windows.

Other heat losses are caused by the HVAC equipment before the air reaches the zones, these losses are called system losses. The four items that require additional heating capacity from the HVAC equipment are:

- 1) Ductwork located in an unheated space.
- 2) Ventilation air (air that is mechanically introduced into the building).
- 3) Combustion air (provided for gas or oil furnaces).

4) Return-air Plenum.

The results can be displayed on the screen or printed. In addition, the results are saved in files, these files are then recalled by HVACCAD interface to give the system plans.

Ventilation program:

The quality of the air inside a building, i.e, its temperature, moisture level, purity, movement and oxygen content, affects the well-being of those who work, live or visit the building. Air becomes stale or contaminated by the use made of the space. People at work decrease the relative proportion of oxygen in the air and will give rise to body odours, moisture and heat. Tobacco smoke, at best an irritant to non-smokers, may increase the risk of their developing lung cancer. Chipboard furniture and carpet may give off formaldehyde, and other furnishings produce dust and fibres. In addition to calculating the heating loads of some places like workshops, basements, labs, etc., using the last program, we need to ventilate these places by fresh air. Ventilation is a return-side load and is time dependent. It is caused by outside air that is deliberately introduced into the HVAC unit. The cold (or hot) air that enters the HVAC unit is heated (or cooled) before it reaches the room. Therefore, it is a system load, and is not calculated for individual zones. This program calculates the heating loads which cover the ventilation loads. However, the ventilation system has been designed in such a way that it is separated from the heating system.

Cooling program:

This is the main program for calculating the cooling loads of the building, it calculates the loads room by room.

The cooling load (or heat gain) is defined as the amount of kW or kcal/h or BTU/h that must be input by the HVAC equipment to maintain the structure at the indoor design temperature when the worst case summer design temperature is being

experienced outside. There are two types of cooling loads; sensible and latent. Sensible cooling refers to the dry bulb temperature of the structure. Latent cooling refers to the wet bulb temperature of the structure. In the summer, humidity is a factor in the selection of the HVAC equipment and the equipment must be sized to handle the latent load.

The *sensible cooling load* occurs through:

- 1) Glass Windows, glass doors, skylights.
- 2) Sunlight striking windows, skylights, or glass door and heating the zone.
- 3) Exterior walls.
- 4) Partition walls (that separate a heated zone from hot zone).
- 5) Ceilings under an attic.
- 6) Roofs.
- 7) Floors over an open crawl space.
- 8) Air infiltration through cracks in the building, doors, and windows.
- 9) Fluorescent lights.
- 10) People in the building.
- 11) Equipment operated in the summer.
- 12) Draw-through fan located in the air stream.

Notice that below grade wall, below grade floors, and floors on concrete slabs do not increase the cooling load on the structure and are therefore ignored.

Other sensible heat gains result from the HVAC equipment before the air reaches the zones, these gains are called system gains. The four items that require additional sensible cooling capacity from the HVAC equipment are:

- 1) Ductwork located in an unheated space.
- 2) Ventilation air (air that is mechanically introduced into the building).
- 3) Blow-thru fan located in air stream.
- 4) Return-air Plenum.

The *latent cooling load* occurs through:

- 1) People.
- 2) Equipment, pools, indoor fountains, etc.
- 3) Air Infiltration through cracks in the building, doors, and windows.

Other latent heat gains are from the HVAC equipment before the air reaches the zones, these gains are called system gains. The item that requires additional latent cooling capacity from the HVAC equipment is:

- Ventilation air (air that is mechanically introduced into the building).

The output will be sensible load, latent load and the flow rate of supply air and its temperature, or the capacity of the fan coils depending on the chosen system.

Refrigeration program:

This program calculates the refrigeration loads for any sized cooler, freezer, warehouse, walk-in unit, etc. Freezer temperatures can be as low as $-50\text{ }^{\circ}\text{C}$. The refrigeration loads include transmission loads, internal loads, product loads, and infiltration loads. Allowance is made for compressor run-time, fan heat, a safety factor, product pull-down time, and loads occurring in the box such as forklifts. The program uses dynamic, on-screen calculations so that the user can instantly see the effect of each item on the loads. The program comes with built-in libraries for products, container, coils, compressors and weather data. These libraries can be modified by the user to update the information and are stored permanently by the program. The program produces an extensive set of reports, including a summary listing of each load and its percentage of the total.

Psychrometric chart program:

The means for simulating the principles of air-conditioning processes are done

in this program. It is composed of:

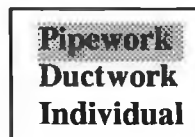
- i) estimating the relevant properties of atmospheric air (Psychrometric properties).
- ii) predicting the behaviour of air when undergoing constant-pressure mixing, heating, cooling, humidification and dehumidification processes.

U-value program:

The calculation of HVAC loads begins with the determination of U-values, which are overall heat transfer coefficients. U-values are calculated by taking the reciprocal of R-values and the conductivities of the materials. It is a complete menu bar program which the user can execute separately or as a subroutine in the last program.

2.3.4 SYSTEMS COMMAND:

This command gets the user through a menu bar which is the second important menu bar, it contains three system option:



Pipework option:

This option gets the user through a program which has four subroutines for the pipe size calculations.

1) Hot and cold water pipe sizing subroutine: This is the main subroutine to calculate the optimum pipe size for hot and cold domestic water supply systems in scientific, residential, and commercial buildings using ASHRAE procedures. Depending on the computer's memory, the system can contain details of a number of pipe sections. This

program also performs a system analysis that produces reports that list, pressure drops, required pressure flow rate, and water velocity at any design system.

- 2) Refrigerants pipe sizing program.
- 3) Gas pipe network program; this is not included in this thesis.
- 4) Steam pipe network program; this is not included in this thesis.

Ductwork option:

This option gets the user through a duct size program which comes in two versions:

- 1) The static regain, equal friction, and constant velocity method.
- 2) The only equal friction, and constant velocity method.

The calculation of duct sizes are printed on the basis of both round and rectangular cross-section. The program can handle all-air systems which are:

- a) Single-zone constant-volume system.
- b) Single-zone constant-volume system with reheat.
- c) Multizone system.
- d) Induction unit system.
- e) Variable-air-volume system.
- f) Dual-duct system.

Individual system option:

This program deals with Direct Expansion (DX) systems, and is divided into three options in a pull-down menu;

- i) Window type air-conditioning units.
- ii) Split system units.
- iii) Central DX coils system.

2.3.5 SETUP COMMAND:

The aim of the setup command in the main menu is to enter the fixed information for the place and the project for which the package will be used (user place and project). For this command we have two options;



User place option defines fixed parameters for the user place, these parameters are elevation above sea level, altitude line, outside design temperatures (summer, winter), relative humidities (summer, winter), etc. The user can enter the requested information as follows;

City	Damascus	Country	SYRIA
Latitude line	32	Altitude above see level	750 m
Outside summer condition:			
Temperature	40 °C	Relative Humidity	35 %
Outside winter condition:			
Temperature	-2 °C	Relative Humidity	65 %
Outside Avarage Temperature 29 °C			

Client project option defines the designer name, client name and his address, project name, number of buildings, the total area of the building, etc. The user can enter the requested information as follows;

Designer	<i>K.A. Alwhban</i>	Address	<i>School of Mech. & Manu. Eng.</i>
City	<i>Dublin 9</i>	Country	<i>Rep. of IRELAND</i>
Client	<i>A.M.S. Hamouda</i>	Address	<i>1 Shantalla Park</i>
City	<i>Dublin 9</i>	Country	<i>Rep. of IRELAND</i>
Project Name	<i>House Heating</i>	Total Area	<i>120</i> m ²
Number of Buildings	<i>1</i>	Heating Safety Factor	<i>10</i> %
Building Opening Hour	<i>8</i>	Sensible Safety Factor	<i>10</i> %
Building Closing Hour	<i>8</i>	Latent Safety Factor	<i>10</i> %

2.3.6 DATABASE COMMAND:

Each program for the design of any HVAC system needs to build up a database of;

- 1) building materials to use for calculating the U-value,
- 2) weather conditions for calculating the heating and cooling loads,
- 3) equipments with their capacities, types and prices.

The purpose of database is also to let the user enter his own data and update the old data. Any selection of this command goes to menu bar of three options which is displayed as follows:



Material option gets the user through a list of materials which includes building structure materials especially those used for U-value calculation, and HVAC components like pipes, duct, and their fittings (elbows, tees, flanges, etc.)

Weather option contains all the weather data schedules list used for calculating the cooling loads that are mentioned in the ASHRAE Handbooks [7,20-23] and ASHRAE Standard [23].

Equipment option gets the user through a list of equipment which can be used in HVAC systems. This is like a catalogue of equipment with their capacities and their prices. The user can update the prices and increase the number of equipment.

2.3.7 HELP COMMAND:

The function of the help command is to guide the user at any time to teach him how to enter the inputs, to define the procedure sequences, and to use the keys of the keyboard. Help command menu contains three options as follows:



Keys option: Gives the user a list of the keys functions in the main menu. By pressing any of these keys, the user gets to a certain procedure or function command.

Index option: This is an alphabetical list of help topics, including the HVACPRO Keywords. Each term in the index is linked to additional information.

The user can get help by:

- 1) Choosing the index command from the help menu bar.
- 2) Pressing the key corresponding to the items first letter.
- 3) Moving the cursor to the item the user wants help on, then pressing F1 from the functions Keys.

Topic option: Choosing this command displays information on the topic determined by the current cursor location.

2.4 HVACCAD PACKAGE DESCRIPTION

Common to most engineering tasks is the need to effectively retrieve data, perform analysis and synthesis based on the data, and store the results for later use. The results of these operations are eventually documented as drawings, bills of materials, manufacturing instructions, technical documents and many kinds of reports.

The engineering analysis and synthesis process incorporates a great deal of know-how which is called expertise. The key to successful engineering drafting automation is the incorporation of this expertise in a computer.

Traditional CAD systems provide some means to express engineering knowledge, such as:

- * parametric programs.
- * graphical Symbols, and
- * existing drawings and geometric models.

In addition, some knowledge domain has been implemented by CAD software vendors in application packages.

Although computer-aided tools provide great potential for automating engineering design, traditional CAD systems have brought major productivity improvements mainly to drafting work in the detail design phase.

The HVACCAD package describes customizing the AutoCAD menu to make it suitable for HVAC system design by adding the commands which the user can use to collect several HVAC components into a group, forming a composite software system. The user can then complete the mechanical drawing of the HVAC system, as often as wanted. The HVACCAD program can also make use of a database information of

standard components which can be found individually or as an assembly of a group of components.

The program considers each component of the HVAC system as an entity or a block. In addition to the mechanical HVAC system drawing, the new package can also provide drawing database, quantities and bill of materials and equipment.

2.4.1 HVACCAD USER INTERFACE:

The user interface of **HVACCAD** is accomplished by integrating AutoCAD tools and relational database. **HVACSYS** is closely integrated with the AutoCAD via the database program and random access files. This means that the user can communicate with the system via **HVACSYS** and AutoCAD via **HVACCAD**. In the **HVACSYS** the structure of rooms, the system design outputs, spaces and components of HVAC system are defined as database information. The user can add knowledge and data or update them in the system whenever required.

The user interface of **HVACCAD** consists of three main programs, which are written in Autolisp programming language. These programs are explained as follows.

2.4.2 PIPEWORK PROGRAMME:

This pipe sizing program is for closed and open systems, and for any fluid by inputting the viscosity and specific gravity. **PIPEWORK** is an AutoCAD-based piping design, layout and drafting program, it is developed to calculate pipe sizing for both cold and hot water central systems (single pipe, two pipe, four pipe) and refrigerant pipe systems. The user inputs the piping layout in simple line-segment form (the start and end point of each section of pipe) with flow rate for every section of pipe. **PIPEWORK** is a 2D and isometric program which uses the AutoCAD pull-down, ICON menus fully, and also the screen menu. It adds a new dimension of productivity for piping and plant design, within the AutoCAD.

PIPEWORK is an integrated program with the HVACSYS package, so that it gets the data produced by HVACSYS as ASCII files such as flow rates and loads. With this program the user can draw the piping network with its components (valves, fittings, hangers, ...), and equipments (boilers, burners, pumps, radiators, unit heaters, expansion tanks, storage calorifiers, ...).

After completing the design, the user gets the output which includes:

- * line lists, plot plans, orthographics.
- * complete bill of materials (including pipe sizing and linear length required, fitting, equipments).
- * Estimated piping system costs of the whole system.

2.4.3 DUCTWORK PROGRAMME:

DUCTWORK is an AutoCAD-based ducting design, layout and drafting program. It is developed to calculate the size of all ductwork based on an iterative static regain procedure for all air systems. It identifies the critical path and downsizes the entire ductwork system to match the critical path pressure drop without permitting zone noise criteria (NC) levels to exceed the design limits. This is also a 2D program which uses AutoCAD pull-down, ICON menus fully and also the screen menu. It adds a new dimension of productivity for ducting and plant design, within AutoCAD.

DUCTWORK is an integrated program with the HVACSYS package, so that it gets the data produced by HVACSYS as ASCII files such as flow rates and loads. With this program the user can draw the ducting network with its components (dampers, fittings, hangers, ...), and equipments (AHU, fancoils, fans, grills, coils, humidifiers, condensing units, DX units, filters, diffusers, ...).

The outputs of this program is an efficient, self-balancing duct design. It gives the user the following:

- * A printout of the static pressure at every duct node, duct sizes, air velocity,

frictions losses.

- * Plot plans, orthographics
- * bill of materials (types, quantities, prices), and estimated costs of the whole system.

2.4.4 PSYCHART PROGRAMME:

PSYCHART is a display of the psychrometric chart. It allows the user to obtain the properties of a defined point, and carry out all air conditioning processes (cooling, heating, mixing, humidification, dehumidification, and general process) which can be applied on the psychrometric chart.

PSYCHART gives reports of all properties of any point on the psychrometric chart, and any process defined by the user, and psychrometric chart drawing of the defined points and processes.

CHAPTER THREE

THEORETICAL BASIS OF HVAC LOAD CALCULATIONS

3.1 INTRODUCTION:

HVAC systems are designed to provide control of space temperature, humidity, air contaminants, differential pressurization and air motion. Usually an upper limit is placed on the noise level that is acceptable within the occupied spaces. To be successful, the system must satisfactorily perform the intended tasks. Most HVAC systems are designed for human comfort as discussed at length in ref. [7,8]. These references discuss the objective of the HVAC design. Industrial applications may have objectives other than human comfort. If human comfort can be achieved while the demands of industry are satisfied, the design will be that much better. However HVACSYS is designed to cover designs both for commercial buildings (mainly human comfort) and for scientific buildings including industrial buildings.

One of the cardinal rules for a good, economical energy efficient design is not to design the total system to meet the most critical requirements of just a small portion of the total area served. That critical area should be isolated and treated separately, then if necessary to control the heat transfer to the building (U-Value). HVAC systems require the solution of energy mass balance equations to define the parameters for the selection of appropriate equipment. The solution of these equations requires the understanding of that branch of thermodynamics called "psychrometrics". The modern designer prefers to use a computer method to calculate HVAC loads, select equipment, and size piping and ductwork. Especially for large or complex projects, computer programs are generally the most cost effective and the most recommended. Where one or more of the following items will probably be modified during the design phase of a project, computer programs should be used:

- * Building orientation
- * Walls, roof, and floor Construction (overall U-Value)
- * Percentage of glazing or glazing area
- * Building or rooms sizes

The use of computers in the thermal analysis of buildings and of HVAC systems has grown from a need to improve the efficiency of the design process. This itself being influenced by changes in technology and by growing economic pressure. Initially computer software were developed for the thermal analysis of buildings, these programs being used to predict the energy demand within each zone, thus allowing rapid appraisal of architectural changes and the selection of equipment based on the resulting peak loads. Programs of this type assume idealised control of the installed plant, the system maintaining constant conditions in the occupied zone.

However for any project, there are mainly eight programs which should be used for the complete design. This chapter covers the developed (HVACSYS) package. This package (HVACSYS) is a set of individual program modules that will interact to enable the user to enter data, process it and inspect the results in a very organized manner. The system is entirely menu driven, the master menu being the first and central menu that will branch to all other menus. The master menu contains the general tasks performed by the developed package as heating, ventilation, cooling, U-Value, psychrometric chart, duct size, and pipe size programs which are treated in this chapter. This chapter briefly explains the different selection of the main programs in the master menu and relevant theoretical equations and programme execution steps.

3.2 HEATING LOAD PROGRAMME:

As a general principle when approaching the question of space heating, it is desirable that the building and the heating system should be considered as a single entity. The form and construction of the building will have an important effect not only upon the method to be adopted to provide heating service, but also upon subsequent recurrent energy cost. The amount of heat required to maintain a given internal

temperature may be greatly reduced by thermal insulation and by any steps taken to reduce an unwanted intake of outside air. Large areas of glass impose very considerable loads upon any heating system and run counter both to the provision of comfort condition and to any prospect of energy efficient operation.

This program computes heat losses through the building using the ASHRAE method [7]. The first step in calculating the heating load is to establish the project's heating design criteria:

- 1) Ambient design Weather conditions: temperature, wind direction and wind speed.
- 2) Space (indoor) air temperature to be maintained in each space during design weather condition.
- 3) Estimate temperature in adjacent unheated spaces.
- 4) Select or compute heat transfer coefficients (U-Values) for outside wall, glass, inside walls, non-basement floors, ceilings...etc.
- 5) Determine the net area of the outside wall, outside roof, glass, roof next to heated spaces, floors, or next to an unheated area. These determinations can be made from building plans.
- 6) Compute heat transmission losses for each kind of wall, glass, floor, ceiling, and roof in the building by multiplying the heat transfer coefficient (U-Value) in each case by the area of the surface and the temperature difference between indoor and outdoor air.
- 7) Compute heat losses from basement or solid ground floor using the method mentioned in ASHRAE 1989 *Handbook of Fundamental* [7].
- 8) Compute heat loss from infiltration and ventilation depending on air changes.
- 9) The sum of the coincidental transmission losses or heat transmitted through the confining walls, floor, ceiling, glass, and other surfaces, plus the energy associated with cold air entering by infiltration or the ventilation air required to replace mechanical exhaust, represents the total heating load.
- 10) In buildings with a sizeable and reasonably steady internal heat release from sources other than the heating system, compute and deduct this heat release under

design conditions from the total heat losses computed above.

11) The pick-up loads that may be required in intermittently heated buildings or in buildings using night thermostat setback must be included. Pick-up loads frequently require an increase in heating equipment capacity to bring the temperature of structure, air, and material contents to the specified temperature.

12) Material and equipment that may be brought into the building at a temperature below inside design temperature must be considered.

The heating load is calculated according to all points mentioned in chapter 2, these procedures are based on ASHRAE *Fundamentals* [7] which are mentioned above and also ASHRAE/IES Standard [23].

The winter outdoor design temperature should be based preferably on minimum temperatures that will not be exceeded for 99 percent of the total hours in the months of December, January, February (*a total 2160 hrs in the northern hemisphere*) and the months of June, July, and August (*in the southern hemisphere a total of 2208 hrs*) [13]. For energy conservation considerations, the outdoor winter design temperature to be based on a temperature which will not exceed 79,5 percent of the same total heating hours. Anyway, the user of this package has the option to choose the outdoor winter design temperature if there is a special case. Also, there is a recommendation table of the inside temperatures according to the defined space, and the user has an option to enter his own temperatures.

3.2.1 THEORETICAL ANALYSIS OF HEAT LOSSES:

Each room in a building is taken in turn and an estimate is made of the amount of heat necessary to maintain a given steady temperature within the space, assuming a steady lower air temperature outside. The calculation falls into two parts;

- * one relating to conduction through the various surrounding structural surfaces, walls, floor and ceiling;
- * and the other to the heat necessary to warm up to room temperature any outside air which, by accident of design, has infiltrated into the space.

Adjacent rooms maintained at the same temperature will have no heat transfer through the partitions or other surfaces between them and these may be ignored. Furthermore, if certain surfaces, such as the ceiling or floor, are used for heat output, then these will not be taken into account so far as heat loss from the room is concerned. They will, however, have inherent losses upwards or downwards to unheated areas and those will have to be allowed for separately.

The total heat losses for each room from several items as explained in chapter two is composed of;

$$Q = Q_t + Q_r \quad (3.2.1)$$

Where:

Q = Heat losses from the room, [Watt].

Q_t = Total Heat losses from room construction, [Watt].

Q_r = Heat loss from the infiltration, [Watt].

Heat losses through room construction:

The total heat losses from room construction may be expressed as follows:

$$Q_t = \sum_{j=1}^{j=m} Q_j (OF + WF)_j + \sum_{k=1}^{k=n} Q_k + Q_{sgf} \quad (3.2.2)$$

Where:

Q_j = Heat losses from external surface j , [Watt].

Q_k = Heat losses from partition k , [Watt].

Q_{sgf} = Heat loss from solid ground floor, [Watt].

OF = Orientation factor for external surfaces, [%].

WF = Wind factor for external surfaces, [%].

According to Russian Standard [24] and CIBSE Guide [8] the orientation and wind factors are applied to the external surfaces (walls, roof, windows, skylight, doors,..).

Orientation Factor: This factor may be taken from the following figure (Fig.(3.1)) for all directions.

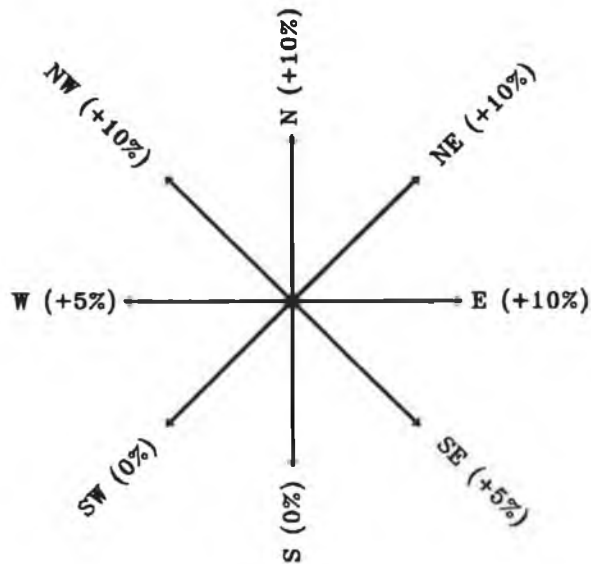


Fig. (3.1) Orientation Factors Diagram

Wind Factor: This factor is applied to external surfaces in the windward side only for each place that has the orientation of the wind and the velocity. It is selected according to these parameters. Table (3.1) shows the wind factor as follows;

Table 3.1 Wind Factors

Wind Factor [%]			
Nature of surface	wind	Velocity	[m/s]
	$V \leq 5$	$5 < V \leq 10$	$V > 10$
Hidden	5	10	15
Exposed	10	20	30

Fig.(3.2) explains the hidden and the exposed surfaces of the buildings:

- Building No. 1 is considered as hidden if $L < 5h$.
- Building No. 2 is considered as a exposed.

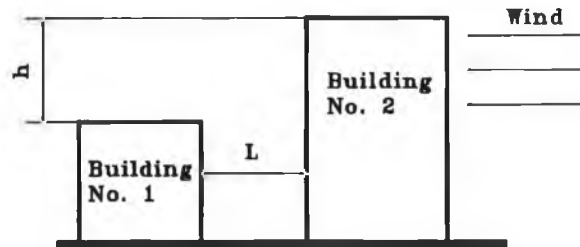


Fig. (3.2) Hidden and exposed surfaces

External surfaces:

External surfaces include glass windows, glass doors, skylights, exterior walls, exterior roof, and basement wall with U-Value calculated according to the ASHRAE method, the heat losses from these surfaces can be calculated by the following equation:

$$Q_j = U_j A_j (t_i - t_o) \quad (3.2.3)$$

where:

Q_j = Heat loss from surface j, [Watt].

U_j = Heat transfer coefficient (U-Value) of the surface j, [$W/m^2\text{°C}$].

A_j = Area of surface j, [m^2].

t_i = Inside temperature in winter, [°C].

t_o = Outside temperature in winter [°C].

Internal surfaces (Partitions):

These surfaces include internal walls, ceilings, floors above and below the ground, walls below the ground and basement. The heat losses from these surfaces can be calculated by the equation (3.2.4) as follows;

$$Q_j = U_j A_j (t_i - t_n) \quad (3.2.4)$$

where:

t_n = Next side temperature (unheated place, ground temperature, place with

lower temperature,.....), [°C].

Solid ground floor:

The heat loss through this surface may be calculated using the Wang and Blight [7] equation and equation (3.2.1) where the U-Value has to be calculated by the Billington Eq. (3.6.4) given by [8,17] and the bigger value is taken. Wang and Blight relationship is written as follows;

$$Q_{sgf} = F_2 P (t_i - t_o) \quad (3.2.5)$$

Where:

Q_{sgf} = Heat loss from solid ground floor, [Watt].

F_2 = Heat loss coefficient, per metre of perimeter, Table 5 chapter 26 in the ASHRAE Fundamentals [7], [W/°C.m].

P = Perimeter or exposed edges of floor, [m].

Infiltration heat loss:

Infiltration of outside air causes both sensible and latent heat loss. The energy required to raise the temperature of outdoor infiltration air to indoor air temperature is the sensible component. The heat loss associated with the net loss of moisture from the space is classified as the latent component.

Sensible Heat loss:

The energy required to warm outdoor air entering by infiltration to the temperature of the room is given by:

$$q_s = C_p \dot{v} \rho (t_i - t_o) \quad (3.2.6)$$

Where:

q_s = Sensible heat loss, [W].

C_p = Specific heat of air, [J/kg°C].

\dot{v} = Flow rate of outdoor air entering building, [L/s].

ρ = Density of air at temperature t_o , [kg/m³].

using standard air where $\rho = 1.2 \text{ Kg/m}^3$, and $C_p = 1.0 \text{ Kj/Kg}^\circ\text{C}$, Equation (3.2.7) reduces to:

$$q_s = 1.2 \dot{v} (t_i - t_o) \quad (3.2.7)$$

The flow rate of outdoor air entering depends on wind speed, direction, width of cracks, size of openings, type of openings and other factors. There are two methods used to obtain the quantity of infiltration air rate which is explained as follows:

① **Crack length method:**

For the designer who prefers the crack method, the basis of calculation is the amount of crack used for computing the infiltration heat loss which should not be less than half the total length of the crack in the outside walls of the room. In buildings without partitions, air entering through cracks on the windward side must leave through cracks on the leeward side. Therefore, one-half of the total crack for each side and end of the building is used for calculation. In a room with one exposed wall, all the crack is used. With two, three, or four exposed walls, the wall with the crack that will result in the greatest or least air leakage, half the total crack is used, whichever is greater.

In a residence, total infiltration loss of the house is generally considered equal to the sum of infiltration losses of the various rooms. But, at any given time, infiltration takes place only on the windward side or sides and not on the leeward. Therefore, for determining total heat requirements of larger buildings,

it is more accurate to base total infiltration loss on the wall with the most total crack or at least half the total crack in the building, whichever is greater.

When the crack method is used for estimating leakage, the air flow rate may be calculated from equation (3.2.8) [16] as follows:

$$\dot{v} = C_i L (\Delta p)^n f_1 f_2 \quad (3.2.8)$$

where:

C_i = Window infiltration coefficient for pressure difference of 1 Pa, [L/s m].

L = Length of window or door crack to be considered, [m].

Δp = Applied pressure difference, [Pa].

n = Exponent relating volume flow rate to applied pressure difference
generally lies in the range 0.6 to 0.7, for Ireland is taken 0.63 [20].

f_1 = Correction factor for geographical location, Table (3.2).

f_2 = Correction factor for internal resistance, Table (3.3).

Table (3.2) Correction factor for geographical location

Wind speed exceeded for 50% of time, [m/s]	Correction factor, f_1	
	sheltered location (inland)	Exposed location (coastal)
3.5	0.85	0.79
4.0	1.0	0.94
4.5	1.16	1.09
5.0	1.32	1.25
5.5	1.49	1.40
6.0	1.67	1.57
6.5	1.84	1.73

Table (3.3) Correction factor for internal resistance.

Window type	Internal structure	Correction factor, f_2
All Types	Single plan (no full partitioning)	1.0
Short length of well fitting window opening joint (say, 20% of facade openable)	single corridor with many side doors: liberal internal partitioning with few interconnecting doors	1.0
long length of well fitting window or short length of poor fitting window joint (say, 20% to 40% of facade openable)	Single corridor	1.0
	Liberal partitioning	0.8
Long length of poor fitting window joint (say, 40% to 50% of facade openable)	Single corridor	0.8
	Liberal partitioning	0.65
Very long length of poor fitting window joint (say, >50% of facade openable)	Single corridor	0.65
	Liberal partitioning	0.4

The infiltration coefficient C_i is defined as the volume flow rate of air per unit length of the opening at an applied pressure difference of 1 Pa, the values of the infiltration coefficient C_i being shown in Table (3.2) . The applied pressure difference may be defined as follows:

$$\Delta p = \frac{1}{2} C_p \rho u^2 \quad (3.2.9)$$

where:

C_p = Pressure coefficient

u = Mean wind speed at height equal to building height, [m/s]

Table (3.4) Air infiltration through windows, [8].

Window type	window infiltration coefficient for pressure difference of 1 Pa Ci [litter/sm]
Horizontally or vertically pivoted weather stripped	0.05
Horizontally or vertically pivoted non-weather stripped	0.25
Horizontally or vertically sliding weather stripped	0.125
Horizontally or vertically sliding non-weather stripped	0.25

Wind speed varies with height and location. Equation (3.2.10) gives an expression which relates this variation to the nature of the terrain across which the wind is passing:

$$u = u_m K_s Z^a \quad (3.2.10)$$

where:

u_m = Mean wind speed at 10 m height in open country (design wind speed of each place) , [m/s]

Z = Height above ground, [m]

K_s = Parameter relating wind speed to nature of terrain

a = Exponent relating wind speed to height above ground

Table (3.5) gives the values of the coefficients K_s according to four types of terrain as follows:

Table (3.5) Values of parameters K_s and a .

Terrain	K_s	a
Open flat country	0.68	0.17
Country with scattered windbreaks	0.52	0.20
Urban	0.35	0.25
City	0.21	0.33

Air Change Method:

Some designers base infiltration on an estimated number of air changes rather than the length of window cracks. The number of air changes given in Tables (3.6) and (3.7), should be considered only as a guide. When calculating infiltration losses by the air change method, Equations (3.2.6) and (3.2.7) can be used by substituting for V the volume of the room multiplied by the number of air changes as follows:

$$\dot{v} = n V \quad (3.2.11)$$

where:

n = Number of air changes.

V = Volume of the infiltrated place equal to multiplying the internal place dimensions ($V=H.L.W$), [m^3].

Table (3.6) Number of air changes for Infiltration

Type of Building	Air infiltration rate [h^{-1}]	Ventilation allowance [$W/m^3 \cdot K$]
Art galleries and museums	1	0.33
Assembly halls, lecture halls	$\frac{1}{2}$	0.17
Banking halls: Large (height > 4m)	1	0.33
Small (height < 4m)	$1\frac{1}{2}$	0.50
Bars	1	0.33
Canteens and dining rooms	1	0.33
Churches and chapels: Up to 7000 m^3	$\frac{1}{2}$	0.17
> 7000 m^3	$\frac{1}{4}$	0.08
Vestries	1	0.33
Dining and banqueting halls	$\frac{1}{2}$	0.17

Type of Building	Air infiltration rate [h ⁻¹]	Ventilation allowance [W/m ³ K]
Exhibition halls: Large (height > 4m)	¼	0.08
Small (height < 4m)	½	0.17
Fire stations; ambulance stations: Appliance rooms	½	0.17
Watch rooms	½	0.17
Recreation rooms	1	0.33
Flats, residences, and hostels: living rooms	1	0.33
Bedrooms	½	0.17
Bed-setting rooms	1	0.33
Bathrooms	2	0.67
Lavatories and cloakrooms	1½	0.50
Service rooms	½	0.17
Staircase and corridors	1½	0.50
Entrance halls and Foyers	1½	0.50
Public Rooms	1	0.33
Gymnasia	¾	0.25
Hospitals: Corridors	1	0.33
Offices	1	0.33
Operating theatre suite	½	0.17
Stores	½	0.17
Wards and patient areas	2	0.67
Waiting rooms	1	0.33
Hotels: Bedrooms (standard)	1	0.33
Bedrooms (luxury)	1	0.33
Public Rooms	1	0.33
Corridors	1½	0.50
Foyers	1½	0.50
Laboratories	1	0.33
Law Courts	1	0.33
Libraries: Reading rooms (height > 4m) .	½	0.17
(height < 4m) ..	¾	0.25
Stack rooms	½	0.17
Store rooms	¼	0.08
Offices: General	1	0.33
Private	1	0.33
Stores	½	0.17

Type of Building	Air infiltration rate [h ⁻¹]	Ventilation allowance [W/m ³ °K]
Police Stations: Cells	5	1.65
Restaurants and tea shops	1	0.33
Schools and colleges: Classrooms	2	0.67
Lecture rooms	1	0.33
Studios	1	0.33
Shops and showrooms: Small	1	0.33
Large	½	0.17
Department store	¼	0.08
fitting rooms	1½	0.50
Store rooms	½	0.17
Sports pavilions: Dressing rooms	1	0.33
Swimming baths; Changing rooms	½	0.17
Bath hall	½	0.17
Warehouses: Working and packing spaces ...	½	0.17
Storage spaces	¼	0.08

Table (3.7) Number of air changes for Infiltration

Construction	Air infiltration rate [h ⁻¹]	Ventilation allowance [W/m ³ °K]
Multi-storey, brick or concrete construction: Lower and intermediate floors	1	0.33
Top floor with flat roof	1	0.33
Top floor with sheeted roof, lined	1¼	0.42
Top floor with sheeted roof, lined	1½	0.50
Single-storey unpartitioned spaces: Brick or concrete construction		
Up to 300 m ³	1½	0.50
300 to 3000 m ³	¾	0.25
300 to 10000 m ³	½	0.17
Over 10000 m ³	¼	0.08

Construction	Air infiltration rate [h ⁻¹]	Ventilation allowance [W/m ³ °K]
Curtain wall or sheet construction, lined:		
Up to 300 m ³	1¾	0.58
300 to 3000 m ³	1	0.33
300 to 10000 m ³	¾	0.25
Over 10000 m ³	½	0.17
Sheet construction, unlined:		
Up to 300 m ³	2½	0.75
300 to 3000 m ³	1½	0.50
300 to 10000 m ³	1	0.33
Over 10000 m ³	¾	0.25

Latent Heat Loss:

When moisture must be added to the indoor air to maintain winter comfort conditions, the energy needed to evaporate an amount of water equivalent to what is lost by infiltration (latent component of infiltration heat loss) must be determined. This energy may be calculated by:

$$q_l = \dot{v} \rho (W_i - W_o) h_{fg} \quad (3.2.12)$$

where:

q_l = Latent heat loss, [W].

W_i = Humidity ratio of indoor air, [kg/kg dry air].

W_o = Humidity ratio of outdoor air, [kg/kg dry air].

h_{fg} = Latent heat of vapour at t_i , [kJ/kg].

If the latent heat of vapour h_{fg} is 2450 kJ/kg, and the air density ρ is 1.2 kg/m³, equation (3.2.12) reduces to:

$$q_l = 2940 \dot{v} (W_i - W_o) \quad (3.2.13)$$

3.2.2 HEATING PROGRAM EXECUTION PROCEDURES:

Fig.(3.3) and Fig.(3.4) show the procedures of the heating load calculation. The execution of the heating program through selecting "**Heating**" command from the "**Programs**" pull-down menu takes the user through a menu for selecting the heating load calculation method, which are "**Room By Room**" and "**Whole Building**". When the user selects "**Room By Room**" option the program will go through a procedure that enters the information for each space then calculate the heating load for the room space and so on for all rooms in the building. If the user selects the "**Whole Building**" option the program will go through the procedure that enter the input data information for all spaces then the calculation for the heating loads for the whole building takes place. For that a menu is displayed on the screen for the selection as following:

This program calculates the Heating Load
for
Commercial and Scientific Buildings
Would you like to calculate:
1 - Room By Room
2 - Whole Building

After that an entry input data for the building are displayed to input the building information which contains building description, dimensions, total area, number of storeys, three storeys that may be multiple in the building and the infiltration input data which may be computed by crack method (glazing sides, windows types, building exposure and building internal layout). The entry input data menu, which is displayed automatically by pressing the "**Enter**" key on the keyboard after selecting the type of procedures. The input data is requested via a menu screen that is accessed through the last menu. The entry data menu screens contain descriptive titles before each input field or data area. The descriptive titles for input fields will appear in reverse video on the monitor. To enter data, the user has to position the cursor to an input field and type in the desired value. Any input data field can always be edited for modification or correction. This entry data menu for the building can be displayed on the screen as

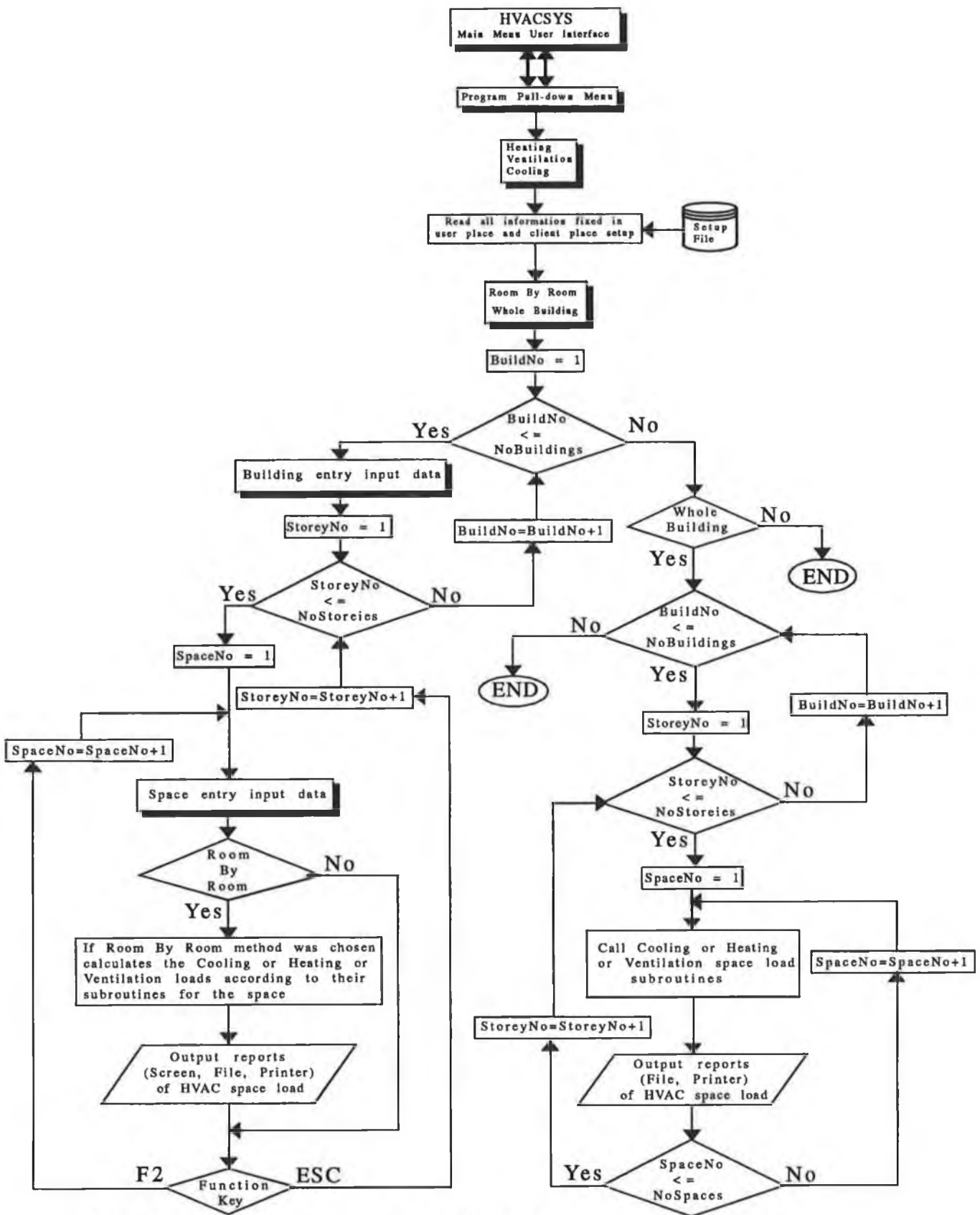


Fig. (3.3) Flow Diagram of The HVAC Main Programme Procedures

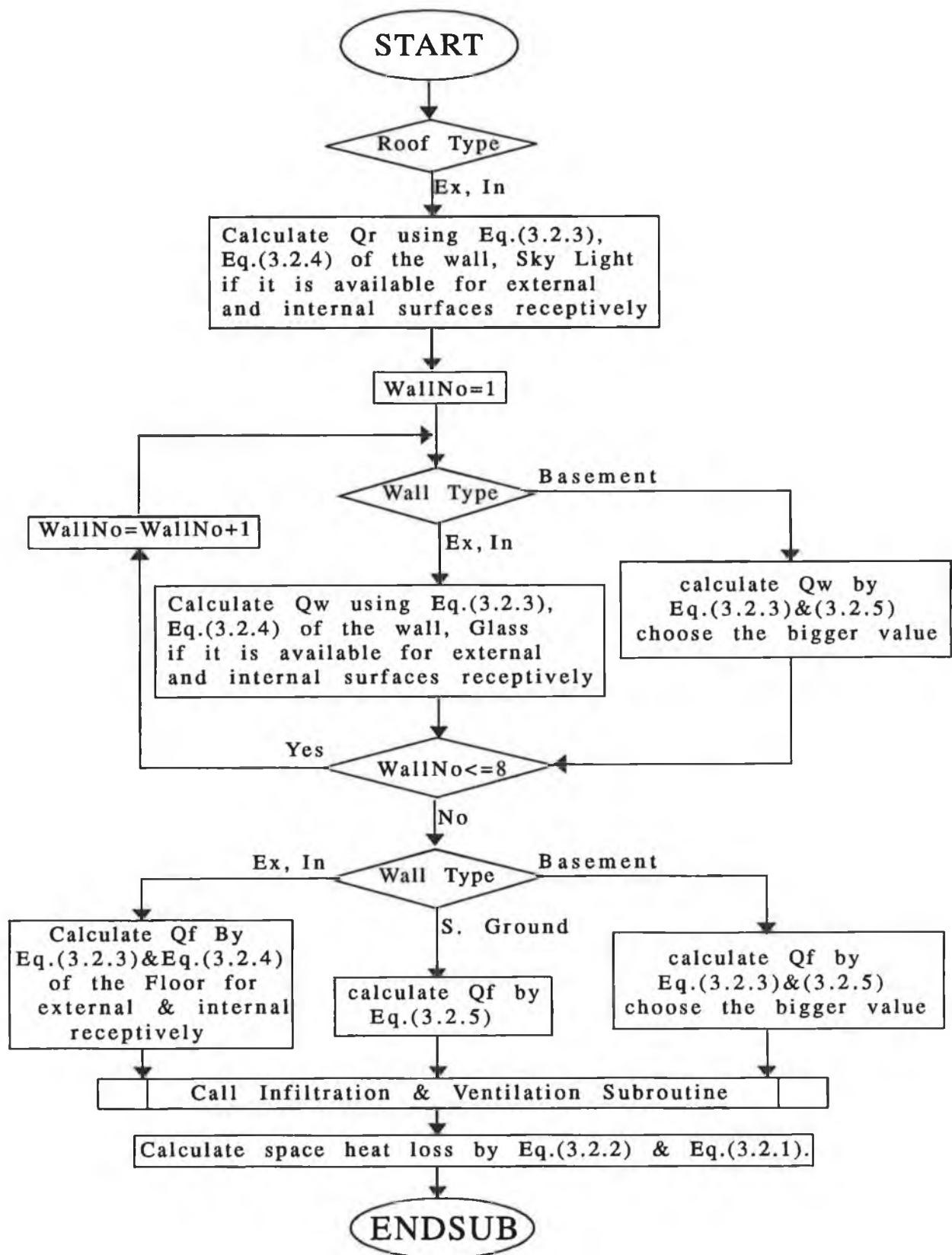


Fig. (3.4) Flow Diagram of The Heating Load Calculation Steps

follows:

Building No 1	
Building Description	School of mech. & Mnfg Engg
Dimensions L x W x H (m)	20x 30 x 15
Number of Storeys	4
Building Exposure (1-Open flat Country,2-Suburban,3-City Centre)	2
Glazing on (2/4) walls	2
If 2 then (Longer/Shorter) wall be glazed (L/S)	L
Windows Pivoted or Sliding (P/S)	P
Windows Weather stripped (Y/N)	Y
Building internal layout (1-Open plan,2-Single Corridor,3-Liberal partitions)	3
Approx % of facade which is openable window	12
Multiple Storeys	
Storey No	2
Multiplication	2
Storey No	0
Multiplication	0
Storey No	0
Multiplication	0

For the building entry menu, the user does not need to enter all information. For example, to continue running the program it is enough to enter only the number of storeys but if the user wants to skip this building and jump to the next he just has to set the number of storeys equal to zero. Pressing "ESC" key to cancel the process for this building at this stage and pressing "Enter" to continue the program execution to the next step, the user has only to follow the help line at the bottom of the screen. A space entry input data appears automatically after that with building, storey and space numbering as header of this menu to keep the user informed on which space he is working on. This menu is displayed on the monitor as shown in the next page:

The dialogue entry input data menu which is shown above has 86 inputs to cover all position of the space. For some input data there is a help input data which can be edited by pressing the "F3" Function key to help the user to enter the correct value. As mentioned above it is not necessary to enter all the input data and for the heating load calculation, there are allowable combinations for each element which can be explained as follows:

Roof: There are three allowable combination for calculating the heat loss from the roof:

- 1 - If the roof is an external surface, the user has to enter the area, U-Value and select the roof type "1".
- 2 - if it is an internal surface with temperature difference, the user has to input the values of area, U-value, temperature difference and roof type is "2"

Building No. 1		Storey No. 1		Space No. 2				
Dimension LxWxH		5.6x6.3x2.7		Description N30 : Printer Room				
Dry Bulb Temperature tdb		21.0 °C		Relative Humidity 50 %				
Roof Information								
Roof	Area (m ²)	0.00	U-Value (W/m ² °C)	0.000	Suspended (Y/N) N			
SkyLight Area	0.00	SkyLight U-Value	0.000	Temp. Diff	0.0			
Walls Information								
Wall No.	1	2	3	4	5	6	7	8
Wl Orientations	SW	SW	NE					
Wl Area (m ²)	8.18	3.47	15.12	0.00	0.00	0.00	0.00	0.00
Wl U-Value	0.481	0.973	1.295	0.0	0.0	0.0	0.000	0.000
Wl (1-Ex,2-In,3-Bs)	1	1	2	0	0	0	0	0
Gl Area	6.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gl U-Value	3.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wind & Orien. Factor	10	10	0	0	0	0	0	0
Partition Temp. Diff	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
Floor Information								
Area (m ²)	35.28	U-Value(W/m ² °C)	0.330	Temp. Diff	23.0			
Type (1-Inter,2-Solid Grnd.,3-Bs) 2								
Infiltration (1-Air Changes,2-Crack) 1		Air Changes No.1.5		Crack Lngth 0.0				
Ventilation (1-Air Chngs,2-CFM/Person) 0		Air Chngs No.0.0		CFM/Person 0.0				

3 - if it is an internal surface without temperature difference, the user has to set the values equal to zero.

Wall: There are four allowable combinations for calculating the heat loss from the wall:

- 1 - If the wall is an external surface, the user has to enter the area, U-Value, glass area, glass U-value, wind and orientation factor and select the wall type "1".
- 2 - if it is a partition with temperature difference, the user has to input the values of area, U-value, temperature difference and wall type is "2"
- 3 - if it is a partition without temperature difference, the user has to set the values equal to zero.
- 4 - if it is a basement , the user has to enter the values of U-value, depth of basement in glass area input, length of basement in glass U-value input and wall type is "3"

Floor: For this item also, there are three allowable combinations:

- 1 - If the floor is an internal surface, the user has to enter the area, U-Value, temperature difference, and select the floor type "1".

- 2 - if it is a solid ground surface, the user has to enter the values of area, U-value, space-ground temperature difference and floor type is "2"
- 3 - if it is an internal surface without temperature difference, the user has to set the values equal to zero.
- 4 - if it is a basement, the user has to enter the values of U-value, depth of basement in glass area input and wall type is "3"

Infiltration: The heat loss from infiltration can be calculated using two methods (for the calculation the flow rate of the air) as mentioned before, then the user has to select the type of infiltration, "1" for air change method and if it is selected the user also has to enter number of air changes, or "2" for crack method and if selected the user has to enter the crack length. Fig.(3.5) shows the procedure for calculating the heat loss through infiltration.

Ventilation: If the ventilation load is needed and if there is no need to design a separate system for ventilation, then the heating load is included as the heat loss from ventilation. The user has to enter the ventilation information if ventilation is needed, e.g. type of ventilation, "1" for air change method and if it is selected the user also has to enter number of air changes, or "2" for CFM per person method and if it is selected the user has to enter the CFM per person. Fig.(3.6) shows the procedure of calculating the heat loss through ventilation.

Some of the input data are "help" input data, which are asked for by pressing "F3" function key after moving the cursor to that input. Some of these input data are:

- * U-Values for all structures (roofs, walls, floors, glass, sky lights).
- * Wind and orientation factors.
- * Air changes for infiltration.
- * Air changes for ventilation.
- * CFM per person for ventilation.

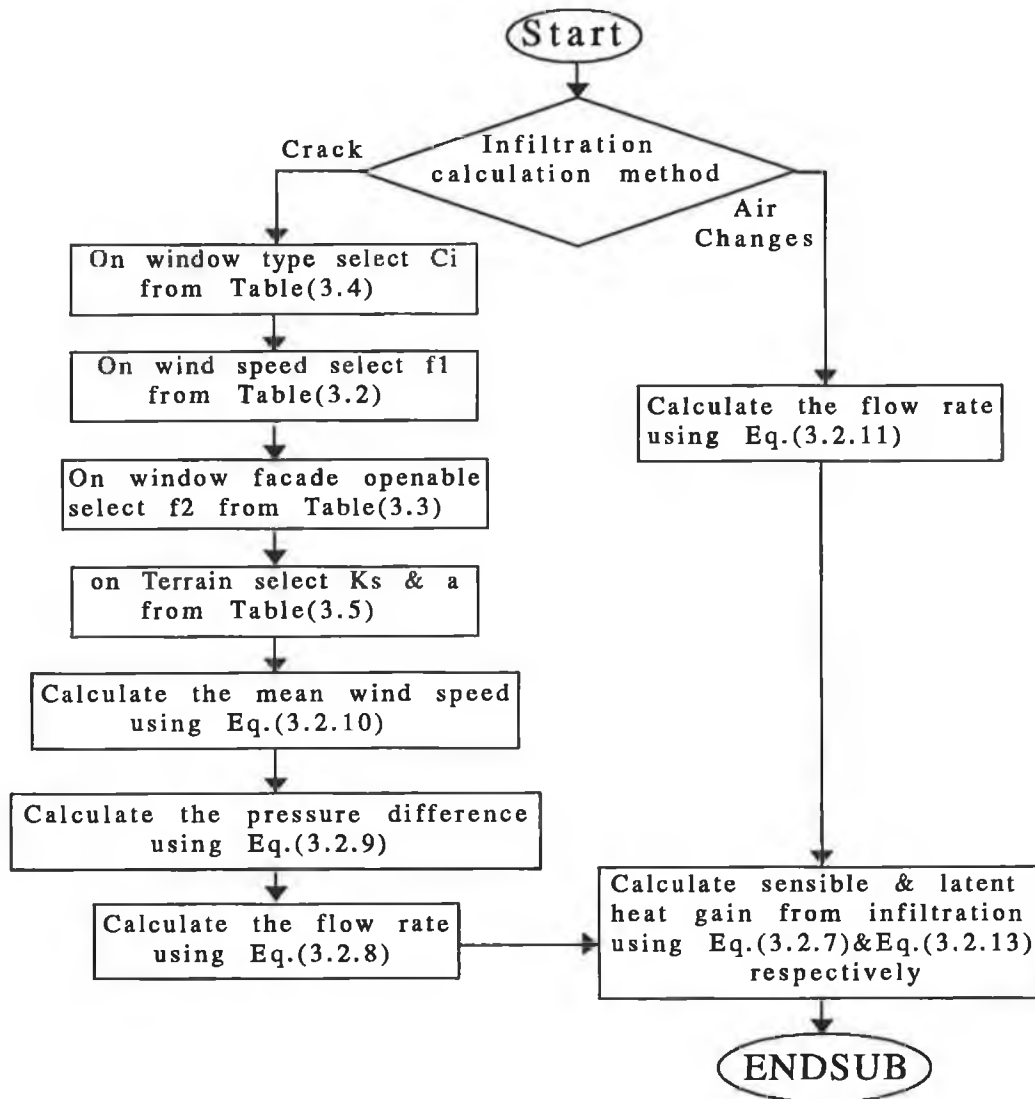


Fig. (3.5) Flow diagram of the infiltration load calculation steps

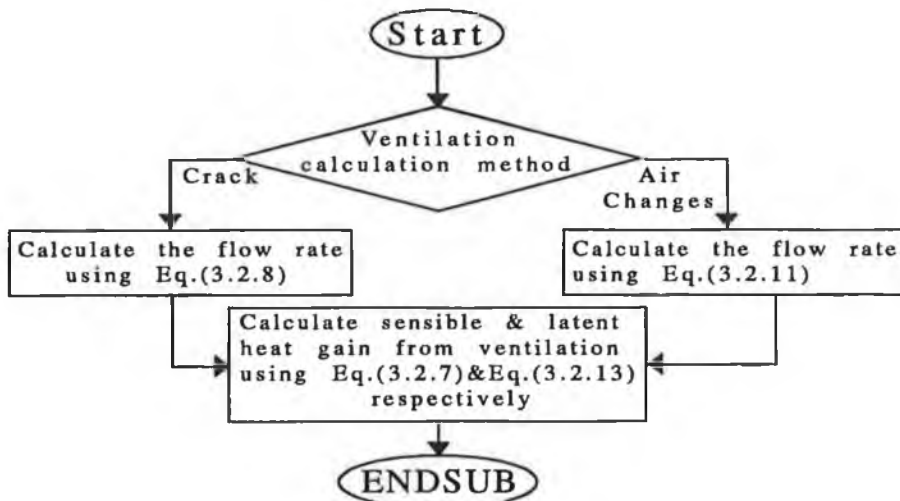


Fig. (3.6) Flow diagram of the ventilation load calculation steps

3.3 VENTILATION PROGRAM:

When positive ventilation using outdoor air is provided by an air heating or air conditioning unit, the energy required to warm the outdoor air to the space temperature must be provided by the unit. The principle for calculation of this load components is identical to that for infiltration. If mechanical exhaust from the space is provided in an amount equal to the outdoor air drawn in by the unit, the unit must also provide for natural infiltration losses.

The amount of ventilation required in any situation depends on the type of building, the number of people and the use being made of the space. Ventilation must comply with local regulations and the provisions of the health and safety at work act, but the ASHRAE [7], CIBSE [8], for example sets out model recommendations which can be used in the absence of more specific requirements. Ventilation rates can be expressed in two ways:

- * As a number of complete air changes (the most commonly used method).
- * or by a given amount of fresh air per person occupying the space.

Air changes must be of outside or fresh air, changing air by recirculation only will not remove or dilute contaminants.

The recommended rates [7,8] take into account of the occupancy levels and activity for specific locations. In some situations such as animal and chemical laboratories, workshops, kitchens, ...etc, where the activity itself is the greatest contributor to the need for ventilation, the rate is usually expressed as a number of air changes, not as fresh air per person. To improve the air quality and further dilute the concentration of contaminants, these ventilation rates can be increased. However, the ventilation rate, the air direction and movement must be controlled. Unless some form of heat recovery is used, the need for heating or cooling due to the increase in the ventilation rate will increase the building's energy consumption.

3.3.1 VENTILATION PROGRAM FORMULATION:

The same formulas (Eq.(3.2.7) and Eq.(3.2.13)) for the infiltration used in the heating program can be used here but only the quantity of the flow rate is different. As explained above there are two methods to determine the quantity of ventilation:

* By knowing the number of persons and the usage of the place, the flow rate can be defined by multiplying the number of persons by the CFM (Cubic Feet per Minute) per person as follows:

$$\dot{v} = 1700 n \text{ CFM} \quad (3.3.1)$$

where:

\dot{v} = Flow rate of outdoor air entering building, [L/s].

n = Number of persons.

CFM = Cubic feet per minute per person, [ft³/min].

* Or by knowing the number of air changes per cubic meter of the place according to its applications, then Eq.(3.2.11) can be used for this option.

3.3.2 VENTILATION PROGRAM EXECUTION PROCEDURES:

Combination of Fig.(3.3) and Fig.(3.6) shows the execution steps for the ventilation load calculation. The execution of the ventilation programme through selecting "**Ventilation**" commands from the "**Programs**" pull-down menu takes the user through a menu to give the user a choice to calculate the ventilation loads of the building room by room or for the whole building as explained in the heating programme. A menu is displayed on the screen for the selection as following:

This program calculates the Ventilation Load
for
Commercial and Scientific Buildings
Would you like to calculate:
1 - **Room By Room**
2 - Whole Building

After selecting the calculation method, an entry input data menu for the building is displayed as following:

Building No 1			
Building Description	School of mech. & Mnfg Engg		
Dimensions L x W x H (m)	20x 30x 15	Number of Storeys	4
Multiple Storeys			
Storey No	2	Multiplication	2
Storey No	0	Multiplication	0
Storey No	0	Multiplication	0

This menu is composed of eleven inputs, and as explained before it is sufficient to continue to the next step to enter the number of storeys. Then enter the input data menu, which is displayed automatically by pressing the "Enter" key on the keyboard. The input data is requested via a menu screen that is accessed through the last menu. This menu will appear on the screen as:

Building No. 1	Storey No. 1	Space No. 1
Dimension LxWxH	4x 5x3.5	Description Mechanical Lab
Dry Bulb Temperature tdb	20 °C	Relative Humidity 50 %
Ventilation Method (1- Air Changes, 2- CFM per Person)	1	
Number of Air Changes	1.5	or CFM per Person 0.0

For this entry input data menu, the user has to enter the ventilation information, and the following allowable combinations of input data for each space give the user an idea how to use this menu:

- The dimensions, description, dry bulb temperature, relative humidity. If the ventilation is to be calculated using air change method, "1" for the ventilation method input field and the number of air changes.
- if the CFM per person is selected, the user has to enter "2" in ventilation method input field, and the CFM per person value.

Fig.(3.6) shows the procedure of calculating the heat loss through ventilation step by step combining with Fig.(3.3). Also a help input data for both air changes and CFM per person can be called by pressing "F3" function key.

3.4 COOLING LOAD PROGRAM:

The variables affecting cooling load calculations are numerous, often difficult to define precisely, and always intricately inter-related. Many cooling load components vary widely in magnitude during a 24 hour period. Since these cyclic changes are often out of phase with each other, they must be analyzed to establish the maximum cooling load for a building or zone. A zoned system need recognize no greater total cooling load capacity than the largest hourly summary of simultaneous zone loads throughout a design day; but it must handle the peak cooling load for each zone at its peak hour. At certain times of the day during the heating or intermediate seasons, some zones may require heating while others require cooling.

A proper cooling load calculation gives values adequate for proper performance. Variation in the heat transmission coefficients of typical building materials and composite assemblies, the differing motivations and skills of those who construct the building, and the manner in which the building is operated are some of the variables that make a numerically precise calculation impossible. While the designer uses reasonable measures to include these factors, the calculation is still only a good estimate of the actual cooling load. The calculation of space sensible and cooling loads is a key step in any building energy estimations. There are two widely used methods for doing these calculations:

- 1) The heat balance method.
- 2) The weighting factor method.

The heat balance method for calculating net space sensible loads is the more fundamental of the two methods. Its development relies on the first law of thermodynamics (conservation of energy) and the principles of matrix algebra. Since there are fewer assumptions required than for the weighting factor method, it is also the more flexible of the two. However, the heat balance method requires more calculations at each point in the estimation process, and therefore is more costly in terms of computer resources.

The purpose of the heat balance method is to allow calculation of the net sensible heating and cooling load on the space air mass. The approach is to write a heat balance equation for each enclosing surface, and for the room air. This set of equations take account of the conduction, convection and radiation heat exchange between the room air, surrounding surfaces, infiltration and internal energy sources. They are then solved for the unknown surface and air temperatures. Once these temperatures are known, they can be used to calculate the convective heat flow to or from the space air mass. The latter constitutes the heating or cooling load which must be met by the space conditioning equipment, CLTD/CLF method in ASHRAE 1989 *Fundamentals Handbook* simulates this method which has been taken for the calculation of cooling loads.

The weighting factor method of calculating spaces sensible load, first introduced by Mitalas and Stephenson [25-27], is a simple but flexible technique that accounts for the important parameters affecting building energy flow. It represents a compromise between simpler method, such as steady-state calculation that ignores the ability of the building mass to store energy, and more complex methods, such as complete energy balance calculations. With this method, space heat gains at constant space temperature are determined from the building architectural data, the ambient weather conditions and internal load profiles. These space heat gain are used, along with the characteristics and availability of heating and cooling systems for the building, to calculate air temperatures and heat extraction rates.

The weighting factor method is based on the assumption that the heat transfer processes occurring in a room can be described by linear equations; and thus the superposition principle can be used for calculation of cooling load and space temperature. Two sets of weighting factors are used: heat gain and air temperature. Heat gain weighting factors represent transfer functions which relate space cooling load to instantaneous heat gain. Air temperature weighting factors represent transfer functions that relates room air temperature to the net energy load of the room.

In the weighting factor method, a two-step process is used to determine the air temperature and heat extraction rate of a room or building zone for a given set of

conditions:

* In the first step, the room's air temperature is assumed to be fixed at some reference value. This reference temperature is usually chosen to be the average air temperature expected for the room over the day period. Instantaneous heat gain is calculated on the basis of this constant air temperature. A space sensible cooling load for the room, defined as the rate at which energy must be removed from the room to maintain the air temperature fixed at its reference value, is calculated on the basis of this constant air temperature. A space sensible cooling load for the room, defined as the rate at which energy must be removed from the room to maintain the air temperature fixed at its reference value, is calculated for each type of instantaneous heat gain. The cooling load generally differs from the instantaneous heat gain because some of the energy from heat gain can be absorbed by walls or furniture and stored for later release to the air. At the end of the first step, the cooling load from the various heat gains are summed to give a total cooling load for the room.

* In the second step, the total cooling load is used (along with information on the HVAC system relevant to the room and a set of air temperature weighting factors) to calculate the actual heat extraction rate and air temperature. The actual heat extraction rate differs from the cooling load because, in practice, the air temperature can vary from the reference value used to calculate the cooling load or because of the HVAC system characteristics.

3.4.1 COOLING PROGRAM THEORETICAL ANALYSES:

To calculate a space cooling load using the CLTD/CLF convention, one has to follow the procedure for the basic heat gain calculations of solar radiation, total heat gain through exterior wall and roof, heat gain through the interior surfaces, and heat gain through infiltration and ventilation. Then the total heat gain or the cooling load for each room from several items as explained above is composed of;

$$Q_{Total} = Q_s + Q_l \quad (3.2.1)$$

Where:

Q_{Total} = Total heat gain from the room, [Watt].

Q_s = Total sensible heat gain from the room, [Watt].

Q_l = Total latent Heat gain from the room, [Watt].

Total sensible heat gain:

The total sensible heat gain from the room may be expressed as follows:

$$Q_s = Q_{Sroof} + \sum_{j=1}^{j=7} Q_{Swall(2j+1)} + \sum_{k=1}^{k=8} (Q_{Sglass} + Q_{Cglass})_{(2k+1)} + \sum_{l=1}^{l=n} Q_{Partition} + Q_{Speople} + Q_{Light} + Q_{Power} + Q_{Sappliance} + Q_{Sinfiltration} + Q_{Sventilation} \quad (3.3.2)$$

Where:

Q_{Sroof} = Solar heat gain from the roof, [Watt]

Q_{Swall} = Solar heat gain from the wall, [Watt]

Q_{Sglass} = Solar heat gain from the glass, [Watt]

Q_{Cglass} = Conduction heat gain from the glass, [Watt]

$Q_{Partition}$ = Heat gain from partition, [Watt].

$Q_{Speople}$ = Sensible heat gain from people, [Watt].

Q_{Light} = Heat gain from Lights, [Watt].

Q_{Power} = Heat Gain form motors, [Watt].

$Q_{Sappliance}$ = Sensible heat gain from appliances, [Watt].

$Q_{Sinfiltration}$ = Sensible heat gain from infiltration, [Watt].

$Q_{Sventilation}$ = Sensible heat gain from ventilation, [Watt].

Total latent heat gain:

The total latent heat gain from the room may be expressed as follows:

$$Q_l = Q_{Lpeople} + Q_{Lappliance} + Q_{Lirfiltration} + Q_{Lventilation} \quad (3.3.3)$$

Where:

$Q_{L\text{people}}$ = Latent heat gain from people, [Watt].

$Q_{L\text{appliance}}$ = Latent heat gain from appliances, [Watt].

$Q_{L\text{infiltration}}$ = Latent heat gain from infiltration, [Watt].

$Q_{L\text{ventilation}}$ = Latent heat gain from ventilation, [Watt].

Solar Heat Gains:

The heat gain from solar radiation through the external surfaces can be determined as following:

Roof:

$$Q_{S\text{roof}} = U_{\text{roof}} A_{\text{roof}} CLTD_{\text{corr}} \quad (3.3.4)$$

where:

U_{roof} = U-Value for the roof, [Watt/m²°C]

A_{roof} = Roof area, [m²]

$CLTD_{\text{corr}}$ = the correction of Cooling Load Temperature Difference, [°C]

The $CLTD_{\text{corr}}$ for roof can be expressed as follow;

$$CLTD_{\text{corr}} = [(CLTD + LM) K + (25.5 - t_R) + (t_a - 29.4)] f \quad (3.3.5)$$

where:

$CLTD$ = Cooling Load Temperature Difference for roof Table 29 chapter 26 at ASHRAE Fundamental 1989, [°C]

LM = $CLTD_{\text{corr}}$ for Latitude and Month applied to Walls and Roofs.

K = Color adjustment factor and is applied after first making month-latitude adjustment:

$K = 1.0$ if dark coloured or light in an industrial area.

$K = 0.5$ if permanently light-coloured (rural area).

25.5, 29.4 = Constants

t_R = Room temperature, [°C].

t_a = The average outside temperature, [°C].

f = Factor for attic fan or ducts above ceiling applied after all other adjustments have been made:

$f = 1.0$ no attic or ducts.

$f = 0.75$ positive ventilation

Wall:

$$Q_{Swall} = U_{wall} A_{wall} CLTD_{corr} \quad (3.3.6)$$

where:

U_{wall} = U-Value for the wall, [Watt/m²°C]

A_{wall} = wall area, [m²]

$CLTD_{corr}$ = the correction of Cooling Load Temperature Difference, [°C]

The $CLTD_{corr}$ for walls can be expressed as follow;

$$CLTD_{corr} = (CLTD + LM) K + (25.5 - t_R) + (t_a - 29.4) \quad (3.3.7)$$

where:

$CLTD$ = Cooling Load Temperature Difference for wall Table 31 chapter 26 at ASHRAE Fundamental 1989, [°C].

K = Color adjustment factor and is applied after first making month-latitude adjustment:

$K = 1.0$ if dark coloured or light in an industrial area.

$K = 0.83$ if permanently medium-coloured (rural area).

$K = 0.65$ if permanently light-coloured (rural area).

Glass and Sky light:

The basic equation for evaluating heat gain from transmitted and absorbed solar

energy through glass, includes the primary terms SHGF and SC and CLF are expressed as:

$$Q_{Sglass} = A_{glass} SC SHGF CLF \quad (3.3.8)$$

where:

A_{glass} = Net glass area of the glass, [m²].

SC = Shading coefficient, for combination of the glass and shading device, these are obtained from Tables 29 and 35 to 39, chapter 27 in *ASHRAE Fundamentals Handbook*, [7].

SHGF = Maximum Solar Heat Gain Factor for glass, [W/m²], obtained from Table 34 or 35 at the same reference for the appropriate latitude, month, and surface orientation.

CLF = Cooling Load Factor, Tables 36 to 39 at same reference as appropriate.

Conduction Heat Gain:

Glass:

The heat gain from conduction through the fenestration is calculated by:

$$Q_{Cglass} = U_{glass} A_{glass} CLTD_{corr} \quad (3.3.9)$$

where:

U_{glass} = U-Value for the glass, [Watt/m²°C]

A_{glass} = Net area of the fenestration, [m²]

$CLTD_{corr}$ = the correction of Cooling Load Temperature Difference, [°C]

The $CLTD_{corr}$ for walls can be expressed as follow;

$$CLTD_{corr} = (CLTD + LM) + (25.5 - t_R) + (ta - 29.4) \quad (3.3.10)$$

where:

CLTD = Cooling Load Temperature Difference for conduction through glass

Table 33 chapter 26 at ASHRAE 1989 *Fundamentals Handbook*,
[°C].

Partitions, Ceilings, Floors:

The heat gain from these surface can be calculated by:

$$Q_{\text{Partition}} = U A \Delta t \quad (3.3.11)$$

Where:

U = Design heat transfer coefficients, [W/m² °C].

A = Areas calculated from building plans, [m²].

Δt = Design temperature difference, unconditioned area to room, [°C].

Internal:

People:

The heat gain from the people is composed of two components as :

Sensible Heat gain: it can be calculated by:

$$Q_{\text{People}} = N PHG_{\text{Sensible}} \quad (3.3.12)$$

Where:

N = Number of people.

PHG_{Sensible} = Sensible heat gain from occupant, [W/Person].

Latent Heat gain: it can be calculated by:

$$Q_{\text{Lpeople}} = N PHG_{\text{Latent}} \quad (3.3.13)$$

Where:

Q_{Lpeople} = Latent heat gain from people, [Watt].

PHG_{Latent} = Latent heat gain from occupant, [W/Person].

Lights:

The heat gain from light can be calculated by the following expression:

$$Q_{\text{Light}} = A LHG \quad (3.3.14)$$

Where:

A = The internal floor area, [m²].

LHG = light heat gain, [W/m²].

Power:

When the equipment is operated by electric motors within a conditioned space, the heat equivalent is calculated as:

$$Q_{Power} = \frac{MHG}{E_M} F_{LM} F_{UM} \quad (3.3.15)$$

Where:

MHG = Total heat gain of motors, [Watt].

E_M = Motor efficiency.

F_{LM} = Motor load factor.

F_{UM} = Motor use factor.

Appliances:

The heat gain from the appliances is composed of two components as :

Sensible Heat gain: it can be calculated by:

$$Q_{Appliance} = \frac{AHG_{Sensible}}{E_A} F_{LA} F_{UA} \quad (3.3.16)$$

Where:

AHG_{Sensible} = Total sensible heat gain from appliance, [Watt].

E_A = Appliance efficiency.

F_{LA} = Appliance load factor.

F_{UA} = Appliance use factor.

Latent Heat gain: it can be calculated by:

$$Q_{Appliance} = \frac{AHG_{Latent}}{E_A} F_{LA} F_{UA} \quad (3.3.17)$$

Where:

$Q_{\text{Appliance}}$ = Latent heat gain from appliances, [Watt].

AHG_{Latent} = Total latent heat gain from appliance, [Watt].

Infiltration and Ventilation:

Infiltration or Ventilation heat gains are also composed of sensible and latent heat gain which may be calculated using Eq(3.2.7) and (3.2.13) as explained in heating load program.

3.4.2 COOLING PROGRAM EXECUTION PROCEDURES:

The Cooling Program is a single program which has within it the facilities to input data, print data and to compute and print heat gains. Any execution of the cooling program, which is selected by pressing "Enter" key after selecting the "Cooling" command from the "Programs" pull-down menu, takes the user through a menu of two options. First option is "Room By Room" command to let the user to calculate the cooling loads room by room after each room entry data and so on for the whole building. Or the second option "Whole Building" by entering the input data for all rooms of the building then calculating the cooling loads for all rooms together. For this step a menu is displayed on the screen for selection as follows:

This program calculates the Cooling Load
for
Commercial and Scientific Buildings
Would you like to calculate:
1 - Room By Room
2 - Whole Building

The same as in heating load program an entry input data for the building are displayed to enter the building information as discussed before, then after the user supplies the building entry input data depending on the calculation method which is selected, an entry input data for the space is displayed as shown in next page.

In this dialogue menu there are 117 input data which give more flexibility to

Building No. 1		Storey No. 1		Space No. 1				
Dimension LxWxH		5.6x6.3x2.7		Description		N30 : Printer Room		
Dry Bulb Temperature tdb		21 °C		Relative Humidity		50 %		
Roof	Area (m ²)	0.00		U-Value (W/m ² °C)	0.000		Suspended (Y/N) Y	
Information	Type (1-13)	0		SkyLight Area	0.00		SkyLight U-Value 0.000	
Attic Duct&Fan Coef.		0.0		Color Coef.	0.0		Exposed (Y/N)	N
Temp. Diff		0.0						
Walls Information		1	2	3	4	5	6	7
Wl Orientations		SW	SW	NE				
Wl Area (m ²)		8.18	3.47	15.12	0.00	0.00	0.00	0.00
Wl U-Value		0.481	0.973	1.295	0.000	0.000	0.000	0.000
Wl (1-Ex,2-In,3-Bs)		1	1	2	0	0	0	0
Gl Area		6.94	0.00	0.00	0.00	0.00	0.00	0.00
Gl U-Value		3.200	0.000	0.000	0.000	0.000	0.000	0.000
GlInShading (1-4), SC		1	1.0	0.0	0.0	0.0	0.0	0.0
GRP(A,B,C,D,E,F,G)		B	G					
Partition Temp. Diff		0.0	0.0	3.0	0.0	0.0	0.0	0.0
Floor	Area (m ²)	35.28		U-Value(W/m ² °C)		0.330		
Information	Type (1-Inter,2-Solid Grnd.,3-Bs)	2		Temp. Diff		3.0		
Number of People	2	Degree of Activity (1-14)		4		Lights (W/m ²) 25.0		
Total Power(W)	9324	Efficiency 1.00		Load Factor 1.00		Use Factor 1.00		
Total Appliances	0	Efficiency 0.00		Load Factor 0.00		Use Factor 0.00		
Infiltration (1-Air Changes,2-Crack)	1	Air Changes No.0.5		Crack Lngth		0.0		
Ventilation (1-Air Chngs,2-CFM/Person)	0	Air Chngs No.0.0		CFM/Person		0.0		

enter the space information. For some of the input data there are a help input data which can be edited by pressing "F3" function key. As mentioned earlier, for the last entry input menu it is not necessary to supply all these inputs. For example for the roof, there are three cases, first if the roof is an internal surface without any temperature different the user has to leave out all input data for the roof or set equal to zero, second if the roof is an internal surface with temperature difference the user has to enter the area, U-value, temperature difference and the roof exposed input is "N". The third case when the surface is exposed to the outside weather all the input has to be entered except the temperature difference. Similarly for the walls input data, there are three cases, first internal wall without any temperature difference for which the user just has to leave out all the input for the surface or at least set the area equal zero, second if the surface is an internal one, the user has to enter the wall area, wall U-value, glass area and glass U-value if it is available, temperature difference, and the wall exposure type as "2", also for the basement wall select, the same as for the internal wall. For the last combination

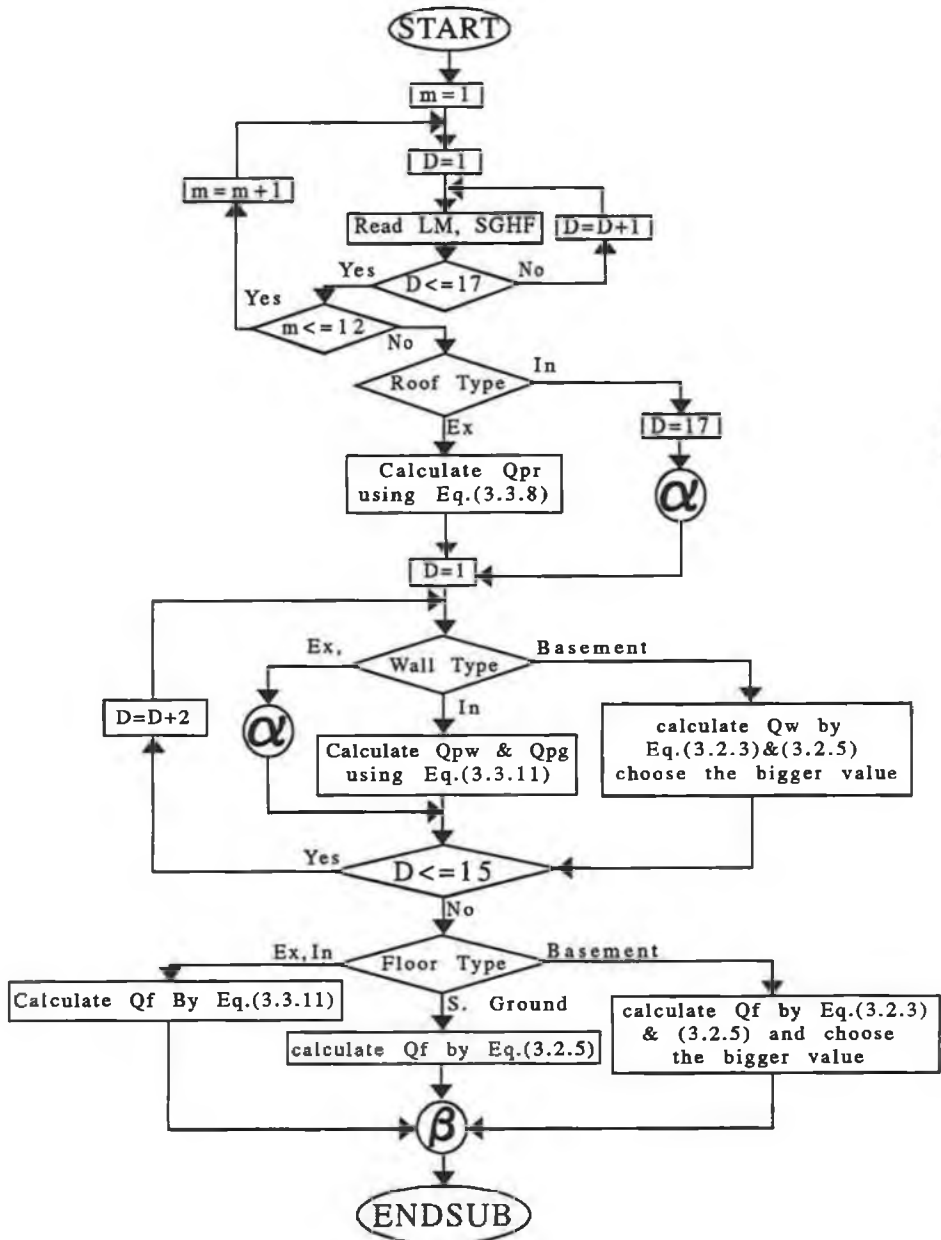
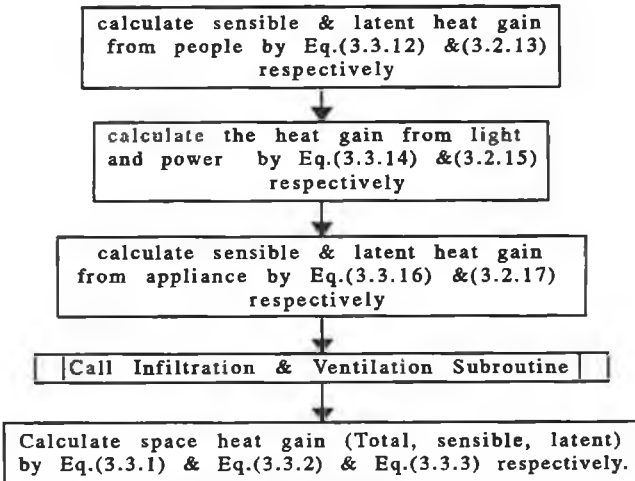
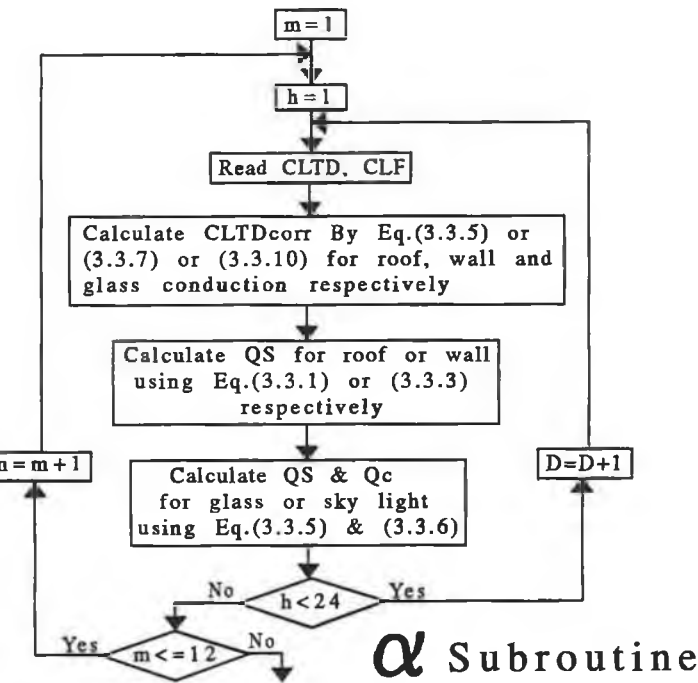


Fig. (3.7) Flow diagram of the cooling load calculation steps



the user has to enter all information for the wall and glass if it is available except the temperature difference. For the floor there are four allowable combinations:

- 1 - All inputs equal to zero if the roof is internal and there is no temperature difference.
- 2 - 4 The user has to input all inputs and for the floor type takes value "1" for internal or "2" for solid ground or "3" for basement floor.

The user also has to input number of people and their activity degree according to table 3 chapter 26 in ref. [7] and the light wattage according to their types in watt per square meter. For calculating the heat gains from power and appliances the user has to enter the total power and appliances if they are available, the efficiency, load factor and use factor which should not equal zero and if the user gives any one factor a zero value then the program automatically assigns a unity value. The heat gain from infiltration can be calculated using two methods for calculating the flow rate of the air as mentioned before, then the user has to select the type of infiltration, "1" for air change method and if it is selected the user also has to enter number of air changes, or "2" for crack method and if selected the user has to enter the crack length. Because in air conditioning the ventilation load is added to the cooling loads, the user has to enter the ventilation information if the ventilation is needed. "1" for air changes method and if it is selected the user also has to enter number of air changes, or "2" for CFM per person method and if it is selected the user has to enter the CFM per person.

When the user completes the input data, he has a choice to continue for another space, another storey, another building and so on by following the commands in the help line. Then the calculation of the elements of the heat gains begin as shown in Fig.(3.3) and Fig.(3.7) which may be explained as follows:

- 1 - Read all information fixed in user place and client place setup which are user name and his address, client place and his address, name of the project, place latitude, the outside temperature and relative humidity in summer and winter and safety factors for cooling and heating loads,

- number of buildings and closing and opening hours.
- 2 - Select the method of calculation procedure, "Room by Room" or "Whole Building".
 - 3 - Open loop for building numbering from 1 to the number of buildings
 - 4 - Enter building information using the building entry input data menu.
 - 5 - Open loop for storey numbering from 1 to the number of storeys.
 - 6 - Open loop for space numbering from 1 to the user choice by pressing "ESC" key.
 - 7 - Enter space information using the space entry input data menu.
 - 8 - If "Room By Room" method is selected calculate the cooling load for the space using space cooling load subroutine which is shown in Fig.(3.7) and displays the results on the screen, and print out if the user wants that. If "Whole Building" method is selected go to the next input for another space without calculations.
 - 9 - If the second option is selected ("Whole Building" method) calculate the cooling load for each space according to the space cooling load subroutine for all rooms in the buildings.
 - 10 - Save the inputs and outputs for printing out the reports or redisplaying or for checking and modifying.

3.5 PSYCHROMETRIC CHART PROGRAM:

The psychrometric chart is one of the most valuable tools available for air conditioning engineer. It is a way of graphically representing the properties of moist air, the knowledge about this chart is required for the design of heating, ventilating and air conditioning (HVAC) systems. This chart provides engineers information on properties of moist air rapidly and conveniently.

The psychrometric chart program is more than an electronic display of the conventional printed chart. For example, it can quickly display numerical values of all properties at any selected point without interpolation. These points can be labelled for

future reference, and reports of their properties can be displayed on the screen or printer. Additionally, the program allows psychrometric processes to be analyzed. The lines for all standard psychrometric processes, such as heating, cooling humidification, mixing and so on, are displayed on the chart by simple user commands. Once displayed, reports giving heating rates, cooling rates, air quantities and water removal or addition rates can be reported.

Psychrometric chart program goes beyond the capabilities of printing the charts. Although the initial display is the standard ASHRAE sea level chart, this can be changed by the user to show a chart for any elevation or pressure and for any range of dry bulb temperature, and can be specified in either Imperial or SI units.

These features will allow the user to carry out psychrometric analysis of air conditioning systems more conveniently, accurately and quickly than before. The user of the program will find that the ease of doing even complex analysis will lead to improved design. The objective of creating a psychrometric program is to enable the rapid calculations, on a normal personal computer without the need for tables or charts.

For calculating the properties of moist air, number of sources [7,8,28-36] have been consulted, and equations given in reference [7] appears to give the more accurate values.

3.5.1 THERMODYNAMIC PROPERTIES OF MOIST AIR:

The following symbols are used throughout the equations:

- t_{db} : Dry bulb temperature, [°C]
- t_{wb} : Wet bulb temperature, [°C]
- t_{dp} : Dew point temperature, [°C]
- T_k : Kelvin temperature, [°K = °C + 273.16]
- P_b : Barometric pressure, [kPa]
- Φ : Relative humidity, [%]
- R_a : Gas constant for dry air, [J/(kg.°k)]

- V : Specific volume of moist air, [m^3/kg]
- W : Humidity ratio of moist air, [kg_w/kg_a]
- W_s : Humidity ratio of moist air at saturation, [kg_w/kg_a]
- P_{ws} : Saturated vapour pressure [kPa]
- P_w : Partial vapour pressure [kPa]
- P_{ws}^* : Saturated vapour pressure at wet bulb temperature [kPa]
- h : Enthalpy of moisture air. [kJ/kg]
- h_a : Enthalpy of dry air. [kJ/kg]
- h_w : Enthalpy of water vapour. [kJ/kg]

Various Formulas:

The purpose of comparing working formulas from several sources is to obtain the most appropriate formula for solving any problem. Working formulas when design calculations were carried out it was found that there is difference between the values calculated using different formulas and the values obtained from the psychrometric chart.

The following approach for calculating the moist air properties is based upon the Tetens relationship [36] for saturation vapour pressure and the psychrometric equation. Tetens method closely approximates the internationally accepted relationship of Goff-Gratch [28-30]. Based on the latter and more accurate measurements, Hyland and Wexler's relationship (1983a) as given in ASHRAE [7] gives a vapour pressure equation for the temperature range 0 to 100 °C. For the temperature range -50 to 0 °C another comparison have been done between Tetens [36], Goff-Gratch [28], CIBSE Guide [8] and Wexler-Hyland [7].

These relationships are based upon pure vapour phase of water, rather than moist air, over plane surface which leads to an error of approximately 0.5 percent.

Saturated vapour pressure relationships :

The determination of the saturation vapour pressure is the most important

calculation in specifying moist air properties since all such properties are a function of the vapour pressure, the comparison is carried out as mentioned above between four equations as follows:

1. The *Tetens relationship* for pure water phase is given by equation (3.5.1) for the temperature range from -50 to 100 °C which may be expressed as follows:

$$P_{ws} = 0.61078 e^{\left(\frac{17.2693882 t}{t + 237.30}\right)} \quad (3.5.1)$$

where:

t = vapour temperature, [°C]

2. The *Goff-Gratch relationship* for the water phase can be written for ease in computer calculation which is divided into two equation as follows:

a. saturation vapour pressure over water for temperature range between 0 to 100 °C

$$\log_{10} \frac{P_{ws}}{101.325} = a_1 (Z - 1) + a_2 \log_{10}(Z) + a_3 (10^{a_4(1 - \frac{1}{Z})} - 1) + a_5 (10^{a_6(Z-1)} - 1) \quad (3.5.2)$$

where:

$$Z = 373.16/T_k$$

$$a_1 = -7.90298, a_2 = 5.02808, a_3 = -1.3816 \text{ E-}7$$

$$a_4 = 11.344, a_5 = 8.1328 \text{ E-}3, a_6 = -3.49149$$

b. saturation vapour pressure over ice for temperature range between -50 to 0 °C:

$$\log_{10} \frac{P_{is}}{101.325} = b_1 (Z - 1) + b_2 \log_{10}(Z) + b_3 \left(1 - \frac{1}{Z}\right) + \log_{10}(b_4) \quad (3.5.3)$$

where:

$$Z = 273.16/T_k$$

$$b_1 = -9.09718, b_2 = -3.56654$$

$$b_3 = 0.876793, b_4 = 0.0060273$$

3. The **CIBSE Guide relationship** as Goff-Gratch equation is composed of two ranges as follows:

a. saturation vapour pressure over water for temperature range between 0 to 100 °C:

$$\log_{10} P_{ws} = 30.59051 - 8.2 \log_{10} T_k + 2.4804 \cdot 10^{-3} T_k - \frac{3142.31}{T_k} \quad (3.5.4)$$

b. saturation vapour pressure over ice for temperature range between -50 to 0 °C:

$$\log_{10} P_{is} = 9.5380997 - \frac{2663.91}{T_k} \quad (3.5.5)$$

4. The **ASHRAE relationship** is published by Hyland and Wexler (1983a). The equation is also composed of two ranges as follows:

a. saturation vapour pressure over ice for temperature range between -50 to 0 °C:

$$\ln P_{is} = \frac{C_1}{T_k} + C_2 + C_3 T_k + C_4 T_k^2 + C_5 T_k^3 + C_6 T_k^4 + C_7 \ln T_k \quad (3.5.6)$$

where:

$$C_1 = -5.6745359 \cdot 10^3$$

$$C_2 = 6.3925247$$

$$C_3 = -9.677843 \cdot 10^{-3}$$

$$C_4 = 6.22115701 \cdot 10^{-7}$$

$$C_5 = 2.0747825 \cdot 10^{-9}$$

$$C_6 = -9.484024 \cdot 10^{-13}$$

$$C_7 = 4.1635019$$

b. the saturation vapour pressure over water for the temperature range of 0 to 200 °C:

$$\ln P_{ws} = \frac{C_8}{T_k} + C_9 + C_{10} T_k + C_{11} T_k^2 + C_{12} T_k^3 + C_{13} \ln T_k \quad (3.5.7)$$

where:

$$C_8 = -5.8002206 \cdot 10^3$$

$$C_9 = 1.3914493$$

$$C_{10} = -4.8640239 \cdot 10^{-2}$$

$$C_{11} = 4.1764768 \cdot 10^{-5}$$

$$C_{12} = -1.4452093 \cdot 10^{-8}$$

$$C_{13} = 6.5459673$$

Fig.(3.8) to Fig.(3.17) and Table (3.8) show the comparison results of the calculated saturation vapour pressures based on equations (3.5.1) - (3.5.7) as a function of temperature. There is excellent agreement between the four equations in the range 0 to 60 °C, Fig.(3.13), Fig.(3.14) and Fig (3.15). Below 0 °C there is obvious considerable difference between the Tetens relationship and those of others, and above 60 ° the Tetens' equation deviates from the other three but never by more than 1 percent. There is better agreement between the ASHRAE and CIBSE equations than that with the Goff-Gratch equation. The obvious advantage of Tetens equation is the ease of calculation. A computer program is developed for these comparison. For the psychrometric properties, the ASHRAE equation is selected because it gives more accurate results for the moist air properties when they are compared with the Standard Psychrometric charts. Also similar comparison between other sources have been done for old equations of Goff-Gratch, Wexler-Greenspan, ASAE standard and Tetens by Albert Weiss (1977) [36].

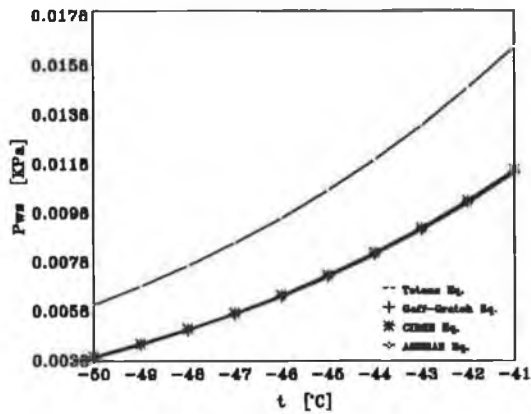


Fig. (3.8) Saturation Vapour Pressure for temperature range -50 to -41 °C

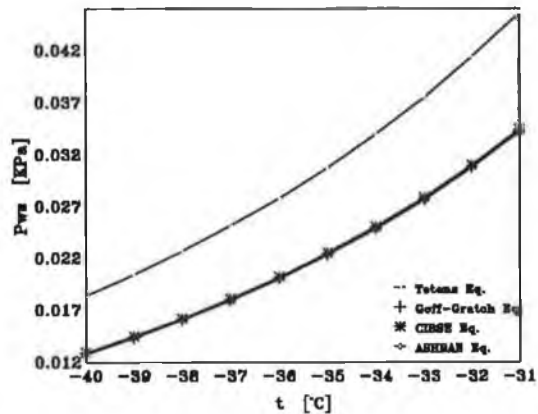


Fig. (3.9) Saturation Vapour Pressure for temperature range -40 to -31 °C

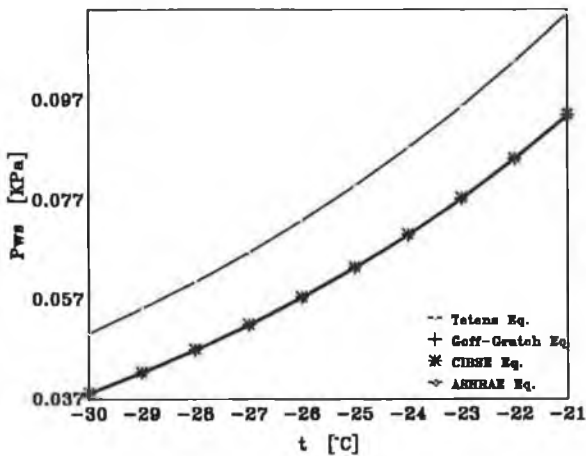


Fig. (3.10) Saturation Vapour Pressure for temperature range -30 to -21 °C

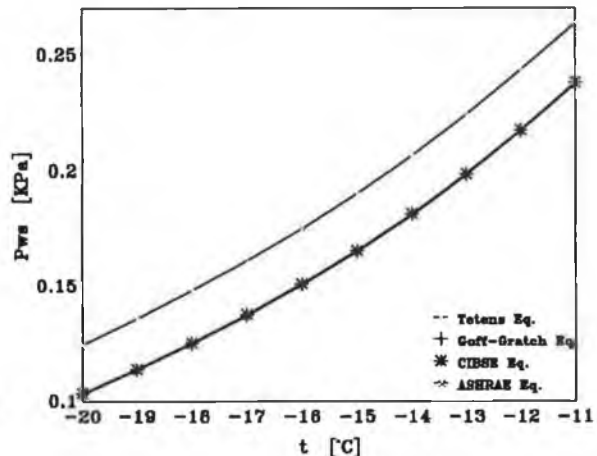


Fig. (3.11) Saturation Vapour Pressure for temperature range -20 to -11 °C

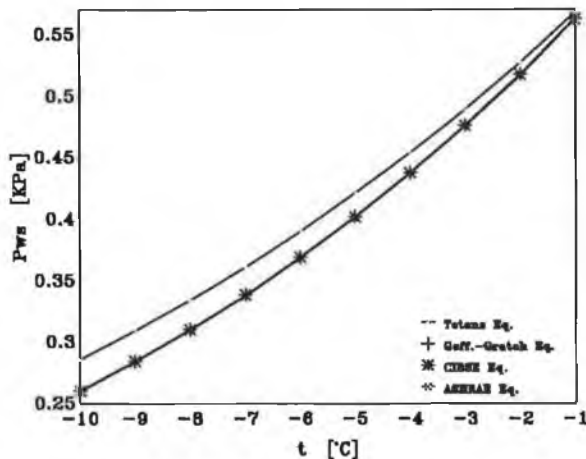


Fig. (3.12) Saturation Vapour Pressure for temperature range -10 to -1 °C

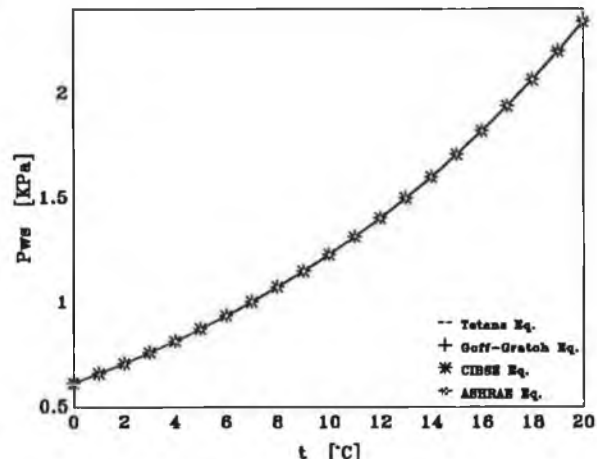


Fig. (3.13) Saturation Vapour Pressure for temperature range 0 to 20 °C

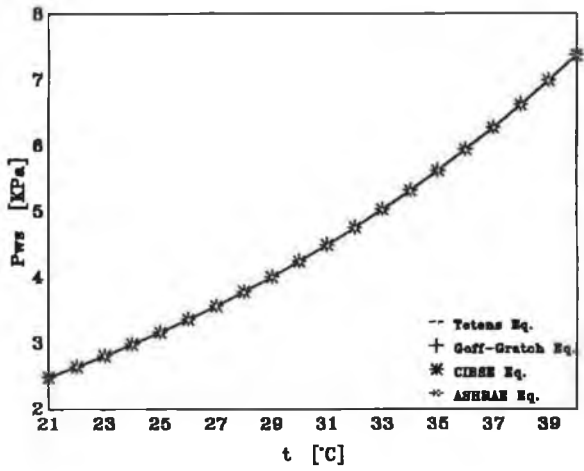


Fig. (3.14) Saturation Vapour Pressure for temperature range 21 to 40 °C

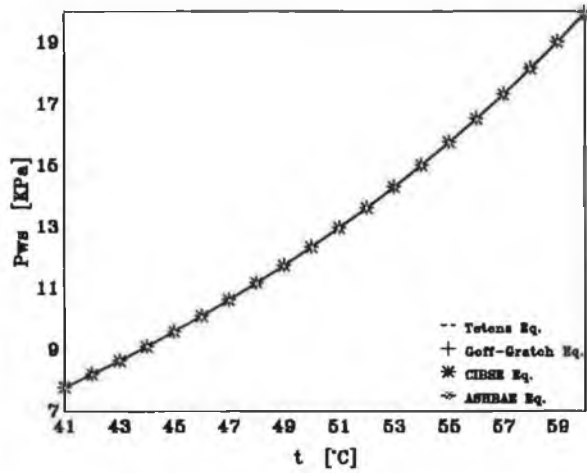


Fig. (3.15) Saturation Vapour Pressure for temperature range 41 to 60 °C

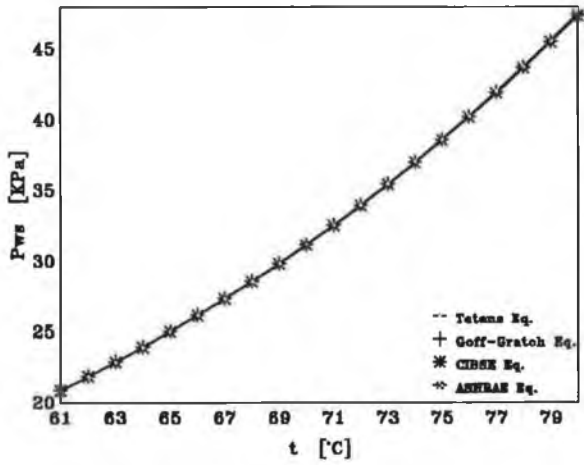


Fig. (3.16) Saturation Vapour Pressure for temperature range 61 to 80 °C

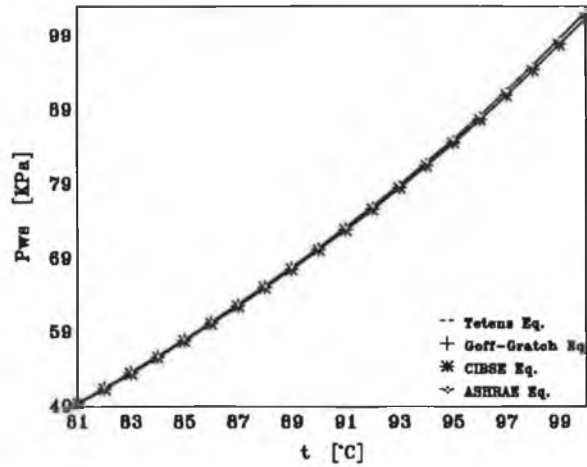


Fig. (3.17) Saturation Vapour Pressure for temperature range 81 to 100 °C

Table (3.8) Results of Saturation Vapour Pressure Comparison

Temp. °C	Saturated Vapour Pressure (Pws), KPa			
	Tetens	Goff-Gratch	CIBSE	ASHRAE
-50	0.00608	0.00394	0.00399	0.00393
-49	0.00683	0.00446	0.00451	0.00445
-48	0.00766	0.00504	0.00509	0.00503
-47	0.00858	0.00568	0.00574	0.00567
-46	0.00960	0.00641	0.00647	0.00639
-45	0.01074	0.00721	0.00729	0.00720
-44	0.01199	0.00811	0.00819	0.00810
-43	0.01337	0.00912	0.00920	0.00910
-42	0.01489	0.01024	0.01033	0.01021
-41	0.01657	0.01148	0.01158	0.01145
-40	0.01842	0.01286	0.01297	0.01283
-39	0.02046	0.01439	0.01451	0.01436
-38	0.02269	0.01609	0.01622	0.01606
-37	0.02515	0.01798	0.01811	0.01794
-36	0.02784	0.02007	0.02021	0.02003
-35	0.03078	0.02238	0.02253	0.02233
-34	0.03401	0.02493	0.02509	0.02488
-33	0.03753	0.02774	0.02792	0.02769
-32	0.04139	0.03085	0.03104	0.03079
-31	0.04559	0.03428	0.03447	0.03421
-30	0.05018	0.03806	0.03826	0.03798
-29	0.05517	0.04221	0.04242	0.04213
-28	0.06061	0.04678	0.04700	0.04669
-27	0.06652	0.05180	0.05203	0.05170
-26	0.07295	0.05731	0.05755	0.05720
-25	0.07993	0.06335	0.06360	0.06323
-24	0.08750	0.06998	0.07023	0.06985
-23	0.09571	0.07724	0.07750	0.07709
-22	0.10460	0.08518	0.08544	0.08502
-21	0.11422	0.09387	0.09413	0.09370
-20	0.12462	0.10336	0.10363	0.10317
-19	0.13587	0.11373	0.11399	0.11352
-18	0.14801	0.12504	0.12530	0.12482
-17	0.16111	0.13737	0.13763	0.13713
-16	0.17524	0.15082	0.15106	0.15056
-15	0.19046	0.16545	0.16568	0.16517
-14	0.20685	0.18138	0.18159	0.18107
-13	0.22449	0.19870	0.19888	0.19836
-12	0.24345	0.21752	0.21767	0.21715
-11	0.26383	0.23795	0.23807	0.23756
-10	0.28571	0.26013	0.26021	0.25970

Continue Table (3.8)

Temp. °C	Saturated Vapour Pressure (Pws), KPa			
	Tetens	Goff-Gratch	CIBSE	ASHRAE
-9	0.30919	0.28418	0.28421	0.28372
-8	0.33436	0.31025	0.31022	0.30975
-7	0.36134	0.33849	0.33839	0.33794
-6	0.39024	0.36905	0.36888	0.36846
-5	0.42117	0.40211	0.40185	0.40147
-4	0.45425	0.43784	0.43750	0.43715
-3	0.48961	0.47646	0.47600	0.47571
-2	0.52740	0.51815	0.51758	0.51734
-1	0.56773	0.56314	0.56243	0.56227
0	0.61078	0.61166	0.61078	0.61078
1	0.65669	0.65754	0.65662	0.65662
2	0.70561	0.70646	0.70547	0.70548
3	0.75774	0.75857	0.75752	0.75753
4	0.81323	0.81405	0.81294	0.81295
5	0.87227	0.87309	0.87191	0.87193
6	0.93506	0.93589	0.93463	0.93465
7	1.00181	1.00264	1.00129	1.00133
8	1.07271	1.07357	1.07213	1.07217
9	1.14800	1.14888	1.14734	1.14739
10	1.22789	1.22882	1.22717	1.22723
11	1.31264	1.31361	1.31184	1.31193
12	1.40248	1.40351	1.40162	1.40172
13	1.49767	1.49879	1.49676	1.49688
14	1.59850	1.59971	1.59753	1.59768
15	1.70523	1.70655	1.70422	1.70438
16	1.81816	1.81960	1.81711	1.81730
17	1.93759	1.93918	1.93650	1.93673
18	2.06383	2.06559	2.06272	2.06299
19	2.19722	2.19917	2.19609	2.19640
20	2.33809	2.34025	2.33696	2.33730
21	2.48680	2.48919	2.48567	2.48606
22	2.64371	2.64636	2.64259	2.64303
23	2.80919	2.81214	2.80809	2.80859
24	2.98365	2.98692	2.98259	2.98315
25	3.16749	3.17110	3.16647	3.16710
26	3.36113	3.36512	3.36016	3.36086
27	3.56500	3.56940	3.56410	3.56488
28	3.77956	3.78440	3.77874	3.77961
29	4.00528	4.01060	4.00455	4.00550
30	4.24263	4.24846	4.24201	4.24305

Continue Table (3.8)

Temp. °C	Saturated Vapour Pressure (Pws), KPa			
	Tetens	Goff-Gratch	CIBSE	ASHRAE
31	4.49213	4.49850	4.49161	4.49275
32	4.75427	4.76122	4.75388	4.75513
33	5.02961	5.03716	5.02935	5.03071
34	5.31868	5.32687	5.31855	5.32003
35	5.62206	5.63092	5.62207	5.62368
36	5.94032	5.94990	5.94049	5.94222
37	6.27409	6.28439	6.27440	6.27628
38	6.62398	6.63505	6.62444	6.62645
39	6.99064	7.00249	6.99123	6.99340
40	7.37472	7.38739	7.37545	7.37778
41	7.77692	7.79042	7.77777	7.78025
42	8.19793	8.21226	8.19889	8.20153
43	8.63849	8.65369	8.63952	8.64234
44	9.09933	9.11539	9.10042	9.10341
45	9.58123	9.59814	9.58234	9.58552
46	10.08498	10.10274	10.08606	10.08943
47	10.61139	10.62997	10.61239	10.61594
48	11.16129	11.18069	11.16217	11.16591
49	11.73555	11.75574	11.73622	11.74015
50	12.33504	12.35596	12.33543	12.33957
51	12.96068	12.98230	12.96070	12.96503
52	13.61339	13.63562	13.61294	13.61746
53	14.29414	14.31691	14.29309	14.29782
54	15.00390	15.02713	15.00213	15.00703
55	15.74368	15.76724	15.74104	15.74614
56	16.51451	16.53830	16.51083	16.51613
57	17.31746	17.34131	17.31256	17.31804
58	18.15361	18.17735	18.14728	18.15294
59	19.02408	19.04753	19.01610	19.02190
60	19.93000	19.95296	19.92012	19.92609
61	20.87256	20.89477	20.86050	20.86663
62	21.85294	21.87418	21.83840	21.84468
63	22.87238	22.89235	22.85503	22.86142
64	23.93213	23.95049	23.91161	23.91812
65	25.03348	25.04987	25.00940	25.01599
66	26.17775	26.19177	26.14967	26.15637
67	27.36628	27.37750	27.33374	27.34050
68	28.60045	28.60845	28.56295	28.56971
69	29.88167	29.88594	29.83866	29.84548
70	31.21138	31.21133	31.16228	31.16908

Continue Table (3.8)

Temp. °C	Saturated Vapour Pressure (Pws), KPa			
	Tetens	Goff-Gratch	CIBSE	ASHRAE
71	32.59106	32.58615	32.53521	32.54199
72	34.02221	34.01170	33.95894	33.96564
73	35.50637	35.48958	35.43494	35.44154
74	37.04511	37.02134	36.96471	36.97118
75	38.64004	38.60847	38.54982	38.55617
76	40.29279	40.25245	40.19184	40.19799
77	42.00503	41.95512	41.89237	41.89837
78	43.77847	43.71788	43.65306	43.65878
79	45.61487	45.54250	45.47557	45.48103
80	47.51598	47.43079	47.36161	47.36672
81	49.48363	49.38423	49.31291	49.31764
82	51.51967	51.40483	51.33124	51.33563
83	53.62598	53.49423	53.41839	53.42230
84	55.80449	55.65438	55.57619	55.57964
85	58.05714	57.88713	57.80651	57.80950
86	60.38594	60.19424	60.11124	60.11366
87	62.79292	62.57779	62.49231	62.49425
88	65.28016	65.03964	64.95169	64.95301
89	67.84975	67.58198	67.49136	67.49203
90	70.50387	70.20655	70.11336	70.11344
91	73.24467	72.91566	72.81974	72.81906
92	76.07441	75.71125	75.61259	75.61134
93	78.99533	78.59551	78.49408	78.49206
94	82.00975	81.57059	81.46634	81.46360
95	85.12000	84.63883	84.53156	84.52819
96	88.32849	87.80222	87.69199	87.68791
97	91.63763	91.06316	90.94990	90.94518
98	95.04988	94.42406	94.30754	94.30217
99	98.56776	97.88705	97.76733	97.76137
100	102.19382	101.45469	101.33155	101.32500

3.5.2 FORMULATION OF PSYCHROMETRIC PROPERTIES:

To a first approximation, air and water vapour may be considered as perfect gases because the temperature of dry air is usually very high compared with its critical temperature, and because the partial pressure of the water vapour is very low compared with its critical pressure. Therefore, atmospheric air can be considered as a mixture of perfect gases. The equations used in the program were obtained mainly from refs. [7,8]:

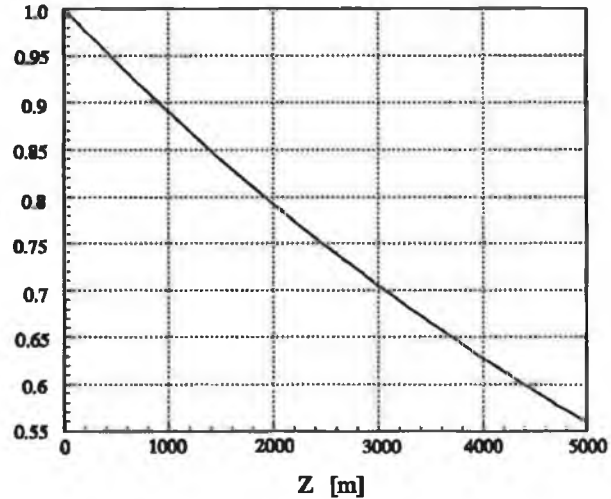


Fig. (3.18) Variation of barometric pressure with altitude

Barometric pressure:

Most psychrometric charts published are for sea level only, the accurate values of each spaces may be corrected by multiplying by appropriate correction factors. Here, using the barometric pressure for each altitude the user can get accurate values of the psychrometric properties of moist air. Fig.(3.18) which gives the relationship between height above sea level and barometric pressure, is drawn from the equation (3.5.8):

$$P_B = P_o e^{\frac{-\rho g_n Z}{1000 P_o}} \quad (3.5.8)$$

where:

- P_B = barometric pressure at altitude Z, [KPa]
- P_o = barometric pressure at see level (=101.325), [KPa]
- ρ = density of air (= 1.20), [Kg/m²]
- g_n = acceleration due to gravity (=9.81), [m/s²]
- Z = Altitude above see level, [m]

Saturation vapour pressure:

Saturated air is that mixture in which the water vapour is saturated; that is when the partial pressure of vapour is the saturation pressure of water at the temperature of air. Equations (3.5.6) and (3.5.7) are used to calculate the saturation vapour pressure in the program.

Relative humidity:

The moisture content in the air is commonly indicated by the relative humidity Φ , defined as the ratio of the mass of water vapour present in a certain volume of air to that present in an equal volume of saturated air at the same temperature and total pressure, i.e.

$$\Phi = \left(\frac{m_v}{m_{vs}} \right)_{T,p} \quad (3.5.9)$$

Using the perfect gas relations, the relative humidity can be expressed as:

$$\Phi = \left(\frac{P_w}{P_{ws}} \right)_T \quad (3.5.10)$$

Humidity ratio:

The humidity ratio (W), indicates the composition of air, it is defined as the ratio of the mass of water vapour to that of dry air in the mixture, i.e.

$$w = \left(\frac{m_v}{m_a} \right)_{v,T} \quad (3.5.11)$$

Applying the perfect gas relations,

$$w = \frac{M_v}{M_a} \frac{P_w}{P_a} \quad (3.5.12)$$

According to Dalton's rule;

$$P = P_a + P_w \quad (3.5.13)$$

and the humidity ratio can be expressed as:

$$W = 0.622 \frac{P_w}{P_B - P_w} \quad (3.5.14)$$

Specific volume:

The volume of air per unit mass of dry air can be evaluated as:

$$v = \frac{V}{M_a} = \frac{R_a T_k}{P_B} (1 + 1.6078 W) \quad (3.5.15)$$

Specific enthalpy:

The enthalpy of moist air per kilogramme of dry air can be evaluated as the sum of the individual partial enthalpies of the components. Therefore, it can be written as:

$$h = h_a + W h_g \quad (3.5.16)$$

where:

h_a = the specific enthalpy for dry air, [KJ/Kg].

h_g = the specific enthalpy for saturated vapour at the temperature of the mixture

$$h_a = C_{pa} t_{db} \quad (3.5.17)$$

$$h_g = 2501 + 1.805 t_{db} \quad (3.5.18)$$

For most engineering applications, it is sufficiently accurate to assume that the constant pressure specific heat C_{pa} of dry air is constant over the relatively limited temperature range of air conditioning processes. Therefore, its value can be taken as that of air at 0 °C (i.e. $C_{pa} \approx 1$ [KJ/Kg°C]). Then the moist air enthalpy becomes:

$$h = t_{db} + W (2501 + 1.805 t_{db}) \quad (3.5.19)$$

Wet bulb temperature t_{wb} :

The psychrometer consists of two thermometers; one thermometer's bulb is covered by a wick that has been thoroughly wetted with water. When the wet bulb is placed in an equilibrium temperature called the wet bulb temperature which is defined as a unique property of a given moist air sample independent of measurement techniques. Equation

(3.5.20) given in ASHRAE [7] as follow:

$$h + (W_s^* - W) h_w^* = h_s^* \quad (3.5.20)$$

where the properties W_s^* , h_w^* and h_s^* are functions only of the temperature t_{wb} for a fixed value of pressure; and the value of t_{wb} which satisfies equation (3.5.20) for given values of h , W , p_{ws} is the wet bulb temperature;

$$h_w^* = 4.186 t_{wb} \quad (3.5.21)$$

$$W_s^* = 0.62198 \frac{P_{ws}^*}{P_B - P_{ws}^*} \quad (3.5.22)$$

by using numerical analysis to solve equation (3.5.20) using Equations (3.5.21) and (3.5.22) and (3.5.6), (3.5.7) by replacing t_{wb} instead of t_{db} , the wet bulb temperature is obtained.

Dew point temperature:

The dew point temperature can be calculated directly by using one of the following equations:

For the dew point temperature range of 0 to 93 °C:

$$t_{dp} = A + B \alpha + C \alpha^2 + D \alpha^3 + E p_w^{0.1984} \quad (3.5.23)$$

and for temperature below 0 °C:

$$t_{dp} = 6.09 + 12.608 \alpha + 0.4959 \alpha^2 \quad (3.5.24)$$

where

t_{dp} = dew point temperature, [°C]

α = $\ln p_w$

A = 6.54

B = 14.526

C = 0.7389

D = 0.09486

$$E = 0.4569$$

Correction for computing p_{ws} , can be applied to all p_{ws} values by multiplying its value by correction factor f_s , the values of f_s are listed in Table (3.9).

Table (3.9) Magnitudes of f_s corrections factor

Temp, °C	Barometric pressure, [KPa]					
	33.8	50.7	67.6	84.5	101	108
-18	1.0016	1.0025	1.0033	1.0040	1.0047	1.0051
-7	1.0016	1.0024	1.0032	1.0039	1.0045	1.0048
+4	1.0018	1.0025	1.0032	1.0038	1.0044	1.0040
16	1.0020	1.0026	1.0033	1.0039	1.0044	1.0047
27	1.0023	1.0029	1.0036	1.0041	1.0046	1.0049
38	1.0027	1.0033	1.0040	1.0045	1.0050	1.0053
49	1.0031	1.0037	1.0044	1.0050	1.0055	1.0057
60	-	1.0041	1.0048	1.0054	1.0059	1.0063

3.5.3 PRINCIPAL AIR CONDITIONING PROCESSES:

Mathematical models for predicting the psychrometric conditions achieved when mixing streams of air, as well as for evaluating the heat exchanged and the amounts of moisture added or removed during the process are assumed to ensue at constant total pressure. The computer program written in order to compute the values of the parameters involved, is also developed to cover all air conditioning processes:

Mixing of air streams process:

The process can be illustrated by considering n streams of air as shown in Fig.(3.19) (Mixing Z1,Z2,Z3 and OSA). The process is assumed to occur adiabatically at the constant total pressure considered. If the flow is steady, the mass balance of the system of Fig.(3.19) can be expressed as:

- For dry air:

$$\sum_{i=1}^n \dot{m}_{ai} = \dot{m}_{amix} \quad (3.5.25)$$

- For water vapour:

$$\sum_{i=1}^n \dot{m}_{vi} = \dot{m}_{vmix} \quad (3.5.26)$$

or

$$\sum_{i=1}^n w_i \dot{m}_{a_i} = w_{mix} \dot{m}_{a_{mix}} \quad (3.5.27)$$

Substituting from Eq. (3.5.25) into Eq. (3.5.27), the humidity ratio of the resulting mixture can be estimated as:

$$w_{mix} = \frac{\sum_{i=1}^n w_i \dot{m}_{a_i}}{\sum_{i=1}^n \dot{m}_{a_i}} \quad (3.5.28)$$

If the mixing fraction X_i of the i th stream is defined as:

$$X_i = \frac{\dot{m}_i}{\sum_{i=1}^n \dot{m}_i} = \frac{\dot{m}_i}{\dot{m}_{mix}} \quad (3.5.29)$$

and noting that,

$$\frac{\dot{m}_{a_i}}{\dot{m}_i} = \frac{\dot{m}_{a_i}}{\dot{m}_{a_i} + \dot{m}_{v_i}} = \frac{\dot{m}_{a_i}}{\dot{m}_{a_i} + w_i \dot{m}_{a_i}} = \frac{1}{1 + w_i} \quad (3.5.30)$$

than Eq. (3.5.28) can be written as:

$$w_{mix} = \frac{\sum_{i=1}^n \frac{X_i w_i}{1 + w_i}}{\sum_{i=1}^n \frac{X_i}{1 + w_i}} \quad (3.5.31)$$

The energy balance of the considered system can be expressed as:

$$\sum_{i=1}^n \dot{m}_{a_i} h_i = \dot{m}_{a_{mix}} h_{mix} \quad (3.5.32)$$

or

$$\sum_{i=1}^n \frac{\dot{m}_i}{1 + w_i} h_i = \frac{\dot{m}_{mix}}{1 + w_{mix}} h_{mix} \quad (3.5.33)$$

In terms of the mixing fractions of the streams, Eq. (3.5.33) can be written as:

$$\sum_{i=1}^n \frac{X_i}{1 + w_i} h_i = \frac{1}{1 + w_{mix}} h_{mix} \quad (3.5.34)$$

The specific enthalpy h_{mix} of the mixture can be evaluated as:

$$h_{mix} = (1 + w_{mix}) \sum_{i=1}^n \frac{X_i}{1 + w_i} h_i \quad (3.5.35)$$

Values estimated for the humidity ratio w_{mix} and specific enthalpy h_{mix} of the mixture can be employed to predict the mixture temperature t_{mix} using a suitable iterative procedure or Eq.(3.5.19).

With the values of the mixture temperature and humidity ratio known, the corresponding relative humidity Φ_{mix} can be evaluated using Eq.(3.5.10).

The mathematical model described above was devised assuming that the final temperature of the mixture would be higher than the dew point temperature of any of the streams involved. No water vapour was, therefore, assumed to condense out of the mixture formed. Whenever this is the case, the resulting relative humidity would be less than, ultimately equal to, 100%. If this assumption is not true, the estimation of the mixture relative humidity would exceed 100%. In this case i.e. when the liquid water is formed, the remaining mixture would be saturated air with a relative humidity of 100%. The continuity Eq.(3.5.25) for dry air, however, still holds. Nevertheless, the energy balance of the system will, now, assume the form:

$$\sum_{i=1}^n \dot{m}_{ad} h_i = \dot{m}_{amix} h_{mix} + \left(\sum_{i=1}^n \dot{m}_{vt} - \dot{m}_{vmix} \right) h_f \quad (3.5.36)$$

where h_f is the specific enthalpy of saturated liquid water condensed at the mixture temperature:

$$h_f = 4.186 t_{mix} \quad (3.5.37)$$

In terms of the mixing fractions of the streams and humidity ratios, Eq.(3.5.36) assumes the form:

$$\sum_{i=1}^n \frac{X_i}{1 + w_i} h_i = \frac{1}{1 + w_{mix}} h_{mix} + \left(\sum_{i=1}^n \frac{X_i w_i}{1 + w_i} - w_{mix} \right) h_f \quad (3.5.38)$$

For the known relative humidity of the mixture (i.e. $\Phi_{mix}=100\%$) and by employing Eq.(3.5.14) and(3.5.19), the temperature of the mixture formed can be estimated from Eq.(3.5.19) using an iterative process.

The values of Φ_{mix} and t_{mix} can be used to evaluate the humidity ratio w_{mix} of the mixture. The mass rate of the condensed moisture, per unit mass flow rate of dry air, is then:

$$\dot{m}_w = \left(\sum_{i=1}^n \frac{X_i w_i}{1 + w_i} - w_{mix} \right) \dot{m}_{amix} \quad (3.5.39)$$

Heating and cooling processes:

In terms of initial state of the air, defined by the values of any two parameters which can define the state point (i.e. t_{db1} and Φ_1), analysis of the heating and cooling processes, in order to achieve a desired final temperature t_{db2} , is aim at:

- I. evaluating the energy interactions as heat, and
- II. predicting the properties at the final state reached.

Constant total pressure heating does not change the humidity ratio and, therefore, the water vapour partial pressure remains unaltered. However, the relative humidity decreases. From the energy balance of the system of Fig.(3.19), the quantity of heat added, per unit flow rate of dry air, during the process considered, can be evaluated as:

$$q_{1-2} = h_2 - h_1 \quad (3.5.40)$$

The specific enthalpy h_1 can be computed in terms of the values of any two parameters which can describe the state point (t_{db1} , Φ_1). As in the process concerned, w_2 and w_1 are equal, h_2 and the final relative humidity can be estimated as functions of the known

values of w_2 and t_{db2} .

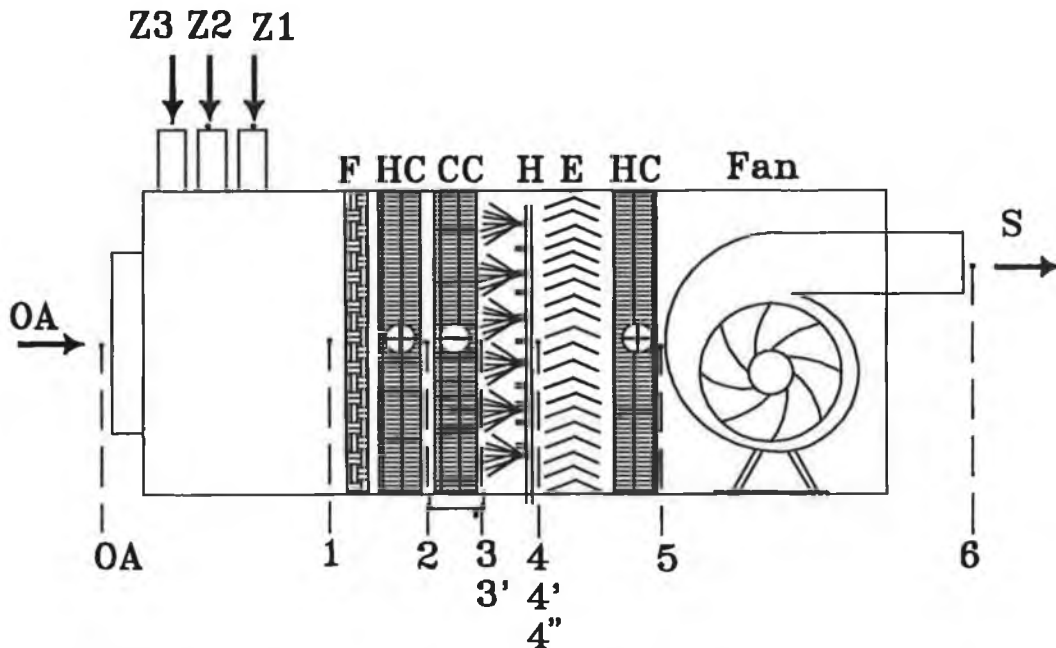


Fig. (3.19) Domestic Air Conditioning System with Air Handling Unit (AHU)

Constant pressure cooling does not alter the humidity ratio if the air is cooled to a temperature t_{db3} , higher than the dew point temperature, i.e. if no condensation of water vapour ensues (process 2-3). In this case, the relative humidity of air rises. The amount of heat interaction can be calculated using EQ.(3.5.40) and the final relative humidity Φ_3 can be estimated as a function of t_{db3} and $w_3(=w_2)$.

Cooling to a temperature below the dew point temperature (process 2-3') results in moisture condensation and lowering the humidity ratio of the air. The air become saturated (i.e. $\Phi_{3'}=100\%$). The amount of moisture condensed, per unit flow rate of dry air, during the process is $w_2-w_{3'}$. The amount of energy transferred as heat, per unit rate of flow of dry air, can be calculated from:

$$q_{2-3'} = (h_{3'} - h_2) + (w_2 - w_{3'}) h_f \quad (3.5.41)$$

where h_f is the specific enthalpy of saturated liquid water at t_{db2} .

Humidifying process:

Two methods are commonly used to increase the humidity ratio of air, namely adiabatic evaporation or evaporation with heat addition. In the adiabatic evaporation process, air passes through a spray of water in a thermally-insulated system, similar to that shown in Fig.(3.19). Some of the water evaporates and the humidity ratio of the air increases, simultaneously, the temperature of the air drops. Such a process runs along a line of constant wet bulb temperature on a psychrometric chart. The humidity ratio could increase to a limiting value at which the air becomes saturated (state 4). i.e. when the temperature of the air drops to the adiabatic saturation temperature.

For a selected value for the final humidity ratio w_4 , the amount of water that evaporates during the process, per unit mass flow rate of dry air, is $w_4 - w_3$.

The energy balance of the system is expressed by EQ.(3.5.40) which can be employed to estimate the value of t_{db4} . The final relative humidity Φ_4 can, then, be evaluated in terms of t_{db4} and w_4 .

During evaporation accompanied by heating, air is passed through a spray of water while, simultaneously, heat is transferred to the system. The cooling due to evaporation opposes the rise in temperature resulting from heat addition. The combined effect, therefore, may be either a net reduction in temperature, as shown by process 3-4' in Fig. (3.19), or a net increase in temperature as illustrated by process 3-4". In process 3-4', the relative humidity Φ rises, whereas in process 3-4", the value of Φ drops. Depending upon the final values of humidity ratio and relative humidity (or alternately the temperature) desired, the corresponding temperature (or relative humidity) can be estimated. The energy balance of the system involved can be used to compute the amount of heat added, per unit mass flow of dry air, as:

$$q_{3-4} = h_4 - (h_3 + (w_4 - w_3) h_f) \quad (3.5.42)$$

where h_f is evaluated at the final temperature t_{db2} .

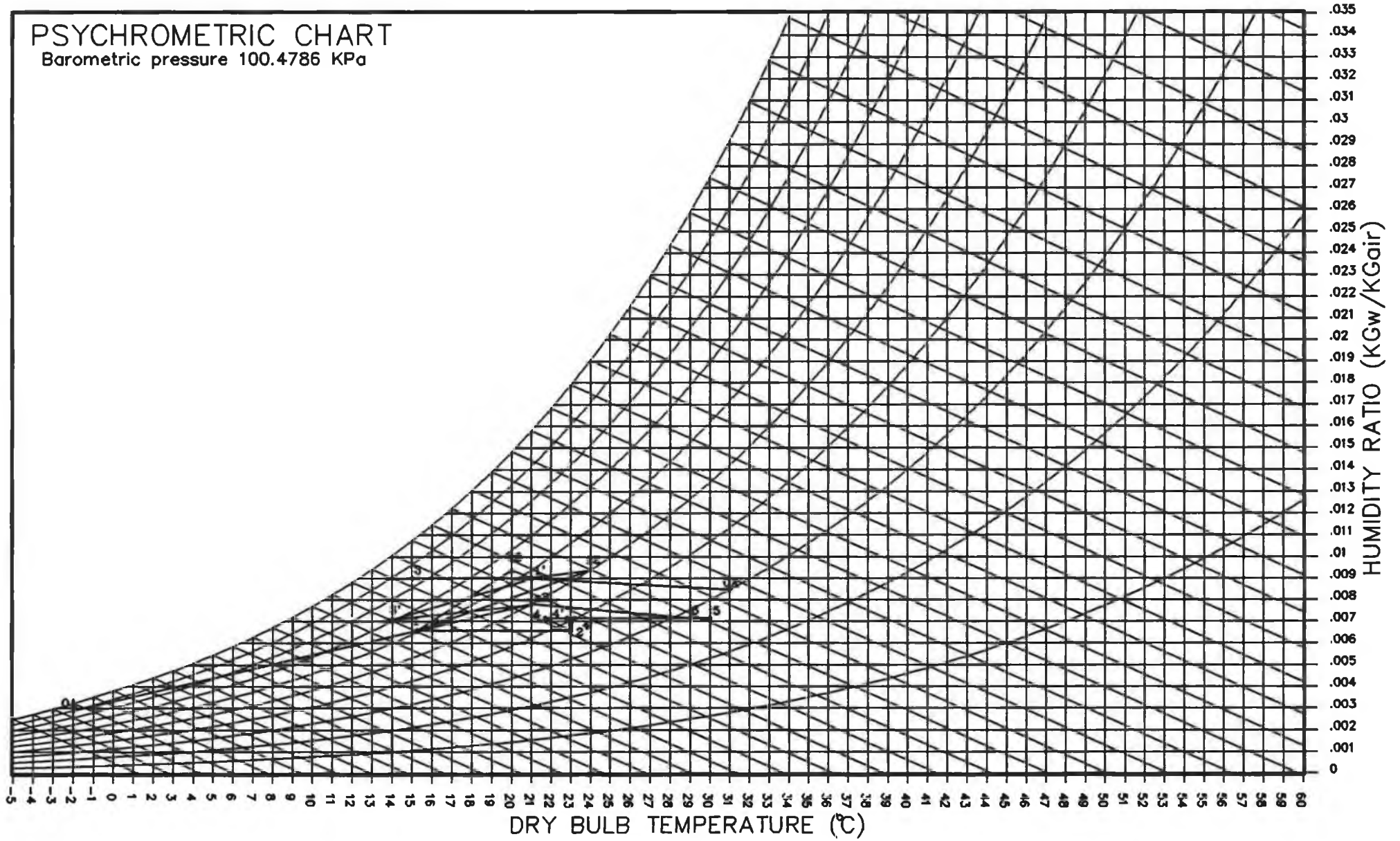


Fig.(3.20) Representation of Air Conditioning Processes on The Psychrometric chart.

Dehumidifying process:

Removal of water vapour from air is commonly accomplished by first cooling the air to below its dew point temperature, allowing, therefore, some water vapour to condense.

The moisture so condensed is removed and the remaining air is, then, heated to the delivery temperature desired. The schematic diagram and the process representation, for the system to achieve this objective, are shown in Fig. (3.20). This indicates that the air should be cooled to a temperature t_{db3} , which is the dew point temperature of the delivery air (state 3'). The amount of energy exchanged as heat during the cooling and heating processes can be estimated using EQ.(3.5.41) and (3.5.40), respectively. The amount of water condensed per unit mass flow rate of dry air is w_2-w_3 . The final relative humidity can be estimated in terms of the values desired for the humidity ratio and temperature of the delivery air.

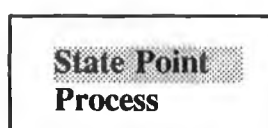
3.5.4 PSYCHROMETRIC CHART PROGRAM EXECUTION PROCEDURES:

This section shows the user how to use psychrometric chart program by working on the most common psychrometric chart command. Not all of the psychrometric chart features are covered by these procedures, but after the user has gone through them he will have a guide line to help him in using the program. Fig.(3.21) shows the hierarchy flow for psychrometric chart procedures, after selecting the psychrometric chart command from Program menu, the user will get through another menu composed of three options as follows;



DEFINE COMMAND:

This command gets the user through a menu to define state points or processes, which is displayed as:



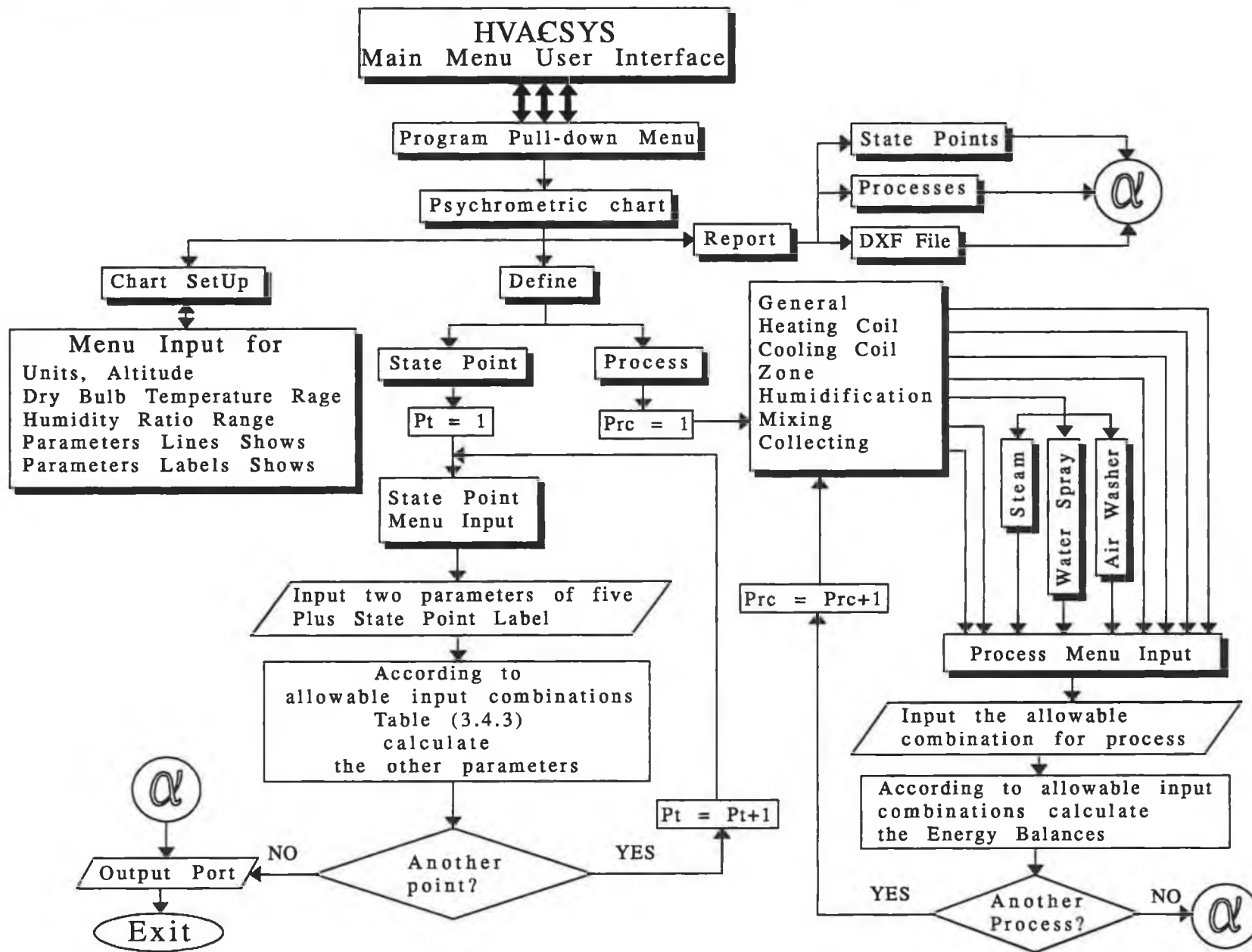


Fig. (3.21) Flow Diagram of The Psychrometric Chart Programme Procedures

I) *State point option:*

This option lets the user to define a state point on the psychrometric chart by inputting two parameters, then the user obtains the other parameters. Since the State Point command is highlighted, meaning that is selected from last menu, depressing <enter> brings up the following entry dialogue box:

State Point No. 1 input on chart with barometric pressure 101.325 [KPa]		
State point label		
Dry bulb temperature	0.00	[°C]
Relative humidity	0	[%]
Wet bulb temperature	0.00	[°C]
Dew point temperature	0.00	[°C]
Humidity ratio	0.00000	[kg _v /kg _a]
Enthalpy	0.000	[kJ/kg]
Specific Volume	0.000	[m ³ /kg]
Partial Vapour pressure	0.000	[kPa]
Saturation Vapour pressure	0.000	[kPa]

There are only 13 cases to define a state point, and all the cases are solved by using the developed program. Table (3.10) shows how for two given parameters, in addition to barometric pressure P_B , to compute the others parameters. Also there is help guide line to ease the inputs, the output directly will appear on the dialogue box.

Table (3.10) *The Allowable Combinations to define State point Parameters*

Parameters given	Parameters to obtain	Equations using	Comments
t_{dib} & Φ	$P_{ws}(t_{dib})$ P_w W v h t_{dp} t_{wb}	Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.14) Eq.(3.5.15) Eq.(3.5.19) Eq.(3.5.23 or 24) Eq.(3.5.20 to 22) & Eq.(3.5.6 or 7)	Requires numerical analysis solution (Newton method)

Parameters given	Parameters to obtain	Equations using	Comments
t_{dib} & t_{wb}	$P_{ws}(t_{wb})$ W_s^* h W P_w $P_{ws}(t_{dib})$ Φ v t_{dp}	Eq.(3.5.6 or 7) Eq.(3.5.22) Eq.(3.5.19) Eq.(3.5.20) Eq.(3.5.14) Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.15) Eq.(3.5.23 or 25)	
t_{dib} & t_{dp}	$P_w = P_{ws}(t_{dp})$ W $P_{ws}(t_{dib})$ Φ v h t_{wb}	Eq.(3.5.6 or 7) Eq.(3.5.14) Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.15) Eq.(3.5.19) Eq.(3.5.20 to 22) & Eq.(3.5.6 or 7)	Requires numerical analysis solution (Newton method)
t_{dib} & W	P_w $P_{ws}(t_{dib})$ Φ v h t_{dp} t_{wb}	Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.14) Eq.(3.5.15) Eq.(3.5.19) Eq.(3.5.23 or 24) Eq.(3.5.20 to 22) & Eq.(3.5.6 or 7)	Requires numerical analysis solution (Newton method)
t_{dib} & h	W P_w $P_{ws}(t_{dib})$ Φ v t_{dp} t_{wb}	Eq.(3.5.19) Eq.(3.5.14) Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.15) Eq.(3.5.23 or 24) Eq.(3.5.20 to 22) & Eq.(3.5.6 or 7)	Requires numerical analysis solution (Newton method)
Φ & t_{wb}	t_{dib} $P_{ws}(t_{dib})$ P_w W v h t_{dp}	Eq.(3.5.19 to 23 & 13) and Eq.(3.5.6 & 7) Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.14) Eq.(3.5.15) Eq.(3.5.19) Eq.(3.5.23 or 24)	Requires numerical analysis solution (Newton method),

Parameters given	Parameters to obtain	Equations using	Comments
Φ & t_{dp}	$P_w = P_{ws}(t_{dp})$ P_{ws} t_{dib} W v h t_{wb}	Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.6 or 7) Eq.(3.5.14) Eq.(3.5.15) Eq.(3.5.19) Eq.(3.5.19 to 22)	Requires numerical analysis solution (Newton method), Requires numerical analysis solution (Newton method),
Φ & W	P_w P_{ws} t_{dib} v h t_{dp} t_{wb}	Eq.(3.5.14) Eq.(3.5.10) Eq.(3.5.6 or 7) Eq.(3.5.15) Eq.(3.5.19) Eq.(3.5.23 or 24) Eq.(3.5.19 to 22)	Requires numerical analysis solution (Newton method), Requires numerical analysis solution (Newton method),
Φ & h	t_{dib} P_{ws} P_w W v t_{dp} t_{wb}	Eq.(3.5.10,14,19) and Eq.(3.5.6 or 7) Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.14) Eq.(3.5.15) Eq.(3.5.23 or 24) Eq.(3.5.19 to 22) & Eq.(3.5.6 or 7)	Requires numerical analysis solution (Newton method), Requires numerical analysis solution (Newton method),
t_{wb} & t_{dp}	$P_w = P_{ws}(t_{dp})$ W t_{dib} P_{ws} Φ v h	Eq.(3.5.6 or 7) Eq.(3.5.14) Eq.(3.5.19 to 22) & Eq.(3.5.6 or 7) Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.15) Eq.(3.5.19)	Requires numerical analysis solution (Newton method),
t_{wb} & W	t_{dib} P_w P_{ws} Φ v h t_{dp}	Eq.(3.5.19 to 22) & Eq.(3.5.6 or 7) Eq.(3.5.14) Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.15) Eq.(3.5.19) Eq.(3.5.23 or 24)	Requires numerical analysis solution (Newton method),

Parameters given	Parameters to obtain	Equations using	Comments
t_{dp} & h	$P_w = P_{ws}(t_{dp})$ W t_{db} P_{ws} Φ v t_{wb}	Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.6 or 7) Eq.(3.5.14) Eq.(3.5.15) Eq.(3.5.19) Eq.(3.5.19 to 22) & Eq.(3.5.6 or 7)	Requires numerical analysis solution (Newton method),
W & h	t_{db} P_w P_{ws} Φ v t_{dp} t_{wb}	Eq.(3.5.19) Eq.(3.5.14) Eq.(3.5.6 or 7) Eq.(3.5.10) Eq.(3.5.15) Eq.(3.5.23 or 24) Eq.(3.5.19 to 22) & Eq.(3.5.6 or 7)	Requires numerical analysis solution (Newton method)

II) Process option:

This option allows the user to define seven different kinds of processes; Heating coil, cooling/dehumidification coil, Zone, Mixing, Collecting, Humidification and General linear process. When the user selects a process from last menu then a process menu which is composed of seven different process, appears as follows;

<p>General linear</p> <p>Heating coil</p> <p>Cooling coil</p> <p>Zone</p> <p>Humidification</p> <p>Collecting</p> <p>Mixing</p>
--

a) General linear:

A general linear process can be used when the entering and leaving conditions of an air stream are known but not necessarily the method of achieving the process. The entry information for this command is displayed as follows;

General linear process		
Process No. 1 inputs on chart		
with barometric pressure 101.25 [KPa]		
State point No. 1 label		
State point No. 2 label		
Flow rate	0.000	[m3/s]
Water enthalpy	0.00	[kJ/kg]
Water temperature	0.00	[°C]
Water state (V=Vapour, L=Liquid)		

With this command, the tentative process screen display looks the same as before the command since both points were given as input. The user can, however, change the process or accept it in the normal manner. The allowed combinations are shown below, according to the help line:

Case 1: Pt1, Pt2, Flow, water enthalpy, water state.

Case 2: Pt1, Pt2, Flow, water temperature, water state.

b) Heating coil command:

The Heating Coil command allows the user to define a sensible heating process. The entry dialogue box for this option is displayed on the screen as:

Heating coil process		
Process No. 1 inputs on chart		
with barometric pressure 101.25 [KPa]		
State point No. 1 label		
State point No. 2 label		
Flow rate	0.000	[m3/s]
Load	0.00	[Watt]
Dry bulb temperature (t_{db})	0.00	[°C]
Enthalpy (h)	0.000	[kJ/kg]

Various combinations of the five parameters can be used to define the heating coil process. The allowed combinations are shown below, according to the help line:

Case 1: Pt1, Flow, Load

Case 2: Pt2, Flow, Load

- Case 3: Pt1, Flow, t_{db2}
- Case 4: Pt1, Flow, h_2
- Case 5: Pt2, Flow, t_{db1}
- Case 6: Pt2, Flow, h_1

c) Cooling Coil Command:

A cooling or dehumidification process is created with Cooling Coil command. The entry dialog box for this command is displayed as:

Cooling coil process		
Process No. 4 inputs on chart		
with barometric pressure 101.25 [KPa]		
State point No. 1 label		
State point No. 2 label		
Flow rate	0.000	[m3/s]
Load (Q_s)	0.00	[Watt]
Dry bulb temperature	0.00	[°C]
Enthalpy (h)	0.00	[kJ/kg]
Apparatus dew point temperature	0.00	[°C]
By pass factor (BPF)	0	[%]

The allowed combinations, which are shown below according to the help line, have to be defined for each selecting of this command:

- Case 1: Pt1, Pt2, Flow
- Case 2: Pt1, Flow, BP, Load
- Case 3: Pt1, Flow, ADP, BP
- Case 4: Pt1, Flow, ADP, t_{db2}
- Case 5: Pt1, Flow, ADP, h_2
- Case 6: Pt1, Flow, ADP, W_2
- Case 7: Pt1, Flow, BP, t_{db2}
- Case 8: Pt1, Flow, BP, h_2
- Case 9: Pt1, Flow, BP, W_2

d) Zone process command:

This command allows the user to define the process that supplies air undergoes as it passes through and conditions a building room or zone. The user can specify either the condition of the supply air and have the program calculate the leaving conditions, or specify the leaving conditions and have the program calculate the necessary supply

condition. Moreover, the user can specify either the load or the flow and the program will calculate the other quantity. The entry parameters are shown in the dialogue box as:

Zone process		
Process No. 3 inputs on chart		
with barometric pressure 101. 25 [KPa]		
State point No. 1 label		
State point No. 2 label		
Flow rate	0.000	[m3/s]
Sensible load	0.00	[Watt]
Dry bulb temperature (t_{db})	0.00	[°C]
Sensible heat ratio (SHR)	0	[%]

The allowed combinations, which are shown below according to the help line, have to be defined for each execution of this command:

- Case 1: Pt1, Flow, Sensible Load, Sensible Heat Ratio
- Case 2: Pt1, Sensible Load, t_{db2}
- Case 3: Pt2, Flow, Sensible Load, Sensible Heat Ratio
- Case 4: Pt2, Sensible Load, t_{db1}

e) Humidification process command:

Humidification of an air stream can be accomplished in several ways, including steam, liquid water spray, or air washing. Note that air washing differs from spray in that the evaporating temperature is assumed to be the incoming air wet bulb temperature for the air washer, whereas the spray type uses the supply water temperature. For that a menu to define the three cases of humidification is displayed on the screen as follows;

Steam Water Spray Air Washer

1) *Steam Humidification Process*: The entry dialogue box for this command is shown as:

**Steam humidification process
Process No. 5 inputs on chart
with barometric pressure 101. 25 [KPa]**

State point No. 1 label		
State point No. 2 label		
Flow rate	0.000	[m3/s]
Humidity ratio (W_2)	0.00000	[Kg/Kg]
Relative humidity (Φ_2)	0	[%]
Steam enthalpy (h_s)	0.000	[KJ/Kg]
Steam temperature (t_s)	0.00	[°C]

The allowed combinations, which are shown below according to the help line, have to be defined for each execution of this command:

- Case 1: Pt1, Flow, Φ_2 , h_s
- Case 2: Pt1, Flow, Φ_2 , t_s
- Case 3: Pt1, Flow, W_2 , h_s
- Case 4: Pt1, Flow, W_2 , t_s
- Case 5: Pt2, Flow, Φ_1 , h_s
- Case 6: Pt2, Flow, Φ_1 , t_s
- Case 7: Pt2, Flow, W_1 , h_s
- Case 8: Pt2, Flow, W_1 , t_s

2) *Water Spray Humidification Process*: The entry dialogue box for this command is shown as follows and the allowed combinations are the same as the last case except the enthalpy and temperature are for water instead of steam:

**Water spray humidification process
Process No. 6 inputs on chart
with barometric pressure 101. 25 [KPa]**

State point No. 1 label		
State point No. 2 label		
Flow rate	0.000	[m3/s]
Humidity ratio (W_2)	0.00000	[kg/kg]
Relative humidity (Φ_2)	0	[%]
Water enthalpy (h_w)	0.000	[kJ/kg]
Water temperature (t_w)	0.00	[°C]

3) *Air Washer Humidification Process*: The entry dialogue box for this command is

shown as follows and the allowed combinations are also as the last case:

Air Washer humidification process Process No. 7 inputs on chart with barometric pressure 101.25 [KPa]		
State point No. 1 label		
State point No. 2 label		
Flow rate	0.000	[m ³ /s]
Humidity ratio (W_2)	0.00000	[kg/kg]
Relative humidity (Φ_2)	0	[%]
Water enthalpy (h_w)	0.000	[kJ/kg]
Water temperature (t_w)	0.00	[°C]

f) Collecting process command:

The collecting process command is used when more than two streams are mixed together, with known amounts and conditions for each stream. Physical examples would include a conditioned space receiving air from several supply outlets, or a return plenum collecting air from several zones. The program creates a collecting process by selecting the command from processes menu, the number of stream which can be mixed are 2,3,4. The allowed combinations are the flow rate and conditions (state point) for each stream, the entry dialogue box for this command is displayed as:

Collecting process Process No. 8 inputs on chart with barometric pressure 101.25 [KPa]		
State point No. 1 label		
Flow rate of stream 1	0.000	[m ³ /s]
State point No. 2 label		
Flow rate of stream 2	0.000	[m ³ /s]
State point No. 3 label		
Flow rate of stream 3	0.000	[m ³ /s]
State point No. 4 label		
Flow rate of stream 4	0.000	[m ³ /s]
Collected state point No. M label		
Total Flow rate of stream M	0.000	[m ³ /s]

g) Mixing Process command:

This command calculates the results of mixing two air streams. This command is different from the other processes considered up to now in that it actually creates two cases of mixing process:

- the one from the conditions of the first air stream to the mixed conditions
- the one from the conditions of the second air stream to the same mixed conditions

Mixing process		
Process No. 7 inputs on chart		
with barometric pressure 101.25 [KPa]		
State point No. 1 label		
State point No. 2 label		
Total flow rate	0.000	[m ³ /s]
Percentage flow rate of Pt.2	0	[%]
Mixed dry bulb temperature (t_{db})	0.00	[°C]
Mixed humidity ratio (W_m)	0.00000	[kg/kg]
Mixed enthalpy (h_m)	0.00	[kJ/kg]
Mixed state point label		

The allowed combinations, which are shown below according to the help line, have to define for each execution of this command:

- Case 1: Pt1, Pt2, Total Flow, h_2
- Case 2: Pt1, Pt2, Total Flow, t_{db2}
- Case 3: Pt1, Pt2, Total Flow, W_2
- Case 4: Pt1, Pt2, Total Flow, Percentage of Pt2

CHART SETUP COMMAND:

This command is to define the limits of the psychrometric chart and the appearance properties lines on drawing chart and calculations. The entry dialogue box for Chart Setup is displayed on the screen as follows:

Chart Title:

Units (SI or ENG):

Elevation above See Level: 0 (m/ft)

Dry Bulb Temperature Range:
 Form 0.00 (°C/°F) To 0.00 (°C/°F)

Humidity Ratio Range:
 From 0.000 To 0.000 (kg/kg:lb/lb)

Show lines: Show labels:

Dry bulb temp.	<input type="checkbox"/>	(Y or N)	<input type="checkbox"/>	(Y or N)
Humidity Ratio	<input type="checkbox"/>	(Y or N)	<input type="checkbox"/>	(Y or N)
Enthalpy	<input type="checkbox"/>	(Y or N)	<input type="checkbox"/>	(Y or N)
Wet bulb temp.	<input type="checkbox"/>	(Y or N)	<input type="checkbox"/>	(Y or N)
Relative Humidity	<input type="checkbox"/>	(Y or N)	<input type="checkbox"/>	(Y or N)

REPORT COMMAND:

This command allows the user to select the type of output. In addition, after finishing working on the chart and automatically getting the report on the screen, the user can press F2 key to print both the state points report and processes report. The user can select Report command to produce the output of his work, he can get state points report, processes report and DXF drawing file. For this step a menu appears to select the type of report as:

STATE POINTS PROCESSES DXF FILE
--

1) *State Points report*: when the user selects the State Points command from last menu, a table of the state points is displayed directly on the screen and he can print out by press the F2 Key from the keyboard, the following table shows the state points report.

STATE POINTS REPORT										
No.	Pt.	TDB,°C	RH,%	TWB,°C	TDP,°C	W, Kg/Kg	H, KJ/Kg	V,m ³ /Kg	Pw, Kpa	Pws, KPa
1	REA	30.00	50	21.71	18.40	0.01332	64.034	0.877	2.124	4.248

II) *Processes report*: Any execution for this command give the user processes report on the screen, and also he can get printout this report by press F2 key which is printed as shown in the following table:

PROCESSES REPORT								
No.	Proc. Type	From Pt.	To Pt.	Flow m ³ /Kg	Sensible Load KJ/Kg	Latent Load KJ/Kg	Water added Kg/hr	Total Load KJ/Kg

III) *DXF File (Drawing File)*: This command allows the user to get DXF file on disk that can be read by the AutoCAD package. This feature allows the user to incorporate psychrometric chart graphical results into reports and drawings. All DXF files are written in the directory established by the AutoCAD directly (i.e. C:\ACAD\). To use the DXF files the user has to execute the AutoCAD package if he was only executing HVACSYS package or if he executed the HVACSYS within the AutoCAD, he has to exit from the HVACSYS package. After that he can call the DXF file by using DXFIN command from AutoCAD and type the file name. Fig.(3.21) shows a psychrometric chart for sea level drawn using DXF file.

3.6 U-VALUE PROGRAM:

The calculation of HVAC loads begin with the determination of U-value, which are overall heat transfer coefficients. U-value are calculated by taking the reciprocal of an R-value (net effective heat transfer resistance). R-value is obtained by dividing the thickness of the material layer by the conductivity of the material used for common building, and these are listed in tables in the Appendix. This program calculates the thermal transmittance or U-value of a structure which may be a wall, roof or floor . In this program the master menu is divided into seven submenus as seen in the flowchart in Fig.(3.22).

The type of surface (eg. outside wall) will define the internal surface resistance. Each normal solid layer has a defined thickness and thermal conductivity, and so on for the

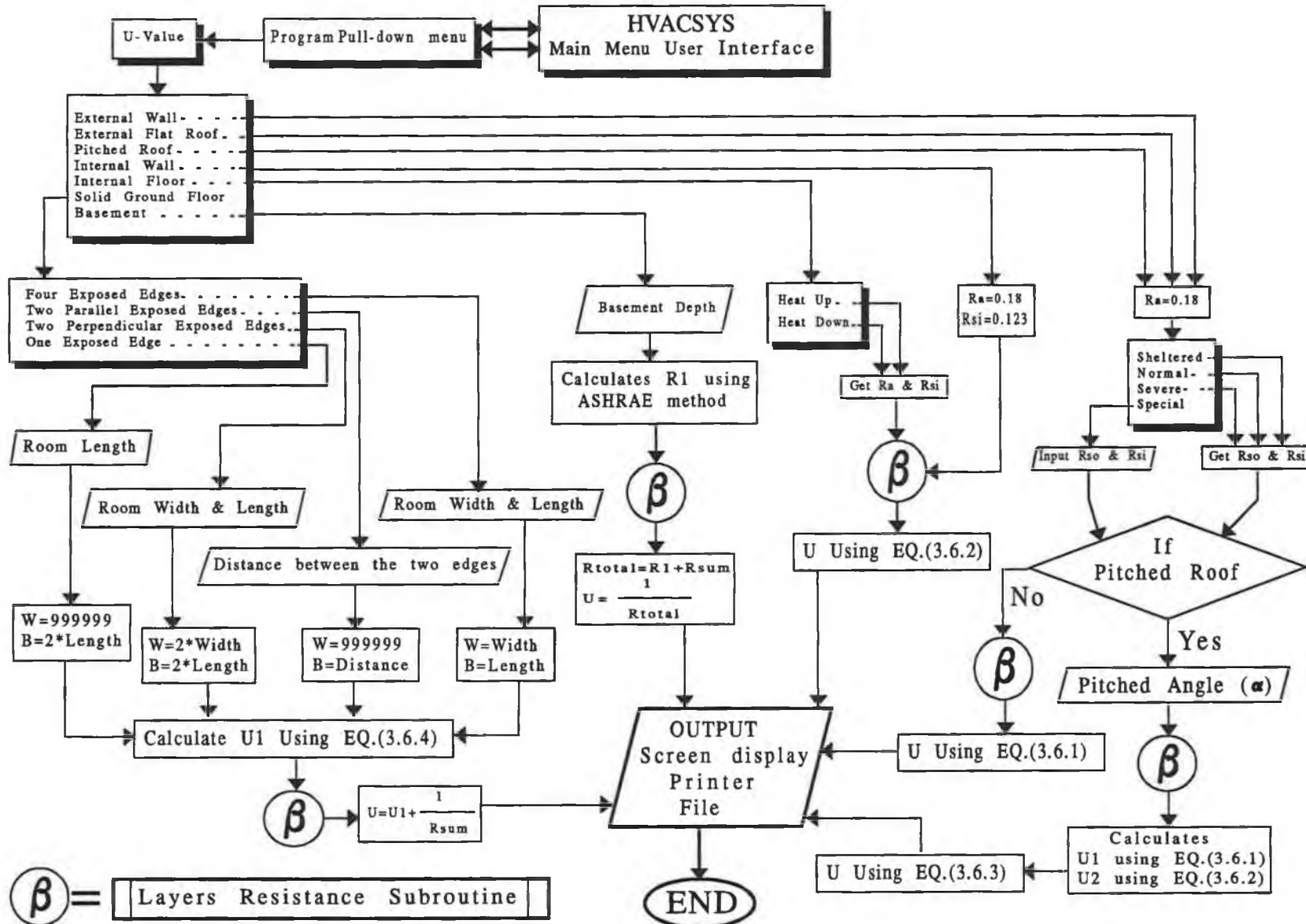


Fig. (3.22) Flow Diagram of The U-Value Programme Procedures

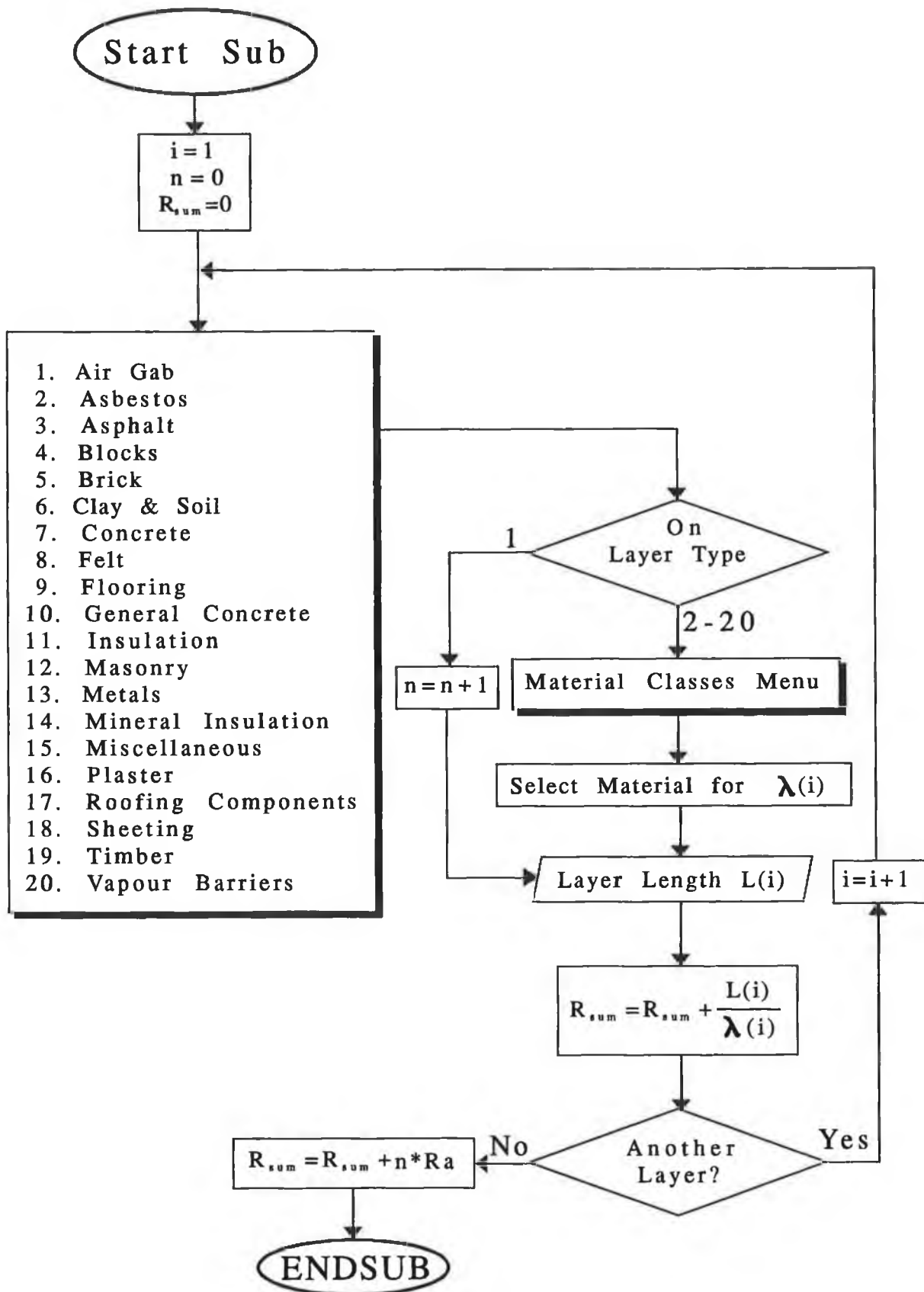


Fig. (3.23) Flow Diagram of The Layer Resistance Subroutine

next layer until the construction of the surface is completed. Up to 20 layers may be specified. Air gaps are not counted as layers, but specified separately. Fraction of air gaps may be used if a non standard thermal resistance is required.

3.5.1 U-VALUE PROGRAM EXECUTION STEPS:

The overall structure of U-value program is given in Fig.(3.22) which is explained the sequences of the running procedure of the program. And Fig.(3.23) shows the main subroutine of the U-value program.

U-Value Submenu:

Any selection of U-value function from submenus gets the user through the U-value program. The following menu called "The surfaces types menu" appears to select the appropriate surface to work on. This menu consists of seven options, as follows:



The user selects the option required to continue the program to the next step.

External Surfaces :

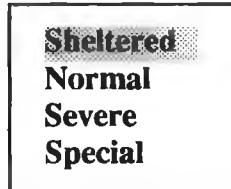
The external surfaces contain the external wall, external roof, and the pitched roof. The CIBSE GUIDE [2] gives the following specifications for the external surfaces;

- * Sheltered is up to the third floor height in city centres.
- * Normal comprises most suburban and country premises; fourth to eighth floors in

city centres.

- * Severe comprises buildings on the coast or exposed hill sites, floors above the fifth in suburban or country districts; ninth and above in city centres.

Then for these definition a site exposure menu is displayed on the screen as follows:



The site exposure menu helps to define the external surface resistances according to Table (3.11).

		Wall	Internal floor		Flat roof
			Heat Up	Heat down	
R_{si}		0.123	0.106	0.15	0.106
R_a		0.18	0.18	0.21	0.18
R_{so}	Sheltered	0.08	0.106	0.15	0.07
	Normal	0.05	0.106	0.15	0.045
	Severe	0.03	0.106	0.16	0.02

Table 3.11 Outside, inside, and air gap thermal resistances

For example the Sheltered option gives for the out side thermal resistance $0.08 \text{ m}^2\text{C/W}$ for the Wall and $0.07 \text{ m}^2\text{C/W}$ for the roof and Roof-part in pitched roof and so on for other options. In addition to that if the user chooses special option, it gives a choice to enter the value of special thermal resistance (R_{si} , R_{so}).

The general equation (3.6.1) for a layered external wall, external roof, and external

floor is :

$$U = \frac{1}{R_{si} + \sum_{i=1}^{i=m} \frac{L_i}{\lambda_i} + nR_a + R_{so}} \quad (3.6.1)$$

Where:

U = Thermal transmittance ($W / m^2\text{°C}$).

R_{si} = Inside surface resistance ($m^2\text{°C} / W$).

R_{so} = Outside surface resistance ($m^2\text{°C} / W$).

R_a = Air gap resistance ($m^2\text{°C} / W$).

n = Number of air gaps.

L_i = Thickness of layer i (m).

λ_i = Thermal conductivity of layer i ($W / m^2\text{°C}$).

m = Number of solid layers.

Pitched Roof:

For pitched roofs the structure is considered in two parts, firstly the ceiling construction and then the roof. Individual U values are computed for both elements using internal surface resistances for the ceiling giving a U value as U_1 by using equation (3.6.2) with only a little change in equation (3.6.1) to become :

$$U = \frac{1}{2 R_{si} + \sum_{i=1}^{i=m} \frac{L_i}{\lambda_i} + nR_a} \quad (3.6.2)$$

And one internal and one external surface resistance for the roof giving a U value as U_2 by using equation (3.6.1). The resulting combined U -value (equation (3.6.3)) is computed using the pitch angle (α) as :

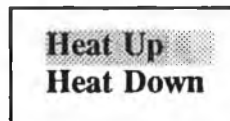
$$U = \frac{U1 U2}{U2 + U1 \cos(\alpha)} \quad (3.6.3)$$

The U-value refers to the plan area of the roof (ie. the ceiling area). the computation assumes that there is no air infiltration into or out of the enclosed roof space. After the site exposure menu for the pitched roof option the computer asks to enter the pitched angle α .

Partitions (Internal surfaces) :

Internal partitions are considered as exposed walls, but with an outside thermal resistance equal to the inside resistance, and U-value is computed by substitution in equation (3.6.2) .

For the internal ceilings there is heat direction menu, it depends on the heat flow up and means that the inside thermal resistance is $0.106 \text{ m}^2\text{C/W}$ and air gap resistance is $0.18 \text{ m}^2\text{C} / \text{W}$ or down which is $.015$ for the inside thermal resistance and 0.21 for the air gap, and it is displayed on the screen as :



Solid ground floors :

The U-Value of a solid ground floor is computed using an expression given by Billington [8,17] (equation (3.6.4), using the room Width (W) and breadth (B) as shown:

$$U = \frac{0.9 e^{\frac{B}{2W}} \ln(6.7 B + 1)}{B} \quad (3.6.4)$$

For four exposed edges W and B are the room dimensions. For two parallel exposed

edges, the user defines B as the distance between the two exposed edges and W is set to 999999m. For two perpendicular exposed edges, the user defines the floor length $L1$ and width $W1$, for calculating purposes, $B = 2 L1$ and $W = 2 W1$. For one exposed edge, the length of the defined edge is $L1$, W is set to 999999m and $B = 2 L1$.

There is a menu of four options according to the above, any selection of an option from this menu will ask the user to enter the parameters discussed before, and the menu appears on the screen as:

<p>Four exposed edges</p> <p>Two parallel exposed edges</p> <p>Two perpendicular exposed edges</p> <p>One exposed edge</p>
--

Basement:

The basements are treated using a method defined in ASHRAE [7]. This involves considering a number of horizontal stripes of the basement wall and computing the mean soil path length to the exposed ground. The computed basement wall U-value is an average for the whole wall, as the actual value reduces with depth. The basement floor U-value is an average value computed at a point one quarter of the basement width (or length if this is less than the width) from the side wall.

Layer Classes Menu:

The construction type menu which is mainly composed of three layer types is as follows:

- 1 - Air Gap layer
- 2-19 - Solid Layers
- 20 - Vapour Barrier layer

This menu called the "layer classes menu" to define each layer materials is displayed on the screen as follows:

- 1 - Air Gap
- 2 - Asbestos
- 3 - Asphalt
- 4 - Blocks
- 5 - Brick
- 6 - Clay and Soil
- 7 - Concrete
- 8 - Felt
- 9 - Flooring
- 10 - General Concrete
- 11 - Insulation
- 12 - Masonry
- 13 - Metals
- 14 - Mineral Insulation
- 15 - Miscellaneous
- 16 - Plaster
- 17 - Roofing Components
- 18 - Sheeting
- 19 - Timber
- 20 - Vapour Barriers

Air gaps:

For each air gap selected, the following detail are held:

- a) Thermal resistance: 0.18 [$\text{m}_2^\circ\text{C}/\text{W}$] for (wall, internal floor (heat upwards), flat roof)
 0.21 [$\text{m}_2^\circ\text{C}/\text{W}$] for (internal floor (heat upwards))
- b) Thickness: it is required only for drawing.

The user must note that the construction can not be defined that has an air gap as the first layer, and if the user makes an error for selecting air gap as the first layer the program will give the user to select another type of layer as the first.

Solid layers:

A solid layer may either be an element from layer type menu and an material option in the submenu of database or a special, the details for which the user will have to enter. The solid layer may be one of 18 materials options, for each material there are many specified classes of this type, which is displayed on the screen as follows:

Table (3.12) Asbestos Material for U-Value Calculation.

ASBESTOS					
No.	Description	Thermal Cond. W/m °C	density Kg/m3	Spce. heat J/Kg°C	Vapor Res. GNs/Kgm
1	Asbestos 83% magnesia	0.070	190	1000	300.00
2	Asbestos cement decking	0.360	1500	1050	300.00
3	Asbestos cement sheet	0.360	700	1050	300.00
4	Asbestos slabs	0.070	145	1000	300.00
5	Asbestos sprayed (80 kg/m3)	0.043	80	816	1000.00
6	Asbestos sprayed (130 kg/m3)	0.046	130	816	1000.00
7	Asbestos sprayed (160 kg/m3)	0.061	160	816	1000.00
8	Asbestos sprayed (240 kg/m3)	0.068	240	816	1000.00
9	Asb cement sheet (700 kg/m3)	0.360	700	1050	333.33
10	Asb cement sheet (1360 kg/m3)	0.220	1360	1050	333.33
11	Asb cement sheet (1520 kg/m3)	0.360	1520	1050	333.33
12	Asb cement sheet (1600 kg/m3)	0.400	1600	1050	333.33
13	Asb cement sheet (2000 kg/m3)	0.660	2000	1050	333.33
14	Asbestos cement board (type 1)	0.577	1922	1005	333.33
15	Asbestos cement board (type 2)	0.389	1970	837	333.33
16	Asbestos cement	0.360	750	2133	1000.00
17	Asb cement, semi compressed	0.370	1200	2133	1000.00
18	Asb cement, fully compressed	0.650	1600	2133	1000.00
19	Asb insul board (500 kg/m3)	0.108	500	840	333.33
20	Asb insul board (577 kg/m3)	0.160	577	840	333.33
21	Asb insul board (720 kg/m3)	0.120	720	840	333.33
22	Asb insul board (900 kg/m3)	0.115	900	840	333.33
23	Asb insul board (1200 kg/m3)	0.250	1200	840	333.33
24	Asbestos cement new	0.360	750	2133	1000.00
25	Asbestos cement aged	0.360	750	2133	1000.00
26	Asbestos cement, red	0.360	750	2133	1000.00
27	Asbestos fibre loose	0.061	128	816	333.33

Layers are defined starting from the inside outwards and each layer may be one of three types as defined. Each type of the material in this menu has a list of different types from these materials as shown in appendix A, Tables 1-16. For example if one selects Blocks option from the menu the material will list into pages and one can select from any page and if the first page is missed it may be displayed again by following the command appearing on the screen. After this stage the user has to define the thickness of each layer and so on for the next layer till finishing the structure.

For building up standard files for the users own material he can refer to materials option in the submenu of database. In addition, for each of the three groups of materials the user may define a special material. easily to select the type of layer, and for this layer there is a materials menu to choose the layer material.

The result of U-value may be displayed or saved to be used when it is needed.

CHAPTER FOUR

CUSTOMIZING CAD SYSTEMS FOR HVAC SYSTEMS DESIGN

4.1 INTRODUCTION:

With the advent of high speed Computers, Computer-Aided Drafting (CAD) system have become omnipresent among design engineers. From the initially very expensive system, with simple interactive geometric capabilities, CAD system have evolved into affordable but sophisticated tools that automate many aspects of design documentation and retrieval. The development of even routine designs, however, has still been a manual (and often tedious) process. These first generations CAD tools have provided gains in drafting productivity of 50% to 200% [30] in repetitive design applications.

This chapter describes the evolution of a new kind of knowledge-based CAD system, HVACCAD. HVACCAD is a computer-supported engineering consulting tool and leading software package for the user in designing the pipe and duct systems. It is based on AutoCAD which is one of the world's leading CAD and graphics program. By providing significant new capabilities to support both the development and documentation of design solutions, HVACCAD increases productivity in design projects by 10 to 15 times, freeing engineers to make fuller use of this skills and creativity. HVACCAD Allows storage and re-use of engineering knowledge, supports engineering teamwork and concurrent engineering, integrates engineering disciplines, and automates generation of documents, including drawing parts list, parts prices, total costs and specifications.

In a HVAC design the individual environmental plant components are connected to other components by pipes, ducts and control systems to form a complete system.

An engineer's schematic diagram may be represented by a network of "Nodes" and "arcs", the nodes representing components such as fans, boiler, burners, pumps, AHU, UH..., and the arcs representing the inter connecting pipes and ducts and their fittings. The concept of developing CAD for drawing HVAC System networks, has been interpreted in a number of different ways by other researchers [37-52]. Thus the user has mainly two systems for further design development;

- 1) duct system
- 2) pipe system and

both these systems are appropriate for the HVAC system design. Each system has its own nodes and arcs, for example for duct work; AHU, dampers, filters, supply outlets, grills, coils, fans is conceived as nodes and the duct and its fitting like elbows, tees, reducers as arcs.

In addition to these subroutines, psychrometric chart program has been developed for any elevation to represent all HVAC Process. It is a complete chart for temperature range -50 to 100 °C, and humidity ratio 0 to 0.35 kg_w/kg_a.

4.2 HVACCAD USER INTERFACE:

The menu file in AutoCAD package is a simple text file containing AutoCAD command strings (ACAD.MNU file). Section of the file can be associated with different menu device, such as the screen and tablet menus. Both pull-down and screen menus have been used in this work. The command HVACCAD is added to the main menu, this command calls the HVACCAD user interface where a special menu file called HVAC.MNU is developed similar to ACAD.MNU which have been customized as menu for HVAC system design, and activates several submenus which invoke the developed routines.

The user interface is accomplished by integrating HVACCAD which is present as customized AutoCAD and relational DATABASE which is calculated or stored by HVACSYS using ASCII files between them. In the product structure rooms, spaces and components of HVAC system are visualized as a logical hierarchy with depending

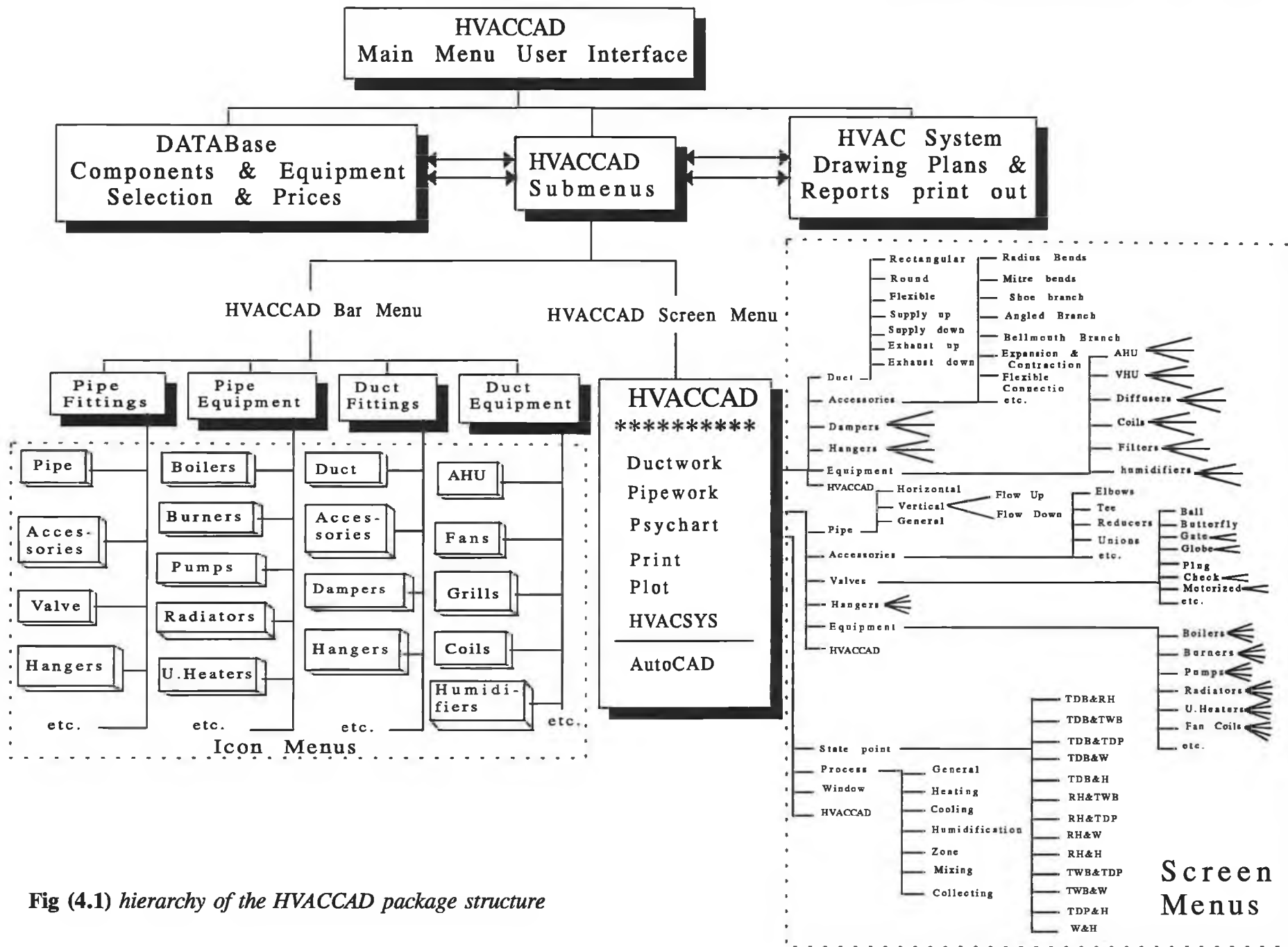


Fig (4.1) hierarchy of the HVACCAD package structure

relations between components. In this way the product structure(the plan), can be made very dynamic compared with a direct link between HVACCAD and DATABase (HVACSYS). In his way the user can deal with HVACCAD while designing his system, he can add knowledge and data to the system whenever he wants.

HVACCAD user interface is divided into two menus as the AutoCAD package; bar menu and screen menu. Fig.(4.1) describes the HVACCAD package which is explained as follows; and Fig.(4.2) shows the HVACCAD user interface:

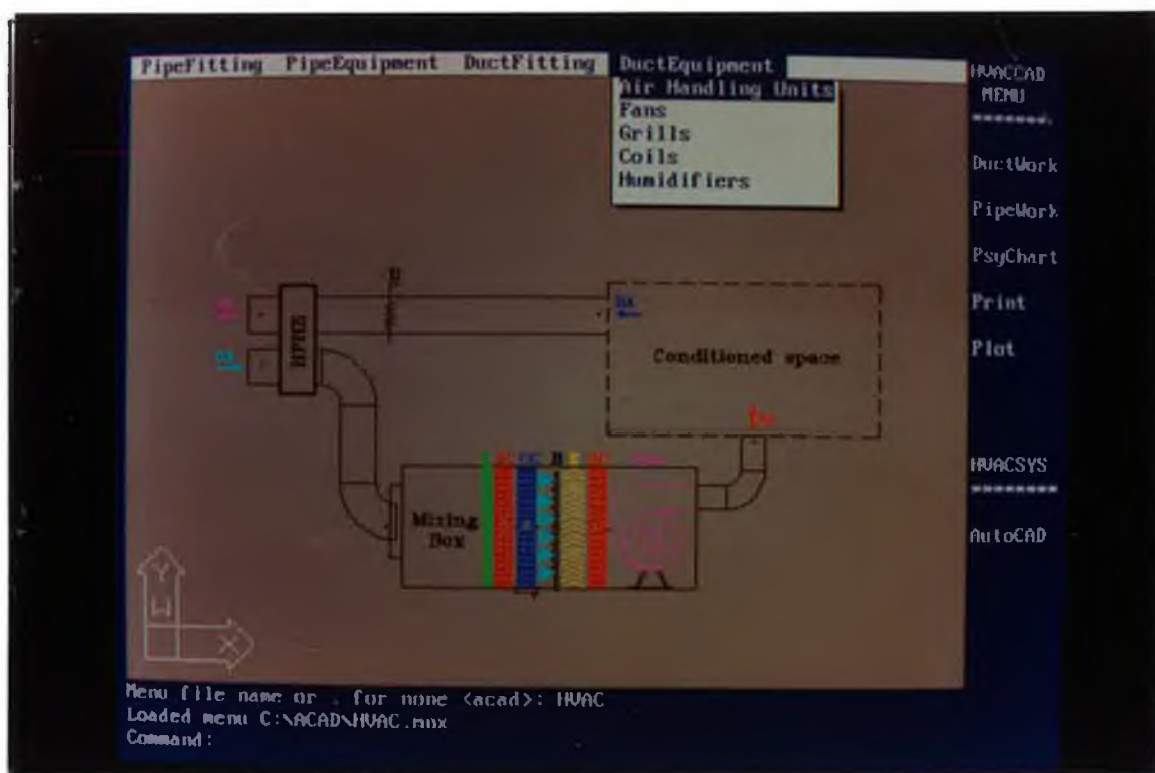


Fig. (4.2) HVACCAD User Interface Picture

4.2.1 BAR (PULL-DOWN) MENU:

It contains four pull down menus which are defined and named POP1 through POP4 in HVAC.MNU file and may be explained and shown as follows;

- 1) **DuctFittings** for duct fittings, which is initially composed of four icon menus for the program;
 - i. Duct icon menu: this menu is displayed on the screen to show the user the positions of all duct cases (horizontal, vertical exhaust (Down, Up), vertical

supply (Down, Up)). A sample of this menu can be designed and displayed as following:

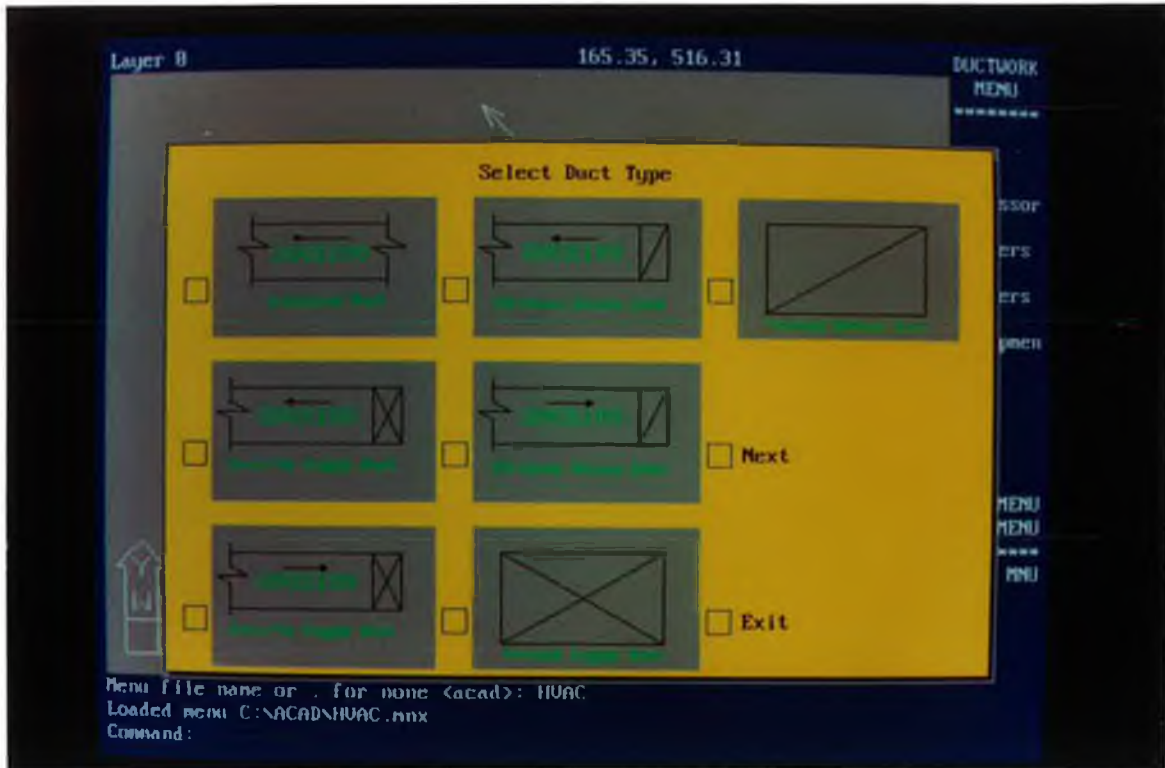


Fig. (4.3) Duct Icon Menu Picture

- ii. Accessories icon menu: the most important in the duct network is the fitting of the duct like elbows with deferent type, tees, wyes, reducers, diffuser, etc. Fig. (4.4) shows a picture of some of the duct fitting.
- iii. Dampers icon menu; the dampers for the duct system are important to control the air distribution and balance the system. The dampers can be classified through: butterfly, multiblade (parallel-blade, opposing-blade), motorizing and manual, fire and smoke controls damper, splitter, gate or slide and shutter.
- iv. Filters icon menu: air filter can be classified as:
 - 1) Fibrous filters which have four general configurations (panel filters, pleated-medium filters, tubular packed or bag filters and roll filters).
 - 2) Membrane filters: membrane filters are made from very thin polymer sheets pieced by extremely small air-flow passages. these are available in

several forms (collimated pore, granular symmetric, granular asymmetric, fibre).

3) Electrostatic filters.

4) Combined forms.

- 2) ***DuctEquip*** for Duct equipment, Which is composed of five commands:
- i. Air Handling Unit (AHU) icon menu: The function of the AHU is to provide air at a quantity, temperature and humidity to offset the sensible and latent heat gains to the space (in the cooling mode) and the heat losses (in the heating mode), while maintaining the required temperature and humidity in the space. AHU can be classified on its arrangements as: (a) single zone, (b) multizone, (c) double duct, (d) variable air volume (VAV) and (e) induction.
 - ii. Fans icon menu: This menu contains all type of fans which can be classified as follows and Fig.(4.5) shows a number of types of fans which can be used:
 1. Axial flow fan, including propeller fans, through which the air flows substantially parallel to the shaft.
 2. Centrifugal fans, which might be called radial-flow fans because the air flows in a radial direction relative to the shaft.
 3. Mixed-flow fans, through which the air flows in a combined axial and a radial directions.
 4. Cross-flow fans, through which the air flows in an inward radial direction and then in an outward radial direction.
 - iii. Diffuser and Grill icon menu: A diffuser is an outlet through which the air supply passes from the duct system to the space being conditioned which can be classified as (multiple strip ceiling diffusers, cone-type ceiling diffusers, perforated-face ceiling diffusers, multi-directional ceiling diffusers, linear ceiling diffusers, side wall diffusers, etc.). A grille is defined as a covering for an opening through which air passes (extract or return air

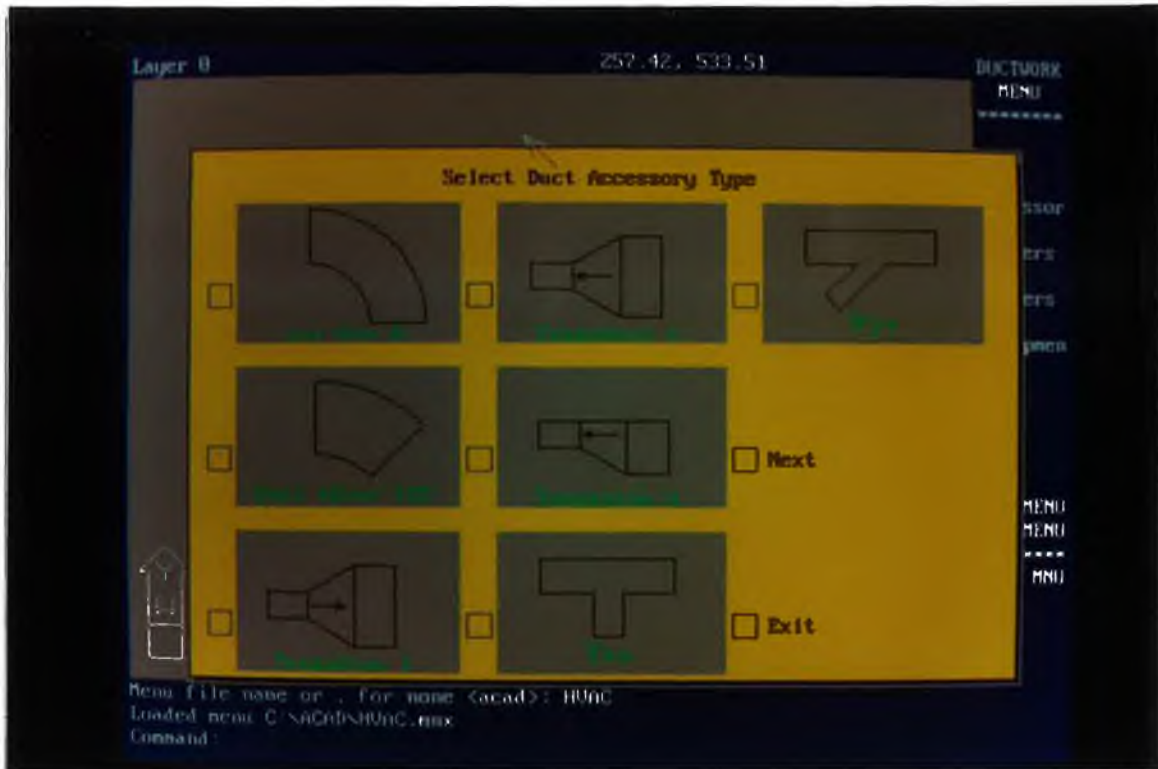


Fig. (4.4) Duct Fittings Icon Menu Picture

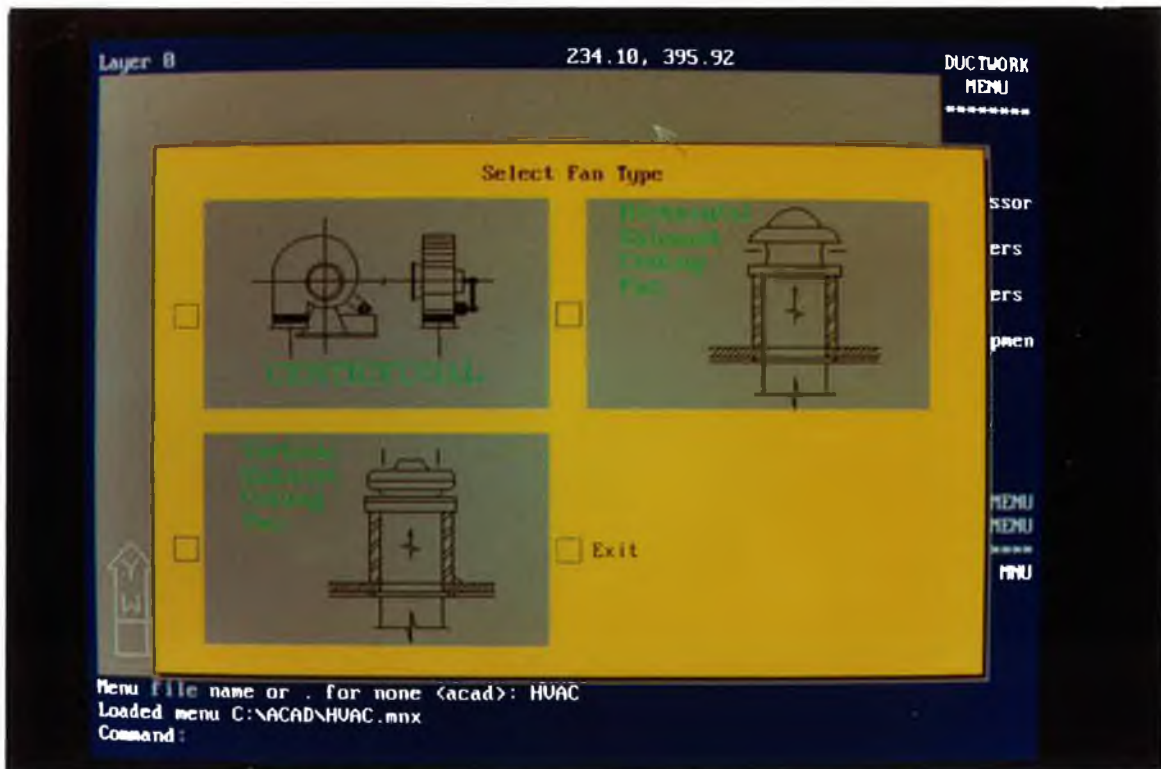


Fig. (4.5) Fans Icon Menu Picture

grilles);. A register is a grille with a damper for volume control. While these are the technically correct definition, common usage refers to supply outlets in walls and floors as grilles or registers, and to ceiling outlets as diffusers.

- iv. Coils icon menu: The coils for cooling and heating can be classified through which the working fluid passes: water coils (hot and cold), direct expansion coils (DX), steam coils and according to the arrangement of rows, tubes, circuits and according to fins type (aluminum, cooper, steel, copper-nickel, or stainless steel) and their arrangements (continuous plate fins, flat, corrugated, or louvred).
 - v. Humidifiers icon menu: According to the type of humidification there are three types of humidifiers (steam humidifiers, spray water humidifier and air washer humidifiers) .
- 3) ***Pipefitting*** for pipe fittings,
- i. Pipe icon menu: This menu contains all types of pipes according to the kind of metal and the insulation according to the pipe place. It can be displayed as shown in Fig.(4.6) with five types of pipes (painted steel pipe, inside insulated steel pipe, outside insulated steel pipe, copper pipe and insulated copper pipe).
 - ii. Accessories icon menu: The major piping materials are produced in the form of standard fittings. Among the more widely used materials are cast-iron, malleable-iron, brass, copper, cast-steel and wrought-steel. Cast-iron fitting might be in three types (threaded, bell-and-spigot, flanged), and cast steel fitting might be flanged and welded, copper might be threaded and welded. Fig.(4.7) shows some types of pipe fittings which are elbows, tees, concentric, eccentric, wyes, caps, crosses, etc.
 - iii. Valves icon menu: The valves can be classified in two types (threaded and flanged, and according to their uses which are gate valve, globe valve, ball valve, butterfly valve, check valve (spring, swing), safety relief valve, solenoid valve, three way valve (motorized, manual). Fig.(4.7) and Fig.(5.8) show some of these valves.
 - iv. Hangers icon menu: Pipe specifications for individual projects must be

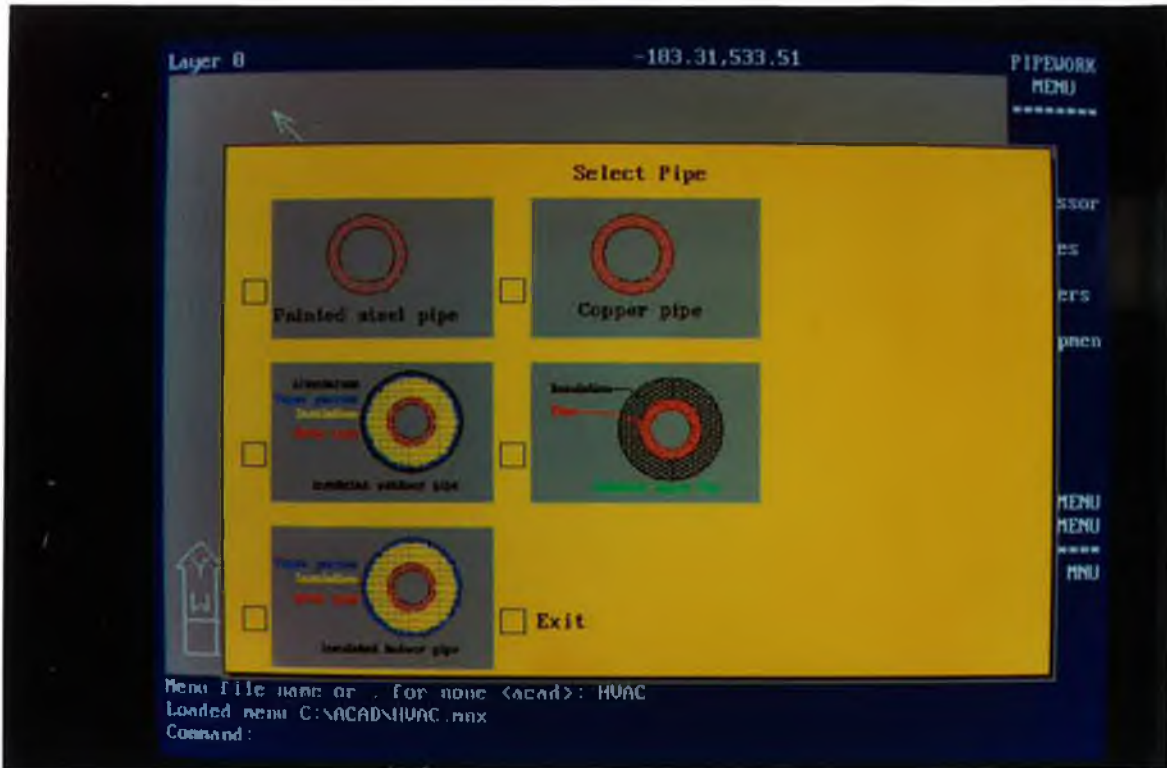


Fig. (4.6) Pipes Icon Menu Picture

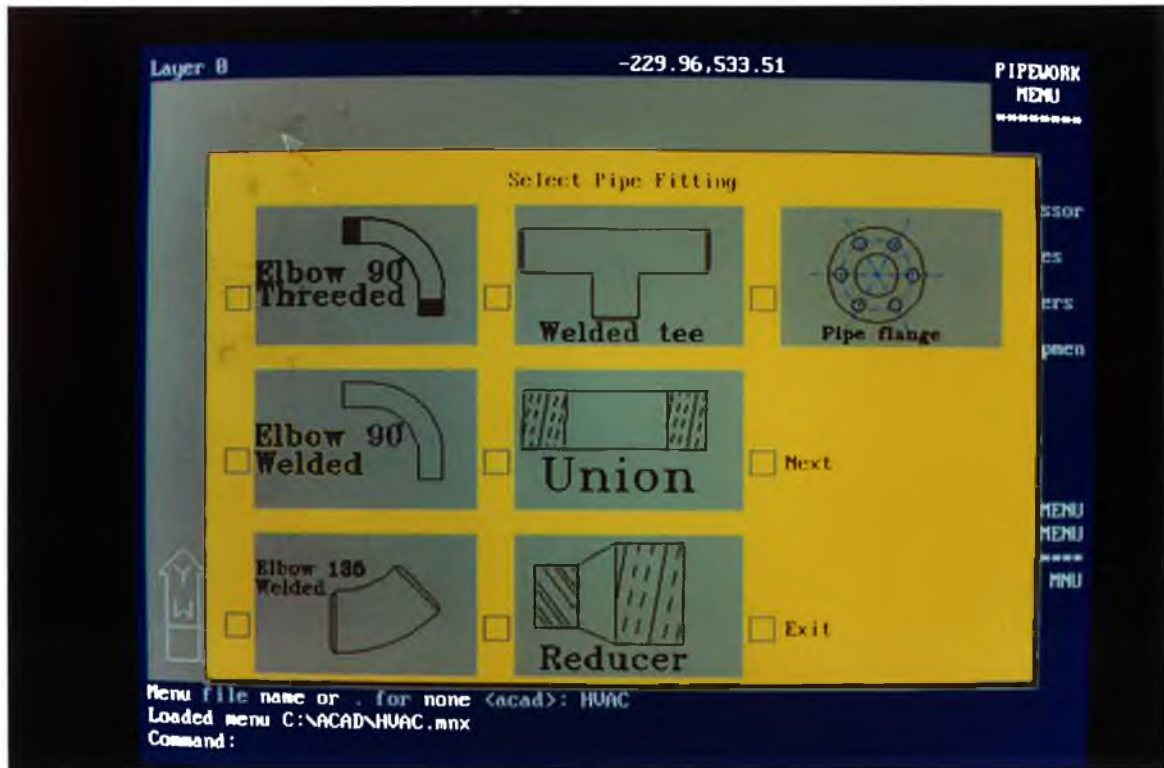


Fig. (4.7) Pipe Fittings Icon Menu Picture

written in such a way as to assure proper support under all operating and environmental conditions and to provide for slope, expansion, anchorage. and insulation protection, then they are mainly classified as supports, anchors, restraints and guides.

4) *PipeEquip* for pipe equipment,

- i. Boilers icon menu: While many types of boilers are manufactured today which differ in size, configuration, materials, and construction methods, the popular types are firetube (usually for hot water), watertube for steam (D-style, A-style), and cast-iron sectional boilers (internal push nipples, external headers). These can also be classified on the type of fuel (gas, oil, solid like Firebox boilers).
- ii. Burners icon menu: according to the boiler type and the capacity, the burners and the type of fuel can be classified as follows:
 - a. Gas burners.
 - b. Oil burners.
 - c. solid fuel burners.
- iii. Pumps icon menu: Pumps can be classified into two basic types; centrifugal (frame-mounted and close-coupled end-suction pumps, double suction centrifugal pumps, vertical multistage pumps, horizontal multistage pumps, submersible pumps, self-priming pumps, axial-flow pumps and regenerative pumps), and positive displacement (reciprocating pumps, power pumps, steam pumps, rotary pumps(sliding-vane, gear). For heating and cooling systems mainly centrifugal pumps are used specially the first one with multi-shapes (inline pump, dual inline pump, base mounted pump, etc.).
- iv. Radiators icon menu: radiators can be classified according to the metal which is made from as follows; cast iron sectional radiators (open front to section, section extended at front), steel radiators (simple convoluted panel (single, double or more), column type like cast-iron radiators, a sinuous coil panel type, tubular type, etc.). Aluminium radiators are the same as cast-iron radiators and may be used as convector, cabinet convectors (flat-top front outlet, slope-top enclosure, flat-top top outlet, etc.).
- v. Unit Heaters icon menu: Unit heaters can be classified as follows:

- By type of air mover: (either propeller or centrifugal blower).
- By physical configuration: (either Vertical or Horizontal air delivery).
 - By heating medium: (Steam, hot water, gas, oil, or electricity).

4.2.2 SCREEN MENU:

This is composed of five commands;

1) *Ductwork command:*

- I. Duct command: For this command the user meet three kind of duct that may be found in duct design:
 - a. Rectangular duct.
 - b. Round duct.
 - c. Flexible duct.

Each of these kinds may have two positions in the drawing therefore there are two commands to cover these: horizontal and vertical. For vertical, there are two types, supply and exhaust. For the supply and exhaust duct there are also two commands to define the direction of flow Up or Down.

- II. Accessories command: For duct accessories like elbows, junctions (tees, wyes, crosses), transitions, etc.
- III. Dampers command;
- IV. Hangers command;
- V. Equipment command: To cover all ductwork equipment like AHU, VHU, diffusers, fans, coils, filters, humidifiers, etc.
- VI. HVACCAD command: To let the user to go back to the main HVACCAD menu. This command will be repeated in each submenu.
- VII. AutoCAD command: To let the user to go back to the main AutoCAD menu. This command is repeated in each submenu.

2) *Pipework command:*

- I. Pipe command: For this command the user meets three positions of pipe that may be found in pipe design:
 - a. Horizontal pipe.

b. Vertical pipe; for this option there are two kinds (flow up and down).

c. General pipe.

II. Accessories command: For pipe accessories like elbows, junctions (tees, wyes, crosses), transitions, etc.

III. valves command:

IV. Hangers command:

VI. Equipment command: To cover all pipework equipment like Boilers, Burners, Pumps, Radiator, Unit heaters, Fan coils, etc.

3) *PsyChart command:*

I. State point command: For this command the user meets 13 commands according to the allowable combinations of the input parameters.

II. Process command: To cover all processes of air conditioning on the psychrometric chart.

III. Window command:

4.3 PIPE SIZE CALCULATION PROGRAM:

This program is an AutoCAD-based piping system design layout and drafting program; it uses the AutoCAD pull-down and ICON menus fully. Drawing initialisation is handled by a start-up macro which automatically controls the placement of the drawing border, "North Arrow", and even sets up boundary limits. Furthermore, the direction of the "North Arrow" has intelligence and its information is used to adjust the User Coordinate System (UCS) accordingly.

PIPEWORK also offers the end user the ability to customise most aspects of the program. The default drawing borders can be replaced with the user's own or with a client's border instead; the user just needs to copy the prototype drawing border as biking up border subroutine and select the user window in the proper directory and it can be used with PIPEWORK.

The program can also be configured to work with either imperial, metric or

mixed metric units. After selecting the drawing size, the software automatically sets up the appropriate distance units.

The best feature of PIPEWORK is its specification-driven interface. All new pipes are assigned to the current pipe specification, such as 150 carbon steel or PN16 Stainless and the current 'spec' can be changed at any time. These specifications are maintained in the same external database common to all the PIPEWORK piping programs, so that there is only one 'spec' being used to create P&IDs, Isometrics and 3D models. This database is completely user definable and supports ANSI, DIN and other common standard components.

PIPEWORK can be used as either a 2D or 3D system and the user can work in any view. However, one may find it easier to work with two simultaneous view ports: top and iso. Pipe centre line is routed in a plan view and insert fittings in one of the four isometric views. The layer facility is used to place each piece of equipment on a separate layer and then grouped pipes by either system to allow better visualisation of a high-density model.

The software employs what appears to be a unique system architecture. All non-graphic attribute information is stored in an external, DATABase files. This seems to reduce the size of the AutoCAD *.DWG file and makes all the material information accessible for reporting, estimating and general material control applications.

Each graphic instant of a valve or fitting is linked, via AutoCAD's handles, to a record in the external DATABase. Some of the dimensional data, such as length or weight, is automatically extracted from the pipe specification. Other information, such as name or mark number, is user assigned at installation. PIPEWORK comes with user customizable forms for each type of component-valves, flanges, fittings, pipe, etc. The database file can also be modified to store the cost or expediting information. This is done so it can become the basis of other configuration management solutions.

Many CAD programs enable the user to lay out piping. However, one of

PIPEWORK's strongest feature is its pipe-editing function. The external database files makes it easy to delete items; no hunting for invisible attribute blocks inserted somewhere in the drawing. Unlike other programs, this one uses the actual pipe line lengths, not attributes, to determine bill of material values. The actual cut length is adjusted by the system to account for threaded or socket-weld engagements and weld gaps. This means the user can use all standard AutoCAD-editing commands, such as STRETCH and MOVE, to adjust piping configurations.

PIPEWORK uses a centre line based routing system and, while they take some getting used to, there are some good tools to perform fitting make-up operations at elbows and tees. A "change length" and "replace pipe" command also assists in making changes to existing pipe runs.

No system is worthwhile unless it can produce standard plan and section drawings PIPEWORK enable the user to create either. Double-line representations of the piping can be created such as is suitable for orthographic drawings

This double-line representation is created on a separate layer called 2-D and a switch enables the user to limit the double line generation to a given pipe size and above. With this, the user can conform to the industry practice of showing small bores in single line. Users have access to all AutoCAD commands for 2D cross-hatching of platforms and detailing of handrails, etc. Standard AutoCAD dimensioning commands are used within the software to present the actual lengths and diameters of pipe runs and equipment. Another important feature of HVACCAD is its ability to make automatic sections. Also, standard details from several parts of the model can be inserted into a separate drawing. This could be useful for exploded views of complex areas.

4.3.1 PIPE SIZING THEORETICAL ANALYSIS:

Before any part of the water piping system can be sized, the probable rate of flow in any particular section of piping should be determined. The rate of flow in the service line, risers, and main branches. The formula which can be applied to get the

flow rate of water is:

$$Q = \dot{m} C_p (t_2 - t_1) \quad (4.3.1)$$

where:

Q = The heating load, [KW].

\dot{m} = Flow rate, [kg/sec]

C_p = Specific heat of the water ($C_p=4.186$ at 20°C), [kJ/kg $^\circ\text{C}$].

t_2 = The supply temperature of heating system, [$^\circ\text{C}$].

t_1 = The return temperature of heating system, [$^\circ\text{C}$].

or by using the flow rate in m^3/hr then the equation becomes:

$$Q = 1.163 \dot{v} (t_2 - t_1) \quad (4.3.2)$$

where:

Q = The heating load, [KW].

\dot{v} = Flow rate, [m^3/hr].

Once the designer has calculated the required flows in cubic meters per second or litres per second for chilled-water, condenser water, process water, and hot water systems or kilograms per hour for steam system and watts per hour for refrigeration, calculation of the size of each piping system can proceed. After calculating the flow rate in m^3/hr using Eq.(4.3.2) according to the velocity range of the water flowing in the pipe, the pipe diameter can be calculated as follows:

$$\dot{v} = \frac{\pi D^2}{4} V \quad (4.3.3)$$

where:

V = Average velocity, [m/s].

D = Pipe diameter, [m].

From the pressure drop caused by fluid friction, in fully developed flows of all "well behaved" (Newtonian) fluids, is described by Darcy-Weisbach equation:

$$\Delta P = f \frac{L}{D} \frac{\rho V^2}{2} \quad (4.3.4)$$

where:

ΔP = Pressure drop, [Pa].

f = Friction factor, dimensionless.

L = Length of pipe, [m].

ρ = Fluid density at mean temperature, [Kg/m³].

This equation is often presented in head or specific energy form as:

$$\Delta h = \frac{\Delta P}{\rho g} = f \frac{L}{D} \frac{V^2}{2g} \quad (4.3.5)$$

where:

Δh = Head loss, [m].

g = Acceleration of gravity, [m/s²].

In this form, the density of the fluid does not appear explicitly (although it is in the Reynolds number, which influences f). The friction factor f is a function of the pipe roughness ϵ , inside diameter D , and a dimensionless parameter, Reynolds number:

$$Re = \frac{D V}{\nu} \quad (4.3.6)$$

where:

ν = Kinematic viscosity of the fluid, [m²/s].

The friction factor is frequently presented on a Moody chart, giving a function of Re with ϵ/D as a parameter. A useful fit of smooth and rough pipe data for the usual turbulent flow regime is the Colebrook equation:

$$\frac{1}{\sqrt{f}} = 1.74 - 2 \log \left[\frac{2 \epsilon}{D} + \frac{18.7}{Re \sqrt{f}} \right] \quad (4.3.7)$$

where:

ϵ = absolute roughness of the pipe wall, [m].

The equation is implicit in f , f appears on both sides, so that a value for f is usually obtained iteratively. A less widely used alternative to Darcy-Weisbach formulation for calculating pressure drop is the Hazen-Williams equation, expressed as:

$$\Delta P = 6.819 L \left(\frac{V}{C} \right)^{1.852} \left(\frac{1}{D^{1.167}} \right) (\rho g) \quad (4.3.8)$$

or

$$\Delta h = 6.819 L \left(\frac{V}{C} \right)^{1.852} \left(\frac{1}{D^{1.167}} \right) \quad (4.3.9)$$

where:

C = Roughness factor.

Recommended values of C are 150 for plastic pipe and copper tubing, 140 for new steel pipe, down to 100 for below and badly corroded or very rough pipe.

Valve and Fitting losses:

Valves and fittings cause pressure losses greater than those caused by the pipe alone. One formulation expresses losses as:

or

$$\Delta P = k \frac{\rho V^2}{2} \quad (4.3.10)$$

$$\Delta h = k \frac{V^2}{2g} \quad (4.3.11)$$

where:

k = Geometry and size dependent loss coefficient, Table (1, 2, 3) in Chapter 33 *1989 ASHRAE Handbook Fundamentals*.

4.3.2 PIPING LAYOUT CONSIDERATION:

In order to commence the routing and design of any piping system, the designer will need the following reference information:

- *The system piping and instrumentation diagram (P&ID):* This drawing is the designer's "road map" which shows all equipment, pumps, valves, instrumentation, and other piping speciality items, in sequence, as required for proper system function.
- *The project piping specification:* This document defines the system design and operating pressures and temperatures; piping materials; piping wall thicknesses or schedules; types of fittings to be used, for example, butt weld, socket weld, or screwed; and the valve and flange pressure rating and insulation requirements. In addition, the piping specification defines the fabrication, examinations, testing, inspection, and insulation requirements, including the requirements for seismic insulations, where applicable.
- *Equipment outlines:* These should include their overall dimensions and pipe size, wall thickness, flange pressure rating, and the locating dimensions of all pipe nozzles and other connections.
- *The project general arrangement or equipment location drawings:* These drawings will indicate the preliminary location of all major pieces of equipment in the plant which the designer will either verify or relocate, as required, to

accommodate the physical pipe routing as designed, or redesign the piping to accommodate a particular piece of equipment.

Piping layout then becomes a matter of designing a completely dimensioned routing from one point to another point with all of the branches, valves, piping specialities, and instrumentation of the process since there are many other factors that must be considered, such as interferences, piping flexibility, material costs, pipe supports, operation and maintenance, and safety and construction requirements.

4.3.3 PIPEWORK PROGRAM EXECUTION STEPS:

The actual pipe layout is done by laying out centre lines of the pipe. Selecting PIPE command from the menu and answering the prompts for flow rate and pipe tag number gets the user started. First, the user digitises a point and then is prompted for the elevation. The process is repeated to specify the endpoint of each segment of pipe. Moving directly in a vertical axis is accomplished with the use of the AutoCAD @ function, which stores the last co-ordinate; the user then enters the next elevation. The PIPE command also provides a calculator feature which enables the user to perform simple arithmetical operations during a command. This could be useful for adjusting pipe centre line elevations for 'Top of Steel' or adding five-pipe diameters to a spool piece.

To insert a fitting or valve, the user simply picks the desired item from the ICON menu and digitises any point on the line. HVACCAD checks the pipe size and specification, and then retrieves the appropriate component. This spec-checking feature reduces errors and is a big improvement over other programs, since the user does not need to know the name and specification of the pipe. Another useful feature of HVACCAD piping program is to add the fittings according to their commands in ICON Menu or in screen menu, for example, elbows, tees, stubbines, outlets and other branch connections.

The equipment menu contains AutoLISP routines to create boilers, burners,

vertical and horizontal vessels, centrifugal pumps, radiators, ...etc. These programs use icon menus to display a form containing the necessary parameters, such as Tangent to tangent length, Diameter, Elevation of centre Line, Tag Number, etc. For pipe routing convenience, the vessel centre lines also return tangent line reference elevations when digitised.

The pump routing prompts the user for suction nozzle height and creates nodes at suction and discharge nozzles for future reference. The routine comes with several DATABASE files with standard pump data sheet information. These can be used to develop user's own manufacturer's component library.

4.4 DUCT SIZE CALCULATION PROGRAM:

A standard menu of components is used on the CAD system and, after the details of the building have been entered into the system as a 3-dimensional model including walls, columns, grid lines, slabs and restricted volumes the ductwork design can begin, following the procedure shown in Fig. (4.2.1).

For the branch design it is necessary to set the specification which controls every component under that branch. The designer tells the system what type of component he requires and then uses the HVACCAD system facilities to select the component and its attributes from the specification and catalogue. The cross-sectional dimensions of the fitting are copied from the previous one.

The straight portions of a branch are generated by the system by use of the "implied duct" facility. For economy in manufacture, transport and erection, it is preferable that the implied duct lengths be multiples of the standard straight duct length. In most cases however, the length of the implied duct consists of a number of standard straights and a non-standard duct. In such cases the designer has the following options:

To re-position one or both fittings.

To re-design the length of one or both fittings

To leave the end part as a non-standard straight.

To make a decision, the designer uses the AutoCAD facility which calculates the number of standard straights and evaluates the remaining length. Once a branch has been designed, the designer uses the grout facility to visually check whether the components have been correctly positioned and whether they clash with any existing branches or structure.

The final drawing has to be fully dimensioned and annotated before being sent to the client for approval. The designer identifies the end points of a dimension and then, automatically, the system draws a line with two end arrows and next to it, the correct dimension. Most information is automatically drawn from the database but it is also possible to input any other data, such as notes and reference drawing numbers.

At approval stage, the drawings are sent to the client for approval. The design, although complete, contains no straight duct items as individual components but as implied duct which is replaced by straights after approval.

Output for the factory includes a drawing, list of blank sizes required, costing, production control data, and of course the individual information for each piece to be cut. There is no optimisation program for nesting components in a sheet.

This program is also written in Autolisp language that is provided with the AutoCAD Software. It is appropriately divided into the following sections:

- Interactively asking the user for the start and points of section of the duct system layout.
- By using the Darcy-Weisbach and Colebrook equations and the ASCII file from the load calculation, the duct work will be sized automatically.
- Friction loss in each section of the duct work will be stored in a data base for the total system calculation later.
- Each section of ductwork will be checked against the user-inputted limiting

velocity and allowable ceiling clearance.

- Dimensions of each section of ductwork will be stored in the DATABASE for material take up purposes.

4.4.1 DUCT SIZING THEORETICAL ANALYSIS:

The problem of sizing a duct reduces to the solution of a basic relationship between \dot{v} , the quantity of air flowing in m^3/s , A , the cross-sectional area of the duct in m^2 and V , the mean velocity of airflow in m/s , given by the simple equation Eq.(4.4.1) which is expressed as:

$$\dot{v} = A V \quad (4.4.1)$$

where:

A = Duct area, [m^2].

V = Average velocity, [m/s].

The duct area may be calculated from:

Round duct:

$$A = \frac{\pi D^2}{4} \quad (4.4.2)$$

where:

D = Duct diameter, [m].

Rectangular duct:

$$A = H W \quad (4.4.3)$$

where:

H = Duct height, [m].

W = Duct width, [m].

Of the three variables in the equation, \dot{v} is known from other considerations (the required ventilation rate or the amount of air needed to offset a calculated sensible

heat gain by Eq(4.4.4)) and the problem degenerates into one of choosing a suitable velocity or an appropriate pressure drop rate.

$$Q_s = 1232 \dot{v} (t_s - t_r) \quad (4.4.4)$$

where:

Q_s = Sensible heat gain of space, [Watt].

\dot{v} = The air flow rate, [m³/s]

t_s = Supply air temperature, [°C].

t_r = Space (Return) air temperature, [°C].

From the Darcy-Weisbach equations for round and rectangular duct which are expressed as following:

Round:

$$\Delta P = \left(\frac{fL}{D} + \Sigma C \right) \frac{V^2 \rho}{2g} \quad (4.4.5)$$

where:

C = Local loss coefficient, dimensionless. Fitting loss coefficients are listed according to their types and dimensions in chapter 32 (Page 32.21-32.46) *1989 ASHRAE Handbook Fundamentals* [7].

L = Duct length, [m].

Rectangular:

$$\Delta P = \left(\frac{fL}{D_h} + \Sigma C \right) \frac{V^2 \rho}{2g} \quad (4.4.6)$$

where the equivalent friction diameter D_h (Hydraulic diameter) is:

$$D_h = 2 \frac{HW}{H+W} \quad (4.4.7)$$

Substituting \dot{v}/A into Darcy-Weisbach equations (Eq.(4.4.5), (4.4.6)) for the velocity V to obtain the pressure drop of a single duct section in terms of diameter D and the equivalent velocity diameter D_v , for the round and rectangular ducts respectively, thus:

Round duct:

$$\Delta P = 0.881 \frac{\mu \rho \dot{v}^2 D^{-5}}{g} \quad (4.4.8)$$

Rectangular duct:

$$\Delta P = 0.881 \frac{\mu \rho \dot{v}^2 D_v^{-5}}{g} \quad (4.4.9)$$

where μ is defined as:

Round Duct:

$$\mu = fL + \Sigma C D \quad (4.4.10)$$

Rectangular Duct:

$$\mu = \left(\frac{fL}{D_h} + \Sigma C \right) D_v \quad (4.4.11)$$

and the equivalent velocity diameter of a rectangular duct is calculated by Eq.(4.4.8) as following;

$$D_v = \sqrt{\frac{4HW}{\pi}} \quad (4.4.12)$$

Since D and D_v are the same value for round and equivalent rectangular ducts,

flow can be defined in term of diameter and pressure loss by coefficient μ . thus,

$$\dot{v} = 1.1107 \left(\frac{g}{\mu \rho} \right)^{0.5} D^{2.5} \Delta P^{0.5} \quad (4.4.13)$$

For calculation the friction factor f , the type of air flow in the duct must be known which can be determined by Reynolds number which is calculated by:

$$Re = \frac{D_h V}{\nu} \quad (4.4.14)$$

where:

D_h = Hydraulic diameter, [m].

ν = Kinematic viscosity (for the standard air $\nu = 15.8 \times 10^{-6}$), [m²/s].

Within the region of laminar flow (Reynolds number less than 2000), the friction factor is a function of Reynolds number only. For turbulent flow, the friction factor depends on Reynolds number, duct surface roughness and internal hydraulic diameter. The traditional Moody chart depicts the behaviour for round passages. For hydraulically smooth ducts, the friction factor again depends only on Reynolds number, but the dependence is markedly different from the laminar flow. In general, for non smooth surfaces, the friction factor depends on roughness, Reynolds number and hydraulic diameter. However, for a particular level of roughness beyond a sufficiently large Reynolds number, the friction factor becomes independent of Reynolds number, and the flow condition is considered as fully rough. Between the bounding limits of hydraulically smooth behaviour and fully rough behaviour, is a transitional roughness zone where the friction factor depends on both roughness and Reynolds number. In this transitionally rough, turbulent zone, where most cases of air flow occur in air conditioning applications, the friction factor f is calculated By Colebrook's equation. Since this equation can not be solved explicitly for f , iterative techniques have to be

used:

$$\frac{1}{\sqrt{f}} = -2 \log \left[\frac{\epsilon}{3.7 D_h} + \frac{2.51}{Re \sqrt{f}} \right] \quad (4.4.11)$$

4.4.2 DUCTWORK PROGRAM EXECUTION STEPS:

Here is how the program would work. The program would initially load the architectural plan on the PC screen, by asking the user to enter the architect's floor plan file name, it would prompt the user to input the friction loss factor per 100 ft (30 m) of duct, the limiting velocity, the roughness of the sheet metal used, and the allowable ceiling clearance dimension.

The program would then prompt the user for the start point of a duct system layout as soon as this is entered the output file from the load calculation would be read, and the overflow rate (\dot{v}), would be used to calculate the duct size. It would prompt the user to enter an end point to this section of the ductwork and duct work would be drawn to the screen accordingly. Fittings such as elbows, transitions, dampers, and turning vanes would be added automatically, based on selecting the type of fitting from the duct fitting icon menu or dampers icon menu, the section would be added to them, previous duct size, the directions of the next point as the next point, and the flow rate.

The initial inputs, such as the limiting velocity and ceiling clearance would act as check figures to round off the duct size and to limit the duct height or diameter to fit in the ceiling void. This interaction would be carried out until the user enters quit. All the necessary data for friction loss calculation and material would be saved in a data base while the quality interact was being carried out and the user can edit the output using HVACSYS by calling it within HVACCAD interface by clicking the HVACSYS command and then from this package can edit the results.

4.5 PSYCHROMETRIC CHART PROGRAM:

The theoretical analysis explained the work on psychrometric charts in the last chapter in detail from defining a point to all air conditioning processes. The purpose of designing this program is to make the work of the user easier to perform so that the user can use special commands designed to cover all his work on a displayed psychrometric chart which should be called as a DXF file. Considering the AutoCAD coordinates X-Y and transfer them to psychrometric chart coordinates where X axis become as the dry bulb temperature t_{db} and Y axis as humidity ratio W axis, that have been done by multiplying all temperature by 10 and all W values by 283.45.

4.5.1 PSYCHART PROGRAMME EXECUTION STEPS:

After the user selects the Psychart command from HVACCAD screen menu, or by typing Psychart on the **COMMAND:** prompt, automatically the Psychart lisp program will be loaded, and a prompt will ask the user the DXF file name which was designed by HVACSYS Package. Then the user has to enter the DXF file name and press **Enter** key. A full screen psychrometric chart will appear as shown in Fig.(4.10), and also psychart screen menu will appear, then the user can work on the psychrometric chart as he would work on the manual chart by selecting whatever he wants from three commands **Point**, **Process** or **Window**. **Window** command is only for zooming with defining a new board which has the values of parameters (t_{db} , W).

If the user selects the **Point** command, 13 commands (TDB&RH, TDB&TWB, TDB&TDP, TDB&W, TDB&H, RH&TWB, RH&TDP, RH&W, RH&H, TWB&TDP, TWB&W, TDP&H, W&H) will appear in the screen menu to define the state point. The user has the mouse option to select the type of defining the state point. And, he has also the **COMMAND** option to enter the two parameters to define the state point.

When the user selects **Process** command (by clicking on the screen menu by the mouse or typing it after **COMMAND:** prompt), a processes menu will appear on the screen. The user has the option to select the type of process (General, Heating, Cooling, Humidification, Zone, Mixing, and Collecting). Once the process is selected, the prompt will ask the user to input the allowable combinations to define this process.

may be read directly into a components data record.

The HVACCAD program also offers in addition to graphics drawings, for the complete system, a bill of materials for each component with details and the whole system costs are printed out.

CHAPTER FIVE

CASE STUDY AND VALIDATIONS

5.1 INTRODUCTION:

Although the calculation techniques of HVAC loads based on the physical laws of energy and substance conservation is universally true, the computer codes derived by applying this approach will not always be correct. In other words, certain differences between the computed results and the reality can possibly exist. The reason for this is that in every stage of calculations, it is impossible to define in detail and accurately every energy and mass exchange, some less important facts are usually ignored and assumptions are made in the design procedure. Therefore, validations of the packages are important and necessary. From the validations, differences between the results of the developed package and other commercial packages can be discovered and the allowed difference caused by simplifications can then be confirmed.

Traditionally, the validation is proceeded by comparing the predictions from the hand calculation method to the corresponding monitored results. Higher accuracy and reliability can be expected from such validation provided. In this study, a comparison between the developed package and other commercial package (Hevacomp) is presented. The following sections will give the selective results from the developed package for an building example previously designed by Seamus Homan Associates of Dublin.

5.2 CASE STUDY:

The example was an application of air conditioning system for a building built

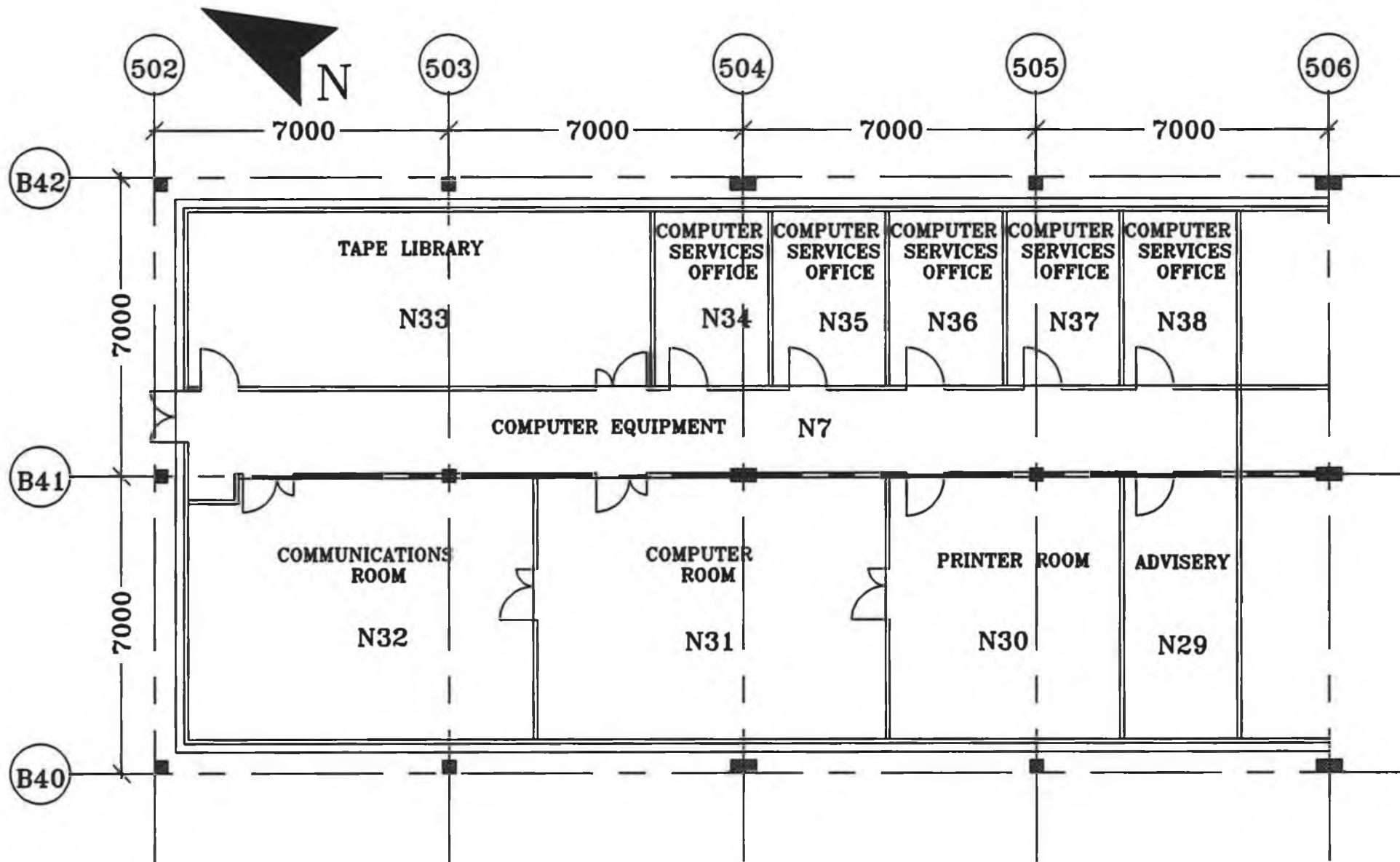


Fig.(5.1) A case study for heating and cooling loads programmes

in Galway. This exercise was organised by Seamus Homan associates. Fig.(5.1) shows a plan of that building. The HVAC loads of the building has been computed by the developed package, where the heating system was applied for rooms numbers N29, N33 to N38, and the air conditioning system applied for rooms N30, N31 and N32. Detailed information for this exercise are given as follows:

5.2.1 GENERAL PROJECT DATA INPUT:

The user has to input the general information of the project using the Setup menus (User place and Client place) as follow:

a) *User Place Menu:*

City	Dublin	Country	Ireland
Latitude line	52	Altitude above see level	85 m
Outside summer condition:			
Temperature	24 °C	Relative Humidity	45 %
Outside winter condition:			
Temperature	-2 °C	Relative Humidity	90 %
Outside Avarage Temperature 21 °C			

b) Client Place Menu:

Designer	K.A. Alwhban	Address	School of Mech. & Manu. Eng.
City	Dublin 9	Country	Rep. of IRELAND
Client	UCG	Address	UCG
City	Galway	Country	Rep. of IRELAND
Project Name	UCG	Total Area	331.5 m²
Number of Buildings	1	Heating Safety Factor	10 %
Building Opening Hour	8	Sensible Safety Factor	10 %
Building Closing Hour	18	Latent Safety Factor	10 %

The following table shows the room dimensions and its application(heating or air-conditioning):

No.	Description	length [m]	Width [m]	Height [m]	System
N29	Advisory	2.8	6.3	2.7	Heating
N30	Printer room	5.6	6.3	2.7	Air Conditioning
N31	Computer room	8.4	6.3	2.7	Air Conditioning
N32	Communications room	8.4	6.3	2.7	Air Conditioning
N33	Tape library	11.2	4.2	2.7	Heating
N34-N38	Computer services offices	2.8	4.2	2.7	Heating
N7	Computer Equipment corridor	25.5	2	2.7	Heating

5.2.2 CALCULATION OF U-VALUES:

To calculate the U-values for the building constructions, the user has to select U-value command from the Program menu. In this case study there are six types of surfaces listed as follows:

Surface 1 (S1):

- layer of glass reinforced plastic
- 25 mm of insulation board - polysterene

Surface 2 (S2):

- 100 mm brick outer leaf.
- 95 mm air cavity.
- 30 mm insulation board-polystyrene
- 100 mm concrete block
- 13 mm plaster - 20AT

Surface 3 (S3):

- 2 mm steel panel
- 25 mm polystyrene insulation board
- 2 mm steel panel

Surface 4 (S4):

- 100 mm block internal partition

Surface 5 (S5):

- 10 mm steel
- 25 mm spray on insulation thick

Surface 6 (S6):

- double glazing in steel frame type unknown.

Surface 7 (S7):

- Solid ground floors for each room.

The results obtained from the developed package are listed as follows:

Surface 1 (S1):

External Wall
Outside Thermal Resistance .05 [m²°C/W]
Inside Thermal Resistance .123 [m²°C/W]

No.	Description	Type	Thick.	Conduct	Dens.	SHeat	VResis.
1	PVC rigid sheet	S	3	0.160	1350	1250	1000.00
2	Polystyrene board	S	25	0.030	25	1000	1000.00
The Calculated U-Value for this construction is 0.976 [W/m ² °C]							

Surface 2 (S2):

External Wall
 Outside Thermal Resistance .05 [m²°C/W]
 Inside Thermal Resistance .123 [m²°C/W]
 Air Gab Thermal Resistance .18 [m²°C/W]

No.	Description	Type	Thick.	Conduct	Dens.	SHeat	VResis.
1	Plaster (lightwt)	S	13	0.160	600	1000	60.00
2	Concrete block (lightwt)	S	100	0.190	600	1000	30.00
3	Polystyrene board	S	30	0.030	25	1000	1000.00
4	Cavity wall ventld air space	A	50	0.000	0	0	0.00
5	Brickwork (external)	S	100	0.840	1700	800	50.00
The Calculated U-Value for this construction is 0.481 [W/m ² °C]							

Surface 3 (S3):

External Wall
 Outside Thermal Resistance .05 [m²°C/W]
 Inside Thermal Resistance .123 [m²°C/W]

No.	Description	Type	Thick.	Conduct	Dens.	SHeat	VResis.
1	Steel	S	3	50.000	7800	500	50000.00
2	Polystyrene board	S	25	0.030	25	1000	1000.00
3	Steel	S	3	50.000	7800	500	50000.00
The Calculated U-Value for this construction is 0.994 [W/m ² °C]							

Surface 4 (S4):

Internal Wall
 Inside Thermal Resistance .123 [m²°C/W]

No.	Description	Type	Thick.	Conduct	Dens.	SHeat	VResis.
1	Concrete block (lightwt)	S	100	0.190	600	1000	30.00
The Calculated U-Value for this construction is 1.295 [W/m ² °C]							

Surface 5 (S5):

External Wall

Outside Thermal Resistance .05 [m²°C/W]
Inside Thermal Resistance .123 [m²°C/W]

No.	Description	Type	Thick.	Conduct	Dens.	SHeat	VResis.
1	Polyurethane foam	S	25	0.026	30	1000	60.00
2	Steel	S	10	50.000	7800	500	50000.00
The Calculated U-Value for this construction is				0.882	[W/m ² °C]		

In the package used by Homan Associates the U-value of the floor is considered to be valid for the whole building (they treat the whole building as one room), and they take this value as an average value for all rooms. Their results are as follows;

a. Solid ground floor (four exposed edges):

Solid Ground Floor
Four Exposed Edges

The Calculated U-Value for this construction is 0.487 [W/m²°C]

b. Solid ground floor (Two Perpendicular exposed edges):

Solid Ground Floor
Two Perpendicular Exposed Edges

The Calculated U-Value for this construction is 0.276 [W/m²°C]

Then they calculated the average value of the two components as:

$$U = \frac{0.487 + 0.276}{2} = 0.382$$

In fact the U-value of each room differs from this average value, and this will not give a correct load for the floor. The U-value must be calculated for the floor of each room separately. The following results show the U-value of the floor of each room:

1) Room N29, N34 to N38: Solid ground floor with one exposed edge;

Solid Ground Floor
One Exposed Edge

The Calculated U-Value for this construction is 0.558 [W/m²°C]

2) Room N30: Solid ground floor with one exposed edge;

Solid Ground Floor
One Exposed Edge

The Calculated U-Value for this construction is 0.33 [W/m²°C]

3) Room N31: Solid ground floor with one exposed edge;

Solid Ground Floor
One Exposed Edge

The Calculated U-Value for this construction is 0.264 [W/m²°C]

4) Room N32 Solid ground floor with two perpendicular exposed edges;

Solid Ground Floor
Two Perpendicular Exposed Edges

The Calculated U-Value for this construction is 0.498 [W/m²°C]

5) Room N33 Solid ground floor with two perpendicular exposed edges;

Solid Ground Floor
Two Perpendicular Exposed Edges

The Calculated U-Value for this construction is 0.758 [W/m²°C]

6) Room N7: Solid ground floor with one exposed edge;

Solid Ground Floor
One Exposed Edge

The Calculated U-Value for this construction is 0.264 [W/m²°C]

After the U-values were calculated for the building, a Table of all U-values is generated and can be called as a help input data, which is displayed as:

Structure Description	Average Weight [Kg/m ²]	U-Value [Watt/m ² °C]
Surface 1: External Wall	5	0.976
Surface 2: External Wall	239	0.481
Surface 3: External Wall	47	0.994
Surface 4: Internal Wall	60	1.295
Surface 5: External Wall	79	0.882
Floor: rooms N29, N34 to N38	-	0.558
Floor: room N30	-	0.330
Floor: room N31	-	0.264
Floor: room N32	-	0.498
Floor: room N33	-	0.758
Floor: room N7	-	0.264

Comparing with the values computed by the company, it has been found that there is close agreement between the two results and very little difference between the result of this program and their result from the primary consideration of the R_{so} and R_{si} .

5.2.3 HEATING LOAD PROGRAM RESULTS:

Heating load of each room was computed and the values of the heating load items were given, as shown below:

D) Building Information:

When the user wants to print the results for Heating loads a header and a summary of building information is printed as shown below followed by the heating

load output for each room:

H V A C S Y S Designer		
School of Mechanical and Manufacturing Engineering, Dublin City University		
Developed by KASSEM ALWAHBAN, SSRC, P.O.Box 4470, Damascus, Syria		
Project: UCG	Design: K. ALWAHBAN	Date: 12-21-1992

North Latitude L = 52 °
Altitude above sea level h = 85 m
Outside Dry-Bulb Temperature Tdo = -2 °C
Outside air humidity ratio RHo = 90 %

II) Room N29:

The input:

Building No. 1 Storey No. 1 Space No. 1								
Dimension LxWxH	2.8x6.3x2.7		Description	N29 : Advisory				
Dry Bulb Temperature tdb	21.0 °C		Relative Humidity	50 %				
Roof Information								
Roof	Area (m ²)	0.00	U-Value (W/m ² °C)	0.000		Suspended (Y/N)	N	
SkyLight Area	0.00	SkyLight U-Value	0.000		Temp. Diff	0.0		
Walls Information								
Wall No.	1	2	3	4	5	6	7	8
Wl Orientations	SW	SW	NE					
Wl Area (m ²)	4.09	1.74	7.56	0.00	0.00	0.00	0.00	0.00
Wl U-Value	0.481	0.973	1.295	0.0	0.0	0.0	0.000	0.000
Wl (1-Ex,2-In,3-Bs)	1	1	2	0	0	0	0	0
Gl Area	3.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gl U-Value	3.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wind & Orien. Factor	10	10	0	0	0	0	0	0
Partition Temp. Diff	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
Floor Information								
Area (m ²)	17.64	U-Value(W/m ² °C)	0.558		Temp. Diff	23.0		
Type (1-Inter,2-Solid Grnd.,3-Bs) 2								
Infiltration (1-Air Changes,2-Crack) 1 Air Changes No.1.5 Crack Lngth 0.0								
Ventilation (1-Air Chngs,2-CFM/Person) 0 Air Chngs No.0.0 CFM/Person 0.0								

The result:

Room N29 : Advisory
 Inside Dry-Bulb Temperature Tdi = 21 °C
 Inside air humidity ratio RH_i = 50 %

Construction	Type	Area	U-Value	δt	q	Wind Factor	Q
Wall No. 1 , SW	External	4.1	0.4810	23.0	45.4	10	49.89
Glass No. 1 , SW	External	3.5	3.2000	23.0	255.4	10	280.93
Wall No. 2 , SW	External	1.7	0.9730	23.0	38.9	10	42.83
Wall No. 3 , NE	Internal	7.6	1.2950	3.0	29.4	0	29.37
Ground Floor	Solid	17.6	0.5580	23.0	226.4	0	226.39
Sensible heat loss through infiltration QSInfil =							565.80
Latent heat loss through infiltration OSInfil =							295.02
Sum of heat losses from the room QTotal =							1490.24
-Total sensible heat loss for the room is QStotal =							1195 Watt
-Total latent heat Loss for the room is QLtotal =							295 Watt
-Total heat loss for the room is QTotal =							1490 Watt

III) Room N30:

The input:

Building No. 1		Storey No. 1		Space No. 2				
Dimension LxWxH 5.6x6.3x2.7		Description N30 : Printer Room						
Dry Bulb Temperature tdb 21.0 °C		Relative Humidity 50 %						
Roof Information								
Roof	Area (m ²)	0.00	U-Value (W/m ² °C)	0.000	Suspended (Y/N) N			
SkyLight Area	0.00	SkyLight U-Value	0.000	Temp. Diff	0.0			
Walls Information								
Wall No.	1	2	3	4	5	6	7	8
Wl Orientations	SW	SW	NE					
Wl Area (m ²)	8.18	3.47	15.12	0.00	0.00	0.00	0.00	0.00
Wl U-Value	0.481	0.973	1.295	0.0	0.0	0.0	0.000	0.000
Wl (1-Ex,2-In,3-Bs)	1	1	2	0	0	0	0	0
Gl Area	6.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gl U-Value	3.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wind & Orien. Factor	10	10	0	0	0	0	0	0
Partition Temp. Diff	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
Floor Information								
Area (m ²)	35.28	U-Value(W/m ² °C)	0.330	Temp. Diff	23.0			
Type (1-Inter,2-Solid Grnd.,3-Bs) 2								
Infiltration (1-Air Changes,2-Crack) 1 Air Changes No.1.5 Crack Lngth 0.0								
Ventilation (1-Air Chngs,2-CFM/Person) 0 Air Chngs No.0.0 CFM/Person 0.0								

The result:

Room N30 : Printer Room
 Inside Dry-Bulb Temperature Tdi = 21 °C
 Inside air humidity ratio RH_i = 50 %

Construction	Type	Area	U-Value	δt	q	Wind Factor	Q
Wall No. 1 , SW	External	8.2	0.4810	23.0	90.5	10	99.54
Glass No. 1 , SW	External	6.9	3.2000	23.0	510.8	10	561.86
Wall No. 2 , SW	External	3.5	0.9730	23.0	77.7	10	85.42
Wall No. 3 , NE	Internal	15.1	1.2950	3.0	58.7	0	58.74
Ground Floor	Solid	35.3	0.3300	23.0	267.8	0	267.78
Sensible heat loss through infiltration QSInfil =							1119.81
Latent heat loss through infiltration OSInfil =							583.90
Sum of heat losses from the room QTotal =							2777.05
-Total sensible heat loss for the room is QStotal =							2193 Watt
-Total latent heat Loss for the room is QLtotal =							584 Watt
-Total heat loss for the room is QTotal =							2777 Watt

IV) Room N31:

The input:

Building No. 1 Storey No. 1 Space No. 3									
Dimension LxWxH 8.4x6.3x2.7			Description N31 : Computer Room						
Dry Bulb Temperature tdb 21.0 °C			Relative Humidity 50 %						
Roof Information									
Roof	Area (m ²)	0.00	U-Value (W/m ² °C)			0.000	Suspended (Y/N)		N
SkyLight Area	0.00	SkyLight U-Value			0.000	Temp. Diff			0.0
Walls Information									
Wall No.	1	2	3	4	5	6	7	8	
Wl Orientations	SW	SW	NE						
Wl Area (m ²)	12.26	5.21	22.68	0.00	0.00	0.00	0.00	0.00	
Wl U-Value	0.481	0.973	1.295	0.0	0.0	0.0	0.000	0.000	
Wl (1-Ex,2-In,3-Bs)	1	1	2	0	0	0	0	0	
Gl Area	10.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Gl U-Value	3.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Wind & Orient. Factor	10	10	0	0	0	0	0	0	
Partition Temp. Diff	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	
Floor Information									
Area (m ²)	52.92	U-Value(W/m ² °C)			0.264	Temp. Diff		23.0	
Type (1-Inter,2-Solid Grnd.,3-Bs) 2									
Infiltration (1-Air Changes,2-Crack) 1			Air Changes No.			1.5	Crack Lngth		0.0
Ventilation (1-Air Chngs,2-CFM/Person) 0			Air Chngs No.			0.0	CFM/Person		0.0

The result:

Room N31 : Computer Room
 Inside Dry-Bulb Temperature Tdi = 21 °C
 Inside air humidity ratio RH_i = 50 %

Construction	Type	Area	U-Value	δt	q	Wind Factor	Q
Wall No. 1 , SW	External	12.3	0.4810	23.0	135.6	10	149.20
Glass No. 1 , SW	External	10.4	3.2000	23.0	766.9	10	843.60
Wall No. 2 , SW	External	5.2	0.9730	23.0	116.6	10	128.25
Wall No. 3 , NE	Internal	22.7	1.2950	3.0	88.1	0	88.11
Ground Floor	Solid	52.9	0.2640	23.0	321.3	0	321.33
Sensible heat loss through infiltration QSInfil =							1685.61
Latent heat loss through infiltration QSInfil =							878.92
Sum of heat losses from the room QTotal =							4095.03
-Total sensible heat loss for the room is					QStotal =	3216	Watt
-Total latent heat Loss for the room is					QLtotal =	879	Watt
-Total heat loss for the room is					QTotal =	4095	Watt

V) Room N32:

The input:

Building No. 1 Storey No. 1 Space No. 4										
Dimension LxWxH	8.4x6.3x2.7		Description N32 : Communications Room							
Dry Bulb Temperature tdb	21.0 °C		Relative Humidity 50 %							
Roof Information										
Roof Area (m ²)	0.00		U-Value (W/m ² °C)			0.000			Suspended (Y/N)	N
SkyLight Area	0.00		SkyLight U-Value			0.000			Temp. Diff	0.0
Walls Information										
Wall No.	1	2	3	4	5	6	7	8		
Wl Orientations	SW	SW	NW	NW	NE					
Wl Area (m ²)	12.26	5.21	8.18	3.35	24.30	0.00	0.00	0.00		
Wl U-Value	0.481	0.973	0.481	0.973	1.295	0.000	0.000	0.000		
Wl (1-Ex,2-In,3-Bs)	1	1	1	1	2	0	0	0		
Gl Area	10.42	0.00	6.94	0.00	0.00	0.00	0.00	0.00		
Gl U-Value	3.200	0.000	3.200	0.000	0.000	0.000	0.000	0.000		
Wind & Orient. Factor	10	10	20	20	0	0	0	0		
Partition Temp. Diff	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0		
Floor Information										
Area (m ²)	52.92		U-Value(W/m ² °C)			0.498			Temp. Diff	23.0
Type (1-Inter,2-Solid Grnd.,3-Bs)									2	
Infiltration (1-Air Changes,2-Crack)									1	
Air Changes No.									1.5	
Crack Lngth									0.0	
Ventilation (1-Air Chngs,2-CFM/Person)									0	
Air Chngs No.									0.0	
CFM/Person									0.0	

The result:

Room N32 : Communications Room
 Inside Dry-Bulb Temperature Tdi = 21 °C
 Inside air humidity ratio RH_i = 50 %

Construction	Type	Area	U-Value	δt	q	Wind Factor	Q	
Wall No. 1 , SW	External	12.3	0.4810	23.0	135.6	10	149.20	
Glass No. 1 , SW	External	10.4	3.2000	23.0	766.9	10	843.60	
Wall No. 2 , SW	External	5.2	0.9730	23.0	116.6	10	128.25	
Wall No. 3 , NW	External	8.2	0.4810	23.0	90.5	20	108.59	
Glass No. 3 , NW	External	6.9	3.2000	23.0	510.8	20	612.94	
Wall No. 4 , NW	External	3.3	0.9730	23.0	75.0	20	89.96	
Wall No. 5 , NE	Internal	24.3	1.2950	3.0	94.4	0	94.41	
Ground Floor	Solid	52.9	0.4980	23.0	606.1	0	606.15	
Sensible heat loss through infiltration							QSInfil =	1685.61
Latent heat loss through infiltration							QSInfil =	878.92
Sum of heat losses from the room							QTotal =	5197.63
-Total sensible heat loss for the room is							QStotal =	4319 Watt
-Total latent heat Loss for the room is							QLtotal =	879 Watt
-Total heat loss for the room is							QTotal =	5198 Watt

VI) Room N33:

The input:

Building No. 1 Storey No. 1 Space No. 5								
Dimension LxWxH	11.2x4.2x2.7	Description	N33 : Tapes Library					
Dry Bulb Temperature tdb	21.0 °C	Relative Humidity	50 %					
Roof Information								
Roof Area (m ²)	0.00	U-Value (W/m ² °C)	0.000		Suspended (Y/N)	N		
SkyLight Area	0.00	SkyLight U-Value	0.000		Temp. Diff	0.0		
Walls Information								
Wall No.	1	2	3	4	5	6	7	8
Wl Orientations	NW	NW	NE	NE	SW			
Wl Area (m ²)	6.13	2.60	16.35	6.94	30.24	0.00	0.00	0.00
Wl U-Value	0.481	0.973	0.481	0.973	1.295	0.000	0.000	0.000
Wl (1-Ex,2-In,3-Bs)	1	1	1	1	2	0	0	0
Gl Area	5.21	0.00	13.89	0.00	0.00	0.00	0.00	0.00
Gl U-Value	3.200	0.000	3.200	0.000	0.000	0.000	0.000	0.000
Wind & Orient. Factor	20	20	20	20	0	0	0	0
Partition Temp. Diff	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0
Floor Information								
Area (m ²)	47.04	U-Value(W/m ² °C)	0.758		Temp. Diff	23.0		
Type (1-Inter,2-Solid Grnd.,3-Bs) 2								
Infiltration (1-Air Changes,2-Crack) 1 Air Changes No.1.5 Crack Lngth 0.0								
Ventilation (1-Air Chngs,2-CFM/Person) 0 Air Chngs No.0.0 CFM/Person 0.0								

The result:

Room N33 : Tapes Library
 Inside Dry-Bulb Temperature Tdi = 21 °C
 Inside air humidity ratio RH_i = 50 %

Construction	Type	Area	U-Value	δt	q	Wind Factor	Q	
Wall No. 1 , NW	External	6.1	0.4810	23.0	67.8	20	81.38	
Glass No. 1 , NW	External	5.2	3.2000	23.0	383.5	20	460.15	
Wall No. 2 , NW	External	2.6	0.9730	23.0	58.2	20	69.82	
Wall No. 3 , NE	External	16.4	0.4810	23.0	180.9	20	217.06	
Glass No. 3 , NE	External	13.9	3.2000	23.0	1022.3	20	1226.76	
Wall No. 4 , NE	External	6.9	0.9730	23.0	155.3	20	186.37	
Wall No. 5 , SW	Internal	30.2	1.2950	3.0	117.5	0	117.48	
Ground Floor	Solid	47.0	0.7580	23.0	820.1	0	820.10	
Sensible heat loss through infiltration							QSInfil =	1497.01
Latent heat loss through infiltration							OSInfil =	780.58
Sum of heat losses from the room							QTotal =	5456.71
-Total sensible heat loss for the room is							QStotal =	4676 Watt
-Total latent heat Loss for the room is							QLtotal =	781 Watt
=====								
-Total heat loss for the room is							QTotal =	5457 Watt

VII) Room N34-N38:

The input:

Building No. 1		Storey No. 1		Space No. 6				
Dimension LxWxH 2.8x4.2x2.7		Description N34-N38 : Services Offices						
Dry Bulb Temperature tdb 21.0 °C		Relative Humidity 50 %						
Roof Information								
Roof	Area (m ²) 0.00	U-Value (W/m ² °C) 0.000	Suspended (Y/N) N					
SkyLight Area	0.00	SkyLight U-Value 0.000	Temp. Diff 0.0					
Walls Information								
Wall No.	1	2	3	4	5	6	7	8
Wl Orientations	NE	NE	SW					
Wl Area (m ²)	5.18	0.64	7.56	0.00	0.00	0.00	0.00	0.00
Wl U-Value	0.481	0.973	1.295	0.000	0.000	0.000	0.000	0.000
Wl (1-Ex,2-In,3-Bs)	1	1	2	0	0	0	0	0
Gl Area	1.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gl U-Value	3.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wind & Orien. Factor	20	20	0	0	0	0	0	0
Partition Temp. Diff	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
Floor Information								
Area (m ²)	11.76	U-Value(W/m ² °C)	0.558	Temp. Diff	23.0			
Type (1-Inter,2-Solid Grnd.,3-Bs) 2								
Infiltration (1-Air Changes,2-Crack) 1 Air Changes No. 1.5 Crack Lngth 0.0								
Ventilation (1-Air Chngs,2-CFM/Person) 0 Air Chngs No. 0.0 CFM/Person 0.0								

The result:

Room N34-N38 : Services Offices
 Inside Dry-Bulb Temperature Tdi = 21 °C
 Inside air humidity ratio RH_i = 50 %

Construction	Type	Area	U-Value	δt	q	Wind Factor	Q
Wall No. 1 , NE	External	5.2	0.4810	23.0	57.5	20	69.03
Glass No. 1 , NE	External	1.7	3.2000	23.0	128.1	20	153.68
Wall No. 2 , NE	External	0.6	0.9730	23.0	14.3	20	17.19
Wall No. 3 , SW	Internal	7.6	1.2950	3.0	29.4	0	29.37
Ground Floor	Solid	11.8	0.5880	23.0	159.0	0	159.04
Sensible heat loss through infiltration QSInfil =							377.20
Latent heat loss through infiltration QSInfil =							196.68
Sum of heat losses from the room QTotal =							1002.19
-Total sensible heat loss for the room is QStotal =							806 Watt
-Total latent heat Loss for the room is QLtotal =							197 Watt

-Total heat loss for the room is QTotal =							1002 Watt

VIII) Room N7:

The input:

Building No. 1		Storey No. 1		Space No. 7						
Dimension LxWxH 25.5x2.0x2.7		Description N7 : Computer Equipment								
Dry Bulb Temperature tdb 21.0 °C		Relative Humidity 50 %								
Roof Information										
Roof Area (m ²)	0.00	U-Value (W/m ² °C)	0.000			Suspended (Y/N) N				
SkyLight Area	0.00	SkyLight U-Value	0.000			Temp. Diff 0.0				
Walls Information										
Wall No.	1	2	3	4	5	6	7	8		
Wl Orientations	NW	NW								
Wl Area (m ²)	1.89	1.74	0.00	0.00	0.00	0.00	0.00	0.00		
Wl U-Value	0.481	0.973	0.000	0.000	0.000	0.0	0.000	0.000		
Wl (1-Ex,2-In,3-Bs)	1	1	0	0	0	0	0	0		
Gl Area	5.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Gl U-Value	3.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
Wind & Orien. Factor	10	10	0	0	0	0	0	0		
Partition Temp. Diff	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
Floor Information										
Area (m ²)	51.00	U-Value(W/m ² °C)	0.264			Temp. Diff	23.0			
						Type (1-Inter,2-Solid Grnd.,3-Bs)	2			
Infiltration (1-Air Changes,2-Crack)						1	Air Changes No.	1.5	Crack Lngth	0.0

The result:

Room N7 : Computer Equipment
 Inside Dry-Bulb Temperature Tdi = 18 °C
 Inside air humidity ratio RH_i = 50 %

Construction	Type	Area	U-Value	δt	q	Wind Factor	Q	
Wall No. 1 , NW	External	1.9	0.4810	20.0	18.2	20	21.82	
Glass No. 1 , NW	External	5.7	3.2000	20.0	362.9	20	435.46	
Wall No. 2 , NW	External	1.7	0.9730	20.0	33.9	20	40.63	
Ground Floor	Solid	51.0	0.2640	23.0	309.7	0	309.67	
Sensible heat loss through infiltration							QSInfil =	1414.50
Latent heat loss through infiltration							OSInfil =	616.04
Sum of heat losses from the room							QTotal =	2838.12
-Total sensible heat loss for the room is					QStotal =	2222	Watt	
-Total latent heat Loss for the room is					QLtotal =	616	Watt	
=====								
-Total heat loss for the room is					QTotal =	2838	Watt	

5.2.4 COOLING LOAD PROGRAM RESULTS:

The cooling load for rooms N30, N31 and N32 was computed according to ASHRAE method (CLTD/CLF method). The information for each room is entered via the Entry-input-data-menu. The results automatically appears on the screen and the user has a choice to save the result and/or to print them. The input data and the results for each room were printed as follows:

I) Building Information:

H V A C S Y S Designer		
School of Mechanical and Manufacturing Engineering, Dublin City University		
Developed by KASSEM ALWAHBAN, SSRC, P.O.Box 4470, Damascus, Syria		
Project: UCG	Design: K. ALWAHBAN	Date: 12-21-1992

North Latitude L = 52 °
Altitude above sea level h = 85 m
Outside Dry-Bulb Temperature Tdo = 24 °C
Outside air humidity ratio RHo = 45 %

II) Room N30:

The input:

Building No. 1		Storey No. 1		Space No. 1				
Dimension LxWxH	5.6x6.3x2.7	Description	N30 : Printer Room					
Dry Bulb Temperature tdb	21 °C	Relative Humidity	50 %					
Roof	Area (m ²) 0.00	U-Value (W/m ² °C)	0.000		Suspended (Y/N)	Y		
Information	Type (1-13) 0	SkyLight Area	0.00		SkyLight U-Value	0.000		
Attic Duct&Fan Coef.	0.0	Color Coef.	0.0		Exposed (Y/N)	N		
Temp. Diff	0.0							
Walls Information	1	2	3	4	5	6		
Wl Orientations	SW	SW	NE					
Wl Area (m ²)	8.18	3.47	15.12	0.00	0.00	0.00		
Wl U-Value	0.481	0.973	1.295	0.000	0.000	0.000		
Wl (1-Ex,2-In,3-Bs)	1	1	2	0	0	0		
Gl Area	6.94	0.00	0.00	0.00	0.00	0.00		
Gl U-Value	3.200	0.000	0.000	0.000	0.000	0.000		
GlInShading (1-4), SC	1 1.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0		
GRP(A,B,C,D,E,F,G)	B	G						
Partition Temp. Diff	0.0	0.0	3.0	0.0	0.0	0.0		
Floor	Area (m ²)	35.28				U-Value(W/m ² °C)	0.330	
Information	Type (1-Inter,2-Solid Grnd.,3-Bs)	2				Temp. Diff	3.0	
Number of People	2	Degree of Activity (1-14)	4				Lights (W/m ²)	25.0
Total Power(W)	9324	Efficiency	1.00		Load Factor	1.00		
Use Factor	1.00							
Total Appliances	0	Efficiency	0.00		Load Factor	0.00		
Use Factor	0.00							
Infiltration (1-Air Changes,2-Crack)	1	Air Changes No.	0.5				Crack Lngth	0.0
Ventilation (1-Air Chngs,2-CFM/Person)	0	Air Chngs No.	0.0				CFM/Person	0.0

The result:

Room N30: Printer Room
 Inside Dry-Bulb Temperature Tdi = 21 °C
 Inside air humidity ratio RH_i = 50 %

Cns.	Area	Uvl	Qs8	Qs9	Qs10	Qs11	Qs12	Qs13	Qs14	Qs15	Qs16	Qs17	Qs18	Qs19	Qs20
W1SW	8	0.5	20	16	16	12	12	8	8	12	16	20	24	32	36
GSSW	7	3.2	656	749	796	890	1171	1592	2061	2435	2622	2622	2295	1733	1405
GCSW	7	3.2	-155	-132	-110	-65	-43	2	2	25	25	2	2	-20	-65
W1SW	4	1.0	-6	-3	4	14	31	55	58	96	103	99	82	51	28
Sum of SHG			515	630	706	851	1171	1657	2129	2568	2766	2743	2403	1796	1404

The maximum cooling solar load for the room is Q_{Smax} = 2766 Watt
 The design month is AUG
 The design hour is 16
 The heat gain from partitions Q_{part} = 59 Watt
 Sensible heat gain from people Q_{ps} = 130 Watt
 Latent heat gain from people Q_{pl} = 60 Watt
 Heat gain from lights Q_{el} = 880 Watt
 Heat gain from equipments Q_{pow} = 9324 Watt

Sensible heat gain from infiltration Q_{Sinf} = 146 Watt
 Latent heat gain from infiltration Q_{Linf} = 75 Watt

-Total sensible heat gain for the room is	Q _{Stotal} = 13305 Watt
-Total latent heat gain for the room is	Q _{Ltotal} = 135 Watt
=====	
-Total heat gain for the room is	Q _{Total} = 13440 Watt

III) Room N31:

The input:

Building No. 1		Storey No. 1		Space No. 2				
Dimension LxWxH 8.4x6.3x2.7		Description N31 : Computer Room						
Dry Bulb Temperature tdb 21 °C		Relative Humidity 50 %						
Roof	Area (m ²) 0.00	U-Value (W/m ² °C) 0.000	Suspended (Y/N) Y					
Information	Type (1-13) 0	SkyLight Area 0.00	SkyLight U-Value 0.000					
Attic Duct&Fan Coef. 0.0	Color Coef. 0.0	Exposed (Y/N) N		Temp. Diff 0.0				
Walls Information	1	2	3	4	5	6	7	8
Wl Orientations	SW	SW	NE					
Wl Area (m ²)	12.26	5.21	22.68	0.00	0.00	0.00	0.00	0.00
Wl U-Value	0.481	0.973	1.295	0.000	0.000	0.000	0.000	0.000
Wl (1-Ex,2-In,3-Bs)	1	1	2	0	0	0	0	0
Gl Area	10.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gl U-Value	3.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GlInShading (1-4), SC	1 1.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0	0 0.0
GRP(A,B,C,D,E,F,G)	B	G						
Partition Temp. Diff	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0
Floor	Area (m ²) 52.92	U-Value(W/m ² °C) 0.264						
Information	Type (1-Inter,2-Solid Grnd.,3-Bs) 2	Temp. Diff 3.0						
Number of People 3	Degree of Activity (1-14) 4	Lights (W/m ²) 25.0						
Total Power(W) 36684	Efficiency 1.00	Load Factor 1.00	Use Factor 1.00					
Total Appliances 0	Efficiency 0.00	Load Factor 0.00	Use Factor 0.00					
Infiltration (1-Air Changes,2-Crack) 1	Air Changes No.0.5	Crack Lngth 0.0						
Ventilation (1-Air Chngs,2-CFM/Person) 0	Air Chngs No.0.0	CFM/Person 0.0						

The result:

Room N31 : Computer Room
 Inside Dry-Bulb Temperature Tdi = 21 °C
 Inside air humidity ratio RH_i = 50 %

Cns.	Area	Uvl	Qs8	Qs9	Qs10	Qs11	Qs12	Qs13	Qs14	Qs15	Qs16	Qs17	Qs18	Qs19	Qs20
WlSW	12	0.5	30	24	24	18	18	12	12	18	24	30	36	48	54
GSSW	10	3.2	974	1113	1183	1322	1739	2366	3061	3618	3896	3896	3409	2574	2087
GCSW	10	3.2	-230	-196	-163	-97	-63	3	3	37	37	3	3	-30	-97
WlSW	5	1.0	-10	-5	6	21	46	81	87	142	152	147	122	76	41
Sum of SHG			764	936	1050	1264	1740	2462	3163	3815	4109	4076	3570	2668	2085

The maximum cooling solar load for the room is $Q_{Smax} = 4109$ Watt
 The design month is AUG
 The design hour is 16

The heat gain from partitions $Q_{part} = 88$ Watt
 Sensible heat gain from people $Q_{ps} = 195$ Watt
 Latent heat gain from people $Q_{pl} = 90$ Watt
 Heat gain from lights $Q_{el} = 1323$ Watt
 Heat gain from equipments $Q_{pow} = 36684$ Watt
 Sensible heat gain from infiltration $Q_{Sinf} = 73$ Watt
 Latent heat gain from infiltration $Q_{Linf} = 38$ Watt

-Total sensible heat gain for the room is $Q_{Stotal} = 42472$ Watt
 -Total latent heat gain for the room is $Q_{Ltotal} = 128$ Watt
 =====
 -Total heat gain for the room is $Q_{Total} = 42600$ Watt

IV) Room N32:

The input:

Building No. 1 Storey No. 1 Space No. 3								
Dimension LxWxH	8.4x6.3x2.7		Description N32 : Communications Room					
Dry Bulb Temperature tdb	21 °C		Relative Humidity 50 %					
Roof	Area (m ²)	0.00	U-Value (W/m ² °C)	0.000		Suspended (Y/N) Y		
Information	Type (1-13)	0	SkyLight Area	0.00		SkyLight U-Value 0.000		
Attic Duct&Fan Coef.	0.0		Color Coef.	0.0		Exposed (Y/N) N Temp. Diff 0.0		
Walls Information	1		2		3		4	
Wl Orientations	SW	SW	SW	SW	NE			
Wl Area (m ²)	12.26	5.21	8.18	3.35	24.30	0.00	0.00	0.00
Wl U-Value	0.481	0.973	0.481	0.973	1.295	0.000	0.000	0.000
Wl (1-Ex,2-In,3-Bs)	1	1	1	1	2	0	0	0
Gl Area	10.42	0.00	6.94	0.00	0.00	0.00	0.00	0.00
Gl U-Value	3.200	0.000	3.200	0.000	0.000	0.000	0.000	0.000
GlInShading (1-4), SC	1	1	1	1	0	0	0	0
GRP(A,B,C,D,E,F,G)	B	G	B	G				
Partition Temp. Diff	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0
Floor	Area (m ²)	52.92			U-Value(W/m ² °C) 0.498			
Information	Type (1-Inter,2-Solid Grnd.,3-Bs)	2			Temp. Diff 3.0			
Number of People	3	Degree of Activity (1-14) 4			Lights (W/m ²) 25.0			
Total Power(W)	28667	Efficiency 1.00			Load Factor 1.00 Use Factor 1.00			
Total Appliances	0	Efficiency 0.00			Load Factor 0.00 Use Factor 0.00			
Infiltration (1-Air Changes,2-Crack)	1	Air Changes No. 0.5			Crack Lngth 0.0			
Ventilation (1-Air Chngs,2-CFM/Person)	0	Air Chngs No. 0.0			CFM/Person 0.0			

The result:

Room N32 : Communications Room
 Inside Dry-Bulb Temperature Tdi = 21 °C
 Inside air humidity ratio RH_i = 50 %

Cns.	Area	Uvl	Qs8	Qs9	Qs10	Qs11	Qs12	Qs13	Qs14	Qs15	Qs16	Qs17	Qs18	Qs19	Qs20
WlSW	12	0.5	30	24	24	18	18	12	12	18	24	30	36	48	54
GSSW	10	3.2	895	1023	1087	1215	1599	2175	2814	3326	3582	3582	3134	2367	1919
GCSW	10	3.2	-230	-196	-163	-97	-63	3	3	37	37	3	3	-30	-97
WlSW	5	1.0	-10	-5	6	21	46	81	87	142	152	147	122	76	41
WlNW	8	0.5	8	4	0	0	0	-4	-4	0	0	4	4	8	16
GSNW	7	3.2	437	504	538	605	605	638	739	1008	1378	1680	1714	1210	974
GCNW	7	3.2	-155	-132	-110	-65	-43	2	2	25	25	2	2	-20	-65
WlNW	3	1.0	-13	-10	-3	4	10	17	27	43	63	80	80	53	23
Sum of SHG			962	1212	1379	1701	2172	2924	3680	4599	5261	5528	5095	3712	2865

The maximum cooling solar load for the room is Q_{Smax} = 5528 Watt
 The design month is JUL
 The design hour is 17
 The heat gain from partitions Q_{part} = 94 Watt
 Sensible heat gain from people Q_{ps} = 195 Watt
 Latent heat gain from people Q_{pl} = 90 Watt
 Heat gain from lights Q_{el} = 1323 Watt
 Heat gain from equipments Q_{pow} = 28667 Watt
 Sensible heat gain from infiltration Q_{Sinf} = 73 Watt
 Latent heat gain from infiltration Q_{Linf} = 38 Watt

-Total sensible heat gain for the room is	Q _{Stotal} = 35880 Watt
-Total latent heat gain for the room is	Q _{Ltotal} = 128 Watt
=====	
-Total heat gain for the room is	Q _{Total} = 36008 Watt

5.2.5 PSYCHROMETRIC CHART PROGRAMME RESULTS:

In order to define all the processes and the state points of the air conditioning unit on the psychrometric chart, the type of system must be selected. For this case the air handling unit (AHU) with VAV system is suitable. It is assumed that for winter 75% and for summer 50% of the return air can be used to mix with fresh air so that the difference between the supply air temperature t_s and the room temperature t_r is 8 °C. A simple AHU consists of a mixing box, filter, preheating coil, cooling coil, water spray humidifier, post heating coil and fan (similar as in Fig.(3.19)) and is selected to maintain this zone. The flow rate for each room can be calculated from Eq.(4.4.4) and also there is a factor called sensible heat ratio (SHR) for each room which can be

calculated from the following equation:

$$SHR = \frac{Q_s}{Q_s + Q_L}$$

1. Summer time:

Cooling loads, flow rates and SHRs are computed in following table:

No.	m [m ₃ /s]	SHR	Q _s [Watt]	Q _L [watt]	Q _T [Watt]
N30	1.35	0.989	13305	154	13454
N31	4.31	0.995	42472	231	42703
N32	3.64	0.993	35880	231	36111
Sum	9.10	0.993	91657	616	92273

Also knowing the outside and inside conditions:

OSA: tdb=24 °C, Φ=45 %

REA: tdb=21 °C, Φ=50 %

SS: tdb=21-8=13 °C

The result:

Processes Report

No.	Process Type	Pt1	Pt2	Flow Rate (m ³ /s)	Sens. Load (Watt)	Lat. Load (Watt)	Water Added (Kg/hr)	Total Load (Watt)
1	Mixing	OSA	MSM	9.100	0.0	0.0	0.000	0.0
2	Zone	REA	SSS	1.350	13305.0	154.8	0.223	13459.8
3	Cooling	MSM	CCC	9.100	-117717.6	-8994.1	-13.970	-126711.7
4	Heating	CCC	SSS	9.100	11211.2	0.0	0.000	11211.2

State Points Report

No.	Pt.	TDB, °C	RH, %	TWB, °C	TDP, °C	W, Kgw/Kga	H, Kj/Kg	V, m ³ /Kg	Pw, KPa	Pws, KPa
1	OSA	24.00	45	15.92	11.39	0.0084331	45.4565	0.86030	1.3441	2.9869
2	REA	21.00	50	14.26	10.23	0.0078009	40.8057	0.85076	1.2446	2.4892
3	SSS	13.00	83	11.04	10.16	0.0077628	32.5974	0.82757	1.2386	1.4988
4	MSM	22.50	47	15.11	10.82	0.0081170	43.1303	0.85552	1.2944	2.7281
5	CCC	12.00	88	10.61	10.16	0.0077628	31.5830	0.82468	1.2386	1.4035

Fig.(5.3) shows a representative of all processes in the summer on the psychrometric chart was drawn as DXF file report which can be drawn using AutoCAD.

2. Winter time:

The flow rate and SHR factor for each room can be calculated as the same in the summer time:

No.	m [m ₃ /s]	SHR	Q _s [Watt]	Q _L [watt]	Q _T [Watt]
N30	0.223	0.79	2193	584	2777
N31	0.326	0.785	3216	879	4095
N32	0.438	0.831	4319	879	5198
Sum	0.987	0.805	9728	2342	12070

Also knowing the outside and inside conditions:

OWA: tdb=-2 °C, Φ=90 %

REA: tdb=21 °C, Φ=50 %

SW: tdb=21+8=29 °C

The result:

Processes Report

No.	Process Type	Pt1	Pt2	Flow Rate (m ³ /s)	Sens. Load (Watt)	Lat. Load (Watt)	Water Added (Kg/hr)	Total Load (Watt)
1	Mixing	OWA	MWM	0.987	00000.0	0.0	0.000	00000.0
2	Zone	REA	SWS	0.438	4319.0	878.4	1.264	5197.4
3	Heating	MWM	HC1	0.987	9423.9	0.0	0.000	9423.9
4	Spray Humid.	HC1	HHH	0.987	-2650.8	1663.0	2.393	-987.8
5	Heating	HHH	HC2	0.987	11168.4	0.0	0.000	11168.4
6	Cooling	HC2	SWS	0.987	-1215.9	0.0	0.000	-1215.9

State Points Report

No.	Pt.	TDB, °C	RH, %	TWB, °C	TDP, °C	W, Kgw/Kga	H, Kj/Kg	V, m ³ /Kg	Pw, KPa	Pws, KPa
1	OWA	-2.00	90	-2.49	-3.24	0.0029001	5.2428	0.77813	0.4663	0.5181
2	REA	21.00	50	14.26	10.23	0.0078009	40.8057	0.85076	1.2446	2.4892
3	MWM	15.25	61	10.76	7.73	0.0065757	31.8769	0.83250	1.0512	1.7342
4	SWS	29.00	28	16.56	8.92	0.0071351	47.2223	0.87298	1.1396	4.0115
5	HC1	23.00	37	13.88	7.73	0.0065757	39.7188	0.85487	1.0512	2.8121
6	HHH	20.82	46	13.88	8.92	0.0071351	38.9283	0.84932	1.1396	2.4611
7	HC2	30.00	27	16.90	8.92	0.0071351	48.2313	0.87586	1.1396	4.2485

Fig.(5.4) shows a representative of all processes in the winter. usind AutoCAD.

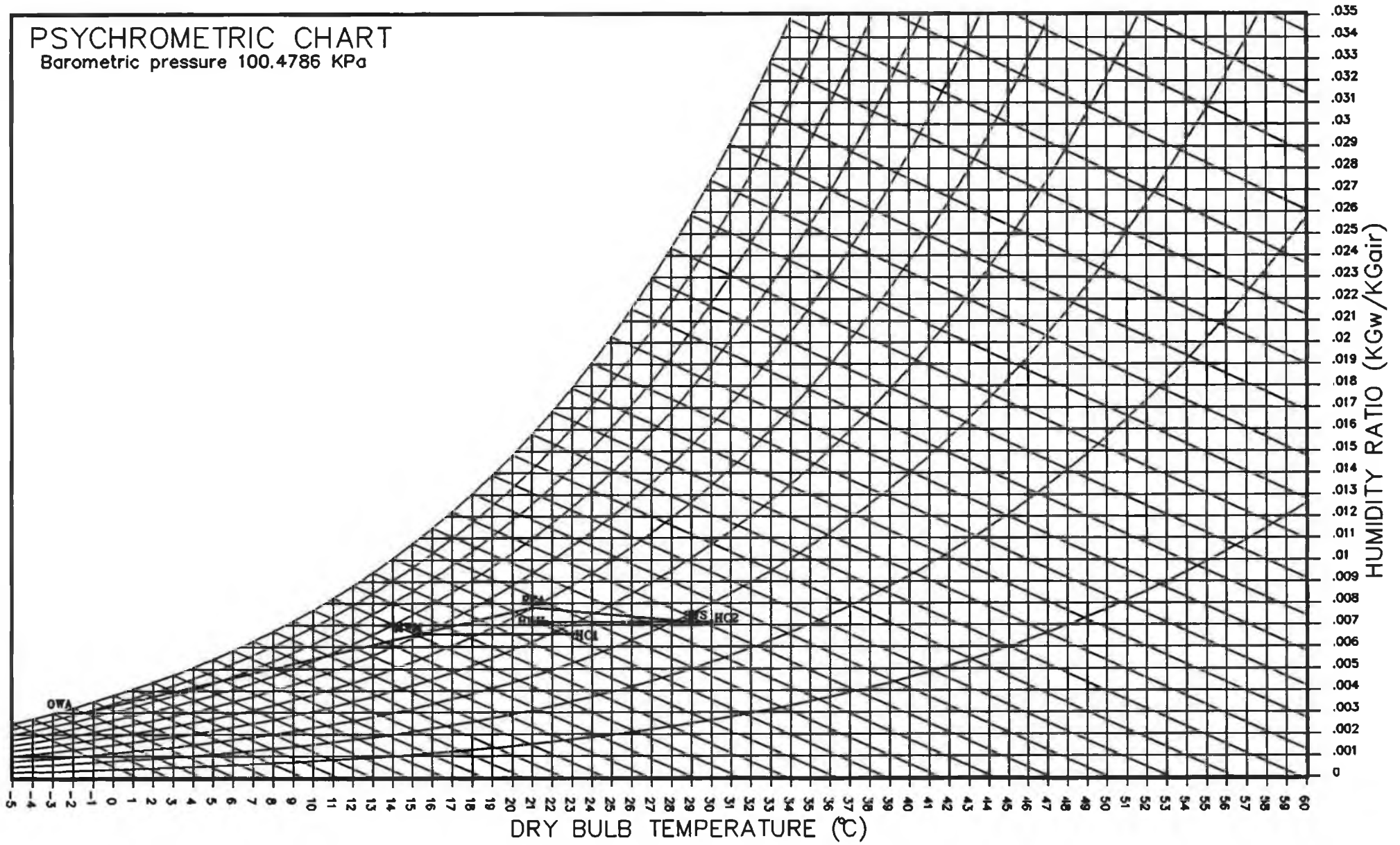


Fig.(5.3) Representation of the processes and the state points in winter time of the system designed.

5.3 DISCUSSION:

I) Heating load:

The following Table shows the values of Heating loads resulting by HVACSYS package and Hevacomp Ltd. program:

No.	Total Sensible Load [Watt]		Total Latent Load [watt]		Total Heating load [Watt]	
	HVACSYS	Hevacomp	HVACSYS	Hevacomp	HVACSYS	Hevacomp
N29	1195	1080	295	-	1490	-
N30	2193	2160	584	-	2777	-
N31	3216	3240	879	-	4095	-
N32	4319	3933	879	-	5198	-
N33	4676	3894	781	-	5457	-
N34-N38	806	701	197	-	1003	-
N7	2222	2222	616	-	2838	-
Sum	21851	20034	5019	-	26870	-

Comparison between the values shows a significant difference between them. This difference comes from many factors considered during the heating load calculation;

- I) Wind factors have been added to the exposed walls in the HVACSYS Package.
- II) The heat loss from the floor for each room was not correct in the compared heating Loads because the other package considered the U-Value for all rooms as the same but the reality was not like that as shown the U-Value program results.
- III) Heat loss from infiltration was not calculated in the compared example, this is correct for the room which need only heating because the radiators only remove sensible load. But for air conditioning it should not be neglected.

II) Cooling load:

The following Table shows the values of cooling loads resulting from the

HVACSYS package and Hevacomp Ltd. program:

No.	Total Sensible Load [Watt]		Total Latent Load [watt]		Total Cooling load [Watt]	
	HVACSYS	Hevacomp	HVACSYS	Hevacomp	HVACSYS	Hevacomp
N30	13305	11274	135	298	13440	11572
N31	42472	39600	128	447	42600	40047
N32	35880	31969	128	447	36004	32416
Sum	91657	82843	391	1192	92044	84035

Again Comparison between the values shows a significant difference between them. This is because:

- I) In HVACSYS, ASHRAE method was used to calculate the cooling load, while in Hevacomp. program, they used CIBSE Guide method.
- II) For the sensible heat gains, the heat gain from the equipment was taken from them as casual load, which includes all heat gains from internal sources. But in HVACSYS these are considered separately (People, Light, Equipment).
- III) For the latent load, they considered the heat gain which comes through the admittance of the room constructions, but in HVACSYS this was not considered.

III) Psychrometric chart:

For all the points and processes on the CIBSE psychrometric chart (Sea level), results of the state point parameters and process loads were approximately in agreement, and the minor differences is because in HVACSYS the psychrometric chart was designed for the client place altitude of 85 m above the sea level.

CHAPTER SIX

CONCLUSIONS AND FURTHER WORKS

6.1 CONCLUSIONS:

The goal of this thesis was to develop a generalised package for the HVAC system design. A research was carried out in order to build a microcomputer code to calculate the HVAC loads, systems (Piping, Ducting or Individual), and produce reports of HVAC loads, system drawings plans and bill of materials. The research was directed towards developing and integrating two packages, the first package HVACSYS is developed to calculate the estimated energy consumption for the building which is mainly based on the calculation the heating, ventilation, cooling loads, some of the auxiliary program (psychrometric chart, U-value, DATABASE, ... etc.), pipe sizing and duct sizing for the commercial and scientific buildings. The second is the HVACCAD which is developed by customizing the AutoCAD package to make it suitable for HVAC system design, also this program contains many sub-programs for each components at HVAC field to draw them. This package consists mainly of Piping, Ducting and Psychart programs.

None of the HVAC softwares developed previously comes as a complete package for HVAC system design or to cover the whole HVAC systems design from calculating the HVAC loads then calculating the systems (piping or ducting) then drawing the final design and printing out the loads and the bill of materials. The integrated system developed here combines HVACSYS and HVACCAD, which allows the user to design the whole HVAC system only by running the AutoCAD then running the HVACSYS from the AutoCAD or HVACCAD.

As explained in chapter five when compared with an example calculated by using Hevacomp programs, the package gives very accurate results. The accuracy is greater for some of the programs, specially the cooling program which can calculate

the load for the whole year and select the peak load for the monthly design and hourly design. In addition to that the user can obtain tabulated reports of the HVAC loads and bill of materials, and HVAC drawing plans.

A general review of existing techniques in the field of buildings and plants system design has been given based on historical experiences. As a conclusion to this project, the developed packages can cope well with the goal arisen in this thesis. The fundamental theory behind the design has been taken from different sources (ASHRAE, CIBSE, Russian, etc.) for the system design. For example, the infiltration rate can be calculated from two methods crack and air change methods; the crack method has been chosen from CIBSE Guide and the air change method was selected according to ASHRAE method. Also for the wind and direction factors which was used for the calculation the heating loads, have been selected according to the Russian standard.

Generally speaking, as a complete system design, this technique may be used in application beyond those mentioned in this thesis, such as control and modelling of HVAC components or for simulating the HVAC system networks.

6.2 FURTHER WORKS

The recent efforts to develop the next generation of the HVAC packages should be based on the concept of this research to produce the whole work as a single package adding some programs for modelling the HVAC components and for simulating each component in the whole system. Further application can be found in that the two packages can be used in any building design office without the presence of any HVAC engineer, or may be used by any user who is a HVAC specialist. In addition to this research the developers can design a complete software based on the expert knowledge of engineers for the layout of HVAC networks according to their applications.

Also further research in this work can be devoted towards incorporating the new versions of the AutoCAD (Release 11 and 12). This will allow the software (the two

packages HVACSYS and HVACCAD) to be transferred to C language which is now used in the AutoCAD instead of AutoLisp which is very difficult to handle.

REFERENCES

- [1] **P.W. Brothers**, "*Knowledge Engineering for HVAC Expert Systems*", ASHRAE Trans., V.94, Part 1, (PP.1063-1073), 1988.

- [2] **G. Hamilton and A. Harrison**, "*Expert Systems for the Construction and Building Services Industry*", Building Services Research and Information Association, Technical note TN 7/86, 1986.

- [3] **M. Katajamaki**, "*Knowledge-Based CAD*", Expert Systems With Applications, V.3, (pp.277-287), 1991.

- [4] **M.V. Horn**, "*Understanding Expert Systems*", Toronto, Bantam Books, 1986.

- [5] **P.J. Camejo and D.C. Hittle**, "*An Expert System for the Design of Heating Ventilating, and Air Conditioning Systems*", ASHRAE Trans., V.94 ,Part 2, 1988.

- [6] **S. Lam**, "*CAE for HVAC System Design: Is It Possible?*", Heating Piping Air Conditioning Journal, April 1989.

- [7] **ASHRAE Handbook, Fundamentals**, ASHRAE Inc., Atlanta, GA, 1989.

- [8] **CIBSE Guide, Section C1**, 1985.

- [9] **W.P. Jones**, "*Air Conditioning Engineering*", Edward Arnold, London, 1985.

- [10] **W.P. Jones**, "*Air Conditioning Applications and Design*", Edward Arnold, London, 1980.

- [11] **P.L. Martin and D.R. Oughton**, "*Faber and Kell's Heating and Air-*

Conditioning of buildings", Butterworths, Kent, 1989.

- [12] **T. Kusuda**, "*The Computer Programme for Heating and Cooling Loads in buildings*", Building Science series, No 69-R, National Bureau Standard, 1978.
- [13] **N.R. Grimm and R.C. Rosaler**, "*Handbook of HVAC design*", McGrawHill, New York, NY 10020, 1990 .
- [14] **Elite Software Development Inc.**, *HVAC TOOLS PROGRAM USERS MANUAL*, (Collection of HVAC Utilities), VERSION 1.03, 1991.
- [15] **Elite Software Development Inc.**, *QHVIC PROGRAM USERS MANUAL (Quick Commercial HVAC Loads)*, VERSION 3.50, 1990.
- [16] **Elite Software Development Inc.**, *PSYCHART PROGRAM USERS MANUAL*, VERSION 1.2, 1990.
- [17] **HevaStar Building Services Package**, Software by Hevacomp Ltd, Version 7, 1990.
- [18] **M.A.P. Murray**, *Component Based Performance Simulation of HVAC Systems*, PhD. Thesis, Loughborough University of Technology, 1984.
- [19] **NESC**, *National Energy Software Centre*, NESC Abstract No. 782 - DOE2, U.S.A., 1981.
- [20] **ASHRAE Handbook**, *Equipment*, ASHRAE Inc., Atlanta, GA, 1988.
- [21] **ASHRAE Handbook**, *HVAC Systems and Applications*, ASHRAE Inc., Atlanta, GA, 1987.
- [22] **ASHRAE Handbook**, *Refrigeration Systems and Applications*, ASHRAE Inc.,

Atlanta, GA, 1986.

- [23] **ASHRAE STANDARD, ASHRAE & IES 90.1-1989**, ASHRAE Inc., 1989.
- [24] **M. Sharabati**, "*Heating And Air Conditioning Engineering*", Damascus University, Damascus, 1983 (In Arabic).
- [25] **G.P. Mitalas and D.G. Stephenson**, "*Room Thermal Response Factors*", ASHRAE Trans., V.73, Part I, 1967.
- [26] **G.P. Mitalas and D.G. Stephenson**, "*Cooling Load Calculation by Thermal Response Factor Method*", ASHRAE Trans., V.73, Part I, 1967.
- [27] **G.P. Mitalas and D.G. Stephenson**, "*Calculation of Heat Transfer Function for Multi-Layer Slabs*", ASHRAE Trans., V.77, 1971.
- [28] **T.Kusuda**, "*Algorithmic for Psychrometric Calculations (Skeleton Tables for the Thermodynamic Properties of Moist Air)*", Building Science Series 21, 1970.
- [29] **ASHRAE**, "*ASHRAE Brochure on Psychrometric*", ASHRAE, Inc., 1977.
- [30] **V.Bahel & H.Bakhsh**, "*Psychrometric With A Microcomputer*", The Heating and Ventilation Engineer, V.60 No. 683, 1987.
- [31] **O.Badr, P.W.O'Callaghan & S.D.Probert**, "*Air-Conditioning Processes*", Applied Energy, V.37 (PP.13-35), 1990.
- [32] **O.Badr, P.W.O'Callaghan & S.D.Probert**, "*Vapour-Compression Refrigeration Systems*", Applied Energy, V.36 (PP.303-331), 1990.
- [33] **Carrier W.H.**, "*Rational Psychrometric Formulae*", ASME Trans., V.33, (PP.1005-1053), 1911.

- [34] **J.M.Hill, S.M.Jeter**, "*Techniques for Obtaining Improved Initial Estimates of Explicit State Variables for Computer-Based Thermodynamic Property Routines*", ASHRAE Trans V.97, 1991.
- [35] **F.A.Sando**, "*An Equation and Computer Program to Determine The Partial Pressure of Water Vapor in The Air Between The Dry Bulb Temperatures of -60 °F and +2 °F*", ASHRAE Trans. V.97, 1991.
- [36] **Albert Weiss**, "*Algorithms for the Calculation of Moist Air Properties on a Hand Calculator*", Transactions of the ASAE, 1977.
- [37] **John O.Staples**, "*Using a Microcomputer Can Ease/Speed HVAC Design*", Specifying Engineer, V.47, Part 1, (PP.82-83), 1982.
- [38] **P.G.S.Rutten**, "*The Adaptability of Air Conditioning Systems*", Australian Refrigeration, Air Conditioning & Heating, December, 1989.
- [39] **R.Genesh, H.J.Sauer,Jr.**, "*Microcomputer Simulation of HVAC System Performance*", Computers in Eng., 31 July 1988, Proceeding Sanfrancisco, ASME, USA.
- [40] **V.I.Hanby, J.A.Wright**, "*HVAC Optimisation Studies: Component Modelling Methodology*", Building Serv. Eng. Res. Technol., V.10 No.1, (PP.35-39), 1989.
- [41] **D.E.Miller**, "*A Simulation to Study HVAC Process Dynamic*", ASHRAE Trans., V.88 PT.2, (PP.809-825), 1982.
- [42] **B. Hutt**, "*Computer Aided Duct Sizing*", The Heating & Air Conditioning Journal, August 1979.
- [43] **Y.S. CHEN**, "*Duct design and drafting by Computer*", Heating/Piping/Air

conditioning J., August, 1974.

- [44] **Y.S. CHEN**, "*Design a procedure for duct Calculation*", Heating/Piping/Air conditioning J., January, 1981.
- [45] **R.J. Tsal, H.F. Behls and R. Mangel**, "*T-Method Duct Design, Part III : Simulation*", ASHRAE Trans. V.96, 1990.
- [46] **C. Park, S.T. Bushby and G.E. Kelly**, "*Simulation of a Large Office Building System Using the HVACSIM+ Program*", ASHREA Trans. V.95, 1989.
- [47] **M. Maddox**, "*CAD or CAM Computer Aided Design or Computer Aided Manufacturing? Different Approaches Amongst Major Ductwork Manufacturers Underline the Progress Now Being Made in the Industry*", the Heating Air Conditioning Journal, November 1986.
- [48] **C. Chen and K. Kengskool**, "*An AutoCAD-Based Expert System for Plant Layout*", Computer Ind. Engng, V.19 Nos.1-4,1990.
- [49] **H. Kulusjarvi**, "*HVAC-ENineering System Description*", VTT Symp. N118 2nd Finnish Frinch Colloquium, 14-15 June 1990 Espoo, Finl. Tech. Research Cent. of Finland.
- [50] **R.W. Amor, L.J. Groves and M.R. Donn**, "*Integrating Design Tools for Building Design*", ASHRAE Trans. V.96, 1990.
- [51] **M.P. Case, I. McConkey, K. McGraw and S.C. Lu**, "*Multiple Cooperating Knowledge Sources for the Design of Building Energy Systems*", ASHRAE Trans. V.96, 1990.
- [52] **K.M. Papamichael and S.E. Selkowitz**, "*Modeling the Building Design Process and Expertise*", ASHRAE Trans. V.96, 1990.

BIBLIOGRAPHY

- [1] **D.W. Trehella**, *Screen Based Graphics for Use in Entering Data for Dynamic Simulation of HVAC Systems*, Report No. OUEL 1793/89, University of Oxford.
- [2] **J.A. Wright**, *The Optimised Design of HVAC Systems*, PhD Thesis, Loughborough University of Technology, 1986.
- [3] **J.H. Konkell**, "Rule-of-Thumb Cost Estimating for building mechanical systems", McGrawHill, New York, NY 10020, 1987.
- [4] **W.C. Whitman and W.M. Johnson**, "Refrigeration & Air Conditioning Technology", Delmar publishers inc., New York, 1988.
- [5] **Althouse, Turnquist, Bracciano**, "Modern Refrigeration and Air Conditioning", The Goodheart-Willcox company, inc., South Holland, 1988.
- [6] **R.M.E. Diament**, "Combustion Calculation by Microcomputer", The Heating and Ventilation Engineer, V.58 No. 674, 1985.
- [7] **R.M.E. Diament**, "The Use of a Micro-Computer for Calculating Air Conditioning Loads: Part 1", The Heating and Ventilation Engineer, V.58 No. 674, 1985.
- [8] **R.M.E. Diament**, "The Use of a Micro-Computer for Calculating Air Conditioning Loads: Part 2", The Heating and Ventilation Engineer, V.58 No. 677, 1985.
- [9] **V. Bahel and R. Srinivasan.**, "A Computer Study for Estimation of Seasonal Energy Consumption and Selection of Air-Conditioner in Six Saudi Arabian Cities", Energy Convers. Mgmt V.28, No.1, (PP. 27-33), 1988.

- [10] **R. Dean, P.E. Rask and S. Jinjun**, "*Ventilation Efficiency Model*", 82nd Annual Meeting & Exhibition Anaheim, California, June 25-30, 1989.
- [11] **A. Sciomachen and R. Sozzi**, "*The Algorithmic Structure of a Decision Support System for a Design of a District Heating network*", Computer Opns Res., V.17, No.2, (PP. 221-230), 1990.
- [12] **M.G. Davies**, "*Room Heat Needs in Relation to Comfort Temperature: Simplified Calculation Methods*", Building Serv. Eng. Res. Technol., V.11, No.4, (PP.123-139),1990.
- [13] **A.K. Athienitis**, "*A Method and Algorithm for Estimation of Transmitted Solar Radiation and its Long-Term Averages Using Fourier Series*", Solar Energy, V.45, No.5, (PP.257-263), 1990.
- [14] **P.J. Burns, K. Han and C.B. Winn**, "*Dynamic Effects of Bang-Bang Control on The Thermal Rerformance of Walls of Various Constructions*", Solar Energy, V.46, No.3, (PP.129-138), 1991.
- [15] **E.R. Hitchin**, "*Developments in Degree-Day Methods of Estimating Energy Use*", Building and Environment, V.25, No.1, (PP.1-6), 1990.
- [16] **P.T. Lewis and D.K. Alexander**, "*HTB2: A Flexible Model for Dynamic Building Simulation*", Building and Environment, V.25, No.1, (PP.7-16), 1990.
- [17] **A.E. Delsante**, "*A Comparison Between Measured and Caculated Heat Losses Through a Slab-on-Ground Floor*", Building and Environment, V.25, No.1, (PP.25-31), 1990.
- [18] **M.J. Cunningham**, "*Modelling of Moisture Transfare in Structures-I. A Description of a Finite-Defference Nodal Model*", Building and Environment, V.25, No.1, (PP.55-61), 1990.

- [19] **P.E.G. Meckler**, "*Supercold Air HVAC System Design and Application*", Proc. Intersoc. Energy Convers Eng. Conf. V.2, Co., USA July 31 - August 5, 1988.
- [20] **H. Bynum**, "*Water Flow in Balanced Buildings*", Australian Refrigeration, Air Conditioning & Heating, September, 1990.
- [21] **L.H. Lafontaine**, "*Radiant Heating and Cooling*", Heating Piping Air Conditioning, V.62, PT.3, (PP.71-78), March 1990.
- [22] **D.P. Froehlich and B.J. Glawe**, "*Parameteric Analysis of Horizontal Air and Liquid Earth Loops*", Journal of Solar Energy Engineering, V.113, May 1991.
- [23] **W.S. Wilke and J. Schmid**, "*Modeling and Simulation of Elements for Solar Heating and Daylighting*", Solar Energy, V.46 No.5, (PP.295-304), 1991.
- [24] **P.T. Tsilingiris**, "*The Potential of Radiant Panels as Terminal Heaters in Solar Space Heating Applications*", Renewable Energy, V.1 No.1, (PP.13-19), 1991.
- [25] **D.P. Fiorino**, "*An Application od State-of-the-Art HVAC and Building Systems*", Energy Engineering, V.85 PT.6, (PP.6-31), 1988.
- [26] **P.C. Agrawal**, "*A Review of Passive Systems for Natural Heating and Cooling of Building*", Solar & Wind Technology, V.6 NO.5, (PP.557-567), 1989.
- [27] **H. Rutkowski and J.H. Healy**, "*Selecting Residential Air-Cooled Cooling Equipment Based on Sensible and Latent Performance*", ASHRAE Trans. V.96, 1990.
- [28] **W.F. Stoecker (Editing)**, "*Procedures for Simulating the Performance of Components and Systems for Energy Calculations*", ASHRAE Group, ASHRAE Inc., 1975.

- [29] **W.F.Stoecker (Editing)**, "*Procedures for Determining Heating and Cooling Loads for Computerizing Energy Calculations - Algorithms for Building Heat Transfare Subroutines*", ASHRAE Group, ASHRAE Inc., 1975.
- [30] **F. Sick, J.P. Kummer**, "*An Extension of the TRNSYS Multizone for Transparent Insulation Applications*", Proceeding 3rd European Conference on Architecture , Paris, 1991.
- [31] **W.F. Stoecker, J.W. Jones**, *REFRIGERATION & AIR CONDITIONING*, Mechanical Technology Series, McGRAW HILL Inc. , 1982.
- [32] **J.P. Holman**, *HEAT TRANSFARE*, McGRAW HILL Inc. , 1986.
- [33] **H.J. Bomanns**, *BASIC PROGRAMMING INSIDE & OUT*, ABACUS 1990.
- [34] **AUTODESK LTD.**, *AutoCAD Release 10, Reference Manual*, 1988.
- [35] **AUTODESK LTD.**, *AUTOLISP Release 10, Programmer's Reference*, 1988.
- [36] **A.I. Obanor**, *Simulation of the Performance of HVAC Systems and Central Plant for Energy Calculations: A Component Based Modelling Approach*, PhD Thesis, Granfield Institute of Technology, November 1985.
- [37] **D. Tang**, *Modelling of Heating and Air Conditioning System*, PhD Thesis, University of Stathclyde, Glasgow, U.K., March 1985.
- [38] **A. Khalili, A.M. Ghazi, G. Huneini and M. Rabah**, *Project Heating and Air Conditioning of the New Building of the College of Dentistry in Damascus University*, Mech. & Elec. Eng. College, Damascus University, 1988.
- [39] **M.J. Alghatam**, *Solar Ventilation and Air Conditioning System Investigation Using the Finite Element Method*, PhD. Thesis, Loughborough University of

Technology, 1985.

- [40] **U. Risley**, "*Air Conditioning Plants*", Translated from Swedish Building Regulations, Risley Trans. 5873, 1989.
- [41] **U. Risley**, "*Design of Air Conditioning Plants: Examples With Standard Approval*", Translated from Swedish Building Regulations, Risley Trans. 5872, 1989.
- [42] **A.C. Pitts**, *Air Movement and Energy Flow in an Air-Conditioned and Partitioned Industrial Environment*, PhD Thesis at Department of Building Science, University of Sheffield, 1985.
- [43] **L.J. Wild**, *Commissioning HVAC Systems Division of Responsibilities*, Report from Technical Memorandum 1/88, BSRIA.

APPENDIX

U-Value Calculation Materials

Table 1 : Asbestos Material for U-Value Calculation.

ASBESTOS					
No.	Description	Thermal Cond. W/m °C	dens- ity Kg/m ³	Spce. heat J/Kg°C	Vapor Res. GNs/Kgm
1	Asbestos 83% magnesia	0.070	190	1000	300.00
2	Asbestos cement decking	0.360	1500	1050	300.00
3	Asbestos cement sheet	0.360	700	1050	300.00
4	Asbestos slabs	0.070	145	1000	300.00
5	Asbestos sprayed (80 kg/m ³)	0.043	80	816	1000.00
6	Asbestos sprayed (130 kg/m ³)	0.046	130	816	1000.00
7	Asbestos sprayed (160 kg/m ³)	0.061	160	816	1000.00
8	Asbestos sprayed (240 kg/m ³)	0.068	240	816	1000.00
9	Asb cement sheet (700 kg/m ³)	0.360	700	1050	333.33
10	Asb cement sheet (1360 kg/m ³)	0.220	1360	1050	333.33
11	Asb cement sheet (1520 kg/m ³)	0.360	1520	1050	333.33
12	Asb cement sheet (1600 kg/m ³)	0.400	1600	1050	333.33
13	Asb cement sheet (2000 kg/m ³)	0.660	2000	1050	333.33
14	Asbestos cement board (type 1)	0.577	1922	1005	333.33
15	Asbestos cement board (type 2)	0.389	1970	837	333.33
16	Asbestos cement	0.360	750	2133	1000.00
17	Asb cement, semi compressed	0.370	1200	2133	1000.00
18	Asb cement, fully compressed	0.650	1600	2133	1000.00
19	Asb insul board (500 kg/m ³)	0.108	500	840	333.33
20	Asb insul board (577 kg/m ³)	0.160	577	840	333.33
21	Asb insul board (720 kg/m ³)	0.120	720	840	333.33
22	Asb insul board (900 kg/m ³)	0.115	900	840	333.33
23	Asb insul board (1200 kg/m ³)	0.250	1200	840	333.33
24	Asbestos cement new	0.360	750	2133	1000.00
25	Asbestos cement aged	0.360	750	2133	1000.00
26	Asbestos cement, red	0.360	750	2133	1000.00
27	Asbestos fibre loose	0.061	128	816	333.33

Table 2 : Asphalt Material for U-Value Calculation.

ASPHELTS					
No.	Description	Thermal Cond. W/m °C	Dens- ity Kg/m ³	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Asphalt bitumen	1.200	2250	1000	50000.0
2	Asphalt mastic	1.150	2325	1000	50000.0
3	Asphalt roofing	0.130	1600	1000	50000.0
4	Bitumen (pure)	0.160	1055	1000	50000.0
5	Bitumen floor	0.850	2400	1000	50000.0

Table 3 : Blocks Material for U-Value Calculation.

BLOCKS					
No.	Description	Thermal Cond. W/m °C	Dens-ity Kg/m3	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Concrete block (heavywt)	1.630	2300	1000	100.00
2	Concrete block (lightwt)	0.190	600	1000	30.00
3	Concrete block (mediumwt)	0.510	1400	1000	50.00
4	Foamed slag conc block (950)	0.200	950	1060	35.42
5	Foamed slag conc block (1040)	0.317	1040	1050	77.08
6	Foamed slag conc block (2000)	0.600	2000	1050	177.08
7	Cellular block outer leaf	0.490	720	1069	35.00
8	Cellular block inner leaf	0.290	720	1069	35.00
9	Clinker concrete block hollow	0.505	865	1069	35.00
10	Clinker block solid inner leaf	0.645	1040	1058	77.08
11	Clinker conc block (1050)	0.350	1050	1057	77.08
12	Clinker conc block (1520)	0.600	1520	1059	77.08
13	Pumice concrete block	0.300	1250	1060	77.08
14	Dense gravel blk (2000 kg/m3)	1.100	2000	1050	177.08
15	Dense gravel blk (2400 kg/m3)	1.750	2400	1042	177.08
16	Pfa conc block (950 kg/m3)	0.200	950	1053	35.42
17	Pfa conc block (1760 kg/m3)	0.500	1760	1063	77.08
18	Exp clay conc blk (720 kg/m3)	0.200	720	1069	35.42
19	Exp clay conc blk (1760 kg/m3)	0.600	1760	1063	77.08
20	Aerated, air cured conc block	0.850	400	1100	35.42
21	Aerated, a/clvd conc blk (400)	0.080	400	1100	35.42
22	Aerated, a/clvd conc blk (800)	0.250	800	1063	35.42

Table 4 : Brick Material for U-Value Calculation.

BRICK					
No.	Description	Thermal Cond. W/m °C	Dens-ity Kg/m3	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Alumin refractory brick	0.290	720	1000	100.00
2	Brickwork (external)	0.840	1700	800	50.00
3	Brickwork (internal)	0.620	1700	800	50.00
4	Silica brick	1.300	1900	1000	100.00
5	Brickwork	0.700	1700	800	41.67
6	Brickwork (1200 kg/m3)	0.310	1200	750	41.67
7	Brickwork (1400 kg/m3)	0.420	1400	750	41.67
8	Brickwork (1600 kg/m3)	0.540	1600	750	41.67
9	Brickwork (1800 kg/m3)	0.710	1800	750	41.67
10	Brickwork (2000 kg/m3)	0.920	2000	750	41.67
11	Brickwork common (dry)	0.810	1760	800	41.67
12	Brick common (1530 kg/m3)	0.650	1530	920	50.00
13	Brick common (1750 kg/m3)	0.600	1750	920	41.67
14	Brick common (1790 kg/m3)	0.720	1790	920	41.67
15	Brick common (1826 kg/m3)	0.820	1826	753	41.67

Continue

BRICK					
No.	Description	Thermal Cond. W/m °C	Density Kg/m ³	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
16	Brick common (1920 kg/m ³)	0.720	1920	795	41.67
17	Brick common (2050 kg/m ³)	0.880	2050	920	41.67
18	Brick common (2200 kg/m ³)	0.800	2200	920	41.67
19	Brick red common (dry)	0.810	1760	920	41.67
20	Fletton brick	0.550	1700	920	41.67
21	Fletton common inner	0.700	1760	920	41.67
22	Fletton claywall outer	0.810	1760	920	41.67
23	Fletton common, frog up	0.930	1760	920	41.67
24	Fletton common inner	0.670	1760	920	41.67
25	Fletton cellular outer	0.900	1760	920	41.67
26	Fletton cellular inner	0.600	1760	920	41.67
27	Fletton facing, outer	1.020	1760	920	41.67
28	Diatomaceous earth brick	0.141	720	920	41.67
29	Brick facing (1500 kg/m ³)	0.500	1500	920	41.67
30	Brick facing (2000 kg/m ³)	1.330	2000	920	41.67
31	Brick facing (2100 kg/m ³)	0.700	2100	920	41.67
32	Brick facing (2175 kg/m ³)	0.830	2175	920	41.67
33	London stock	0.450	1575	920	41.67
34	Brick engineering (2100 kg/m ³)	0.800	2100	920	41.67
35	Brick engineering (2300 kg/m ³)	1.000	2300	920	41.67
36	Sandlime brick (1530 kg/m ³)	0.650	1530	920	50.00
37	Sandlime brick (1890 kg/m ³)	1.340	1890	920	96.35
38	Sandlime brick, red	1.613	1920	920	96.35
39	Sandlime brick, white	0.650	1530	920	50.00
40	Brick wire cut red	1.330	2000	920	41.67
41	Brick fletton dark	0.550	1700	920	41.67
42	Brick fletton light	0.550	1700	920	41.67
43	Brick light buff	0.810	1760	920	41.67
44	Brick cream	0.810	1760	920	41.67
45	Brick white/light cream	0.810	1760	920	41.67
46	Brick glazed ivory	0.810	1760	920	41.67
47	Brick glazed white	0.810	1760	920	41.67
48	Brick purple	0.810	1760	920	41.67
49	Brick stafford blue	0.800	2100	920	41.67
50	Brick yellow buff	0.810	1760	920	41.67

Table 5 : Concrete Material for U-Value Calculation.

CONCRETE					
No.	Description	Thermal Cond. W/m °C	Density Kg/m ³	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Aerated concrete slab	0.160	500	840	40.00
2	Cast concrete dense	1.400	2100	840	200.00
3	Cast concrete lightweight	0.380	1200	1000	40.00
4	Rendering	0.400	1200	1000	100.00
5	Screed	0.410	1200	840	100.00
6	275 R.C SLAB	1.400	2100	840	200.00

Table 6 : Felt Material for U-Value Calculation.

FELT					
No.	Description	Thermal Cond. W/m °C	Dens-ity Kg/m3	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Bitumenous felt (loose laid)	0.200	1000	1000	8000.00
2	Felt in bitumen	0.500	1500	1000	50000.0
3	Roofing felt	0.190	960	1000	4000.00
4	Sarking	0.200	1100	1000	4000.00

Table 7 : Flooring Material for U-Value Calculation.

FLOORING					
No.	Description	Thermal Cond. W/m °C	Dens-ity Kg/m3	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Carpet (foam backed)	0.100	1000	1000	200.00
2	Carpet (wool)	0.055	160	1000	10.00
3	Cork tiles	0.085	540	1000	100.00
4	Felt underlay	0.065	270	1000	10.00
5	PVC flooring	0.220	1600	1000	1000.00
6	Rubber flooring	0.310	1600	1000	200.00
7	Rubber underlay	0.100	400	1000	200.00
8	Timber flooring	0.140	650	1200	60.00
9	Wood block	0.140	650	1200	60.00

Table 8 : General Concrete Material for U-Value Calculation.

GENERAL CONCRETE					
No.	Description	Thermal Cond. W/m °C	Dens-ity Kg/m3	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Concrete 1:2:4	1.400	2360	1030	208.33
2	Concrete (400 kg/m3)	0.150	400	925	35.42
3	Concrete (600 kg/m3)	0.200	600	920	35.42
4	Concrete (800 kg/m3)	0.230	800	925	35.42
5	Concrete (1000 kg/m3)	0.300	1000	920	77.08
6	Concrete (1200 kg/m3)	0.380	1200	920	77.08
7	Concrete (1400 kg/m3)	0.510	1400	920	77.08
8	Concrete (1600 kg/m3)	0.660	1600	920	77.08
9	Concrete (1800 kg/m3)	0.870	1800	920	77.08
10	Concrete (2000 kg/m3)	1.130	2000	920	77.08
11	Concrete (2200 kg/m3)	1.450	2200	920	77.08
12	Concrete (2400 kg/m3)	1.830	2400	920	77.08
13	Dense concrete (2000 kg/m3)	1.130	2000	1000	77.08
14	Dense concrete (2100 kg/m3)	1.400	2100	840	77.08
15	Dense concrete (2300 kg/m3)	1.100	2300	1070	77.08
16	Concrete screed (1200 kg/m3)	0.410	1200	840	77.08
17	Concrete screed (2100 kg/m3)	1.280	2100	1000	77.08

Table 9 : Insulations Material for U-Value Calculation.

INSULATIONS					
No.	Description	Thermal Cond. W/m °C	Density Kg/m ³	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Cork board	0.042	145	1800	100.00
2	Cork granules	0.046	115	1800	100.00
3	Glassfibre quilt	0.040	12	840	5.00
4	Mineral wool felt	0.039	50	1000	5.00
5	Mineral wool mat	0.036	130	1000	5.00
6	Perlite granules	0.042	65	1000	5.00
7	Phenolic board	0.038	30	1400	260.00
8	Polystyrene beads	0.030	25	1000	300.00
9	Polystyrene board	0.030	25	1000	1000.00
10	Polyurethane board	0.020	30	1000	60.00
11	Polyurethane foam	0.026	30	1000	60.00
12	Urea formaldehyde foam	0.032	15	1500	15.00
13	Vermiculite granules	0.065	100	1000	15.00
14	Glass fibre (12 kg/m ³)	0.040	12	833	15.00
15	Glass fibre (25 kg/m ³)	0.035	25	1000	15.00
16	Glasswool (24 kg/m ³)	0.039	24	920	7.81
17	Glasswool (200 kg/m ³)	0.040	200	670	6.25
18	Glass foamed	0.045	125	840	6.25
19	Mineral wool, fill type	0.039	150	840	5.99
20	Mineral wool board	0.048	240	1050	14.06
21	Strawboard	0.100	370	1000	62.50
22	Polystyrene sheet (16 kg/m ³)	0.040	16	1210	109.38
23	Polystyrene sheet (32 kg/m ³)	0.033	32	1210	385.42
24	Polystyrene, exp, open cell	0.033	25	1200	348.96
25	Polystyrene, exp, closed cell	0.033	25	1200	1000.00
26	Polystyrene, expanded	0.030	140	1380	307.29
27	Polyurethane, foamed	0.026	30	1260	312.50
28	Polyurethane board	0.025	30	1400	510.42
29	PVC, expanded	0.045	70	1000	208.33
30	Urea formaldehyde, foamed	0.032	30	1500	22.40
31	Woodwool slab (300 kg/m ³)	0.067	300	1000	15.00
32	Woodwool slab (400 kg/m ³)	0.080	400	1000	26.04
33	Woodwool slab (500 kg/m ³)	0.100	500	1000	27.08
34	Woodwool slab (800 kg/m ³)	0.130	800	1000	27.08
35	Cork	0.041	100	1800	10.00
36	Cork granulated (115 kg/m ³)	0.046	115	1000	104.17
37	Cork granulated (120 kg/m ³)	0.047	120	1800	78.13
38	Cork granulated (130 kg/m ³)	0.045	130	1760	78.13
39	Cork board (100 kg/m ³)	0.039	100	1800	26.04
40	Cork board (130 kg/m ³)	0.040	130	1800	62.50
41	Cork board (145 kg/m ³)	0.042	145	1000	104.17
42	Cork board (160 kg/m ³)	0.046	160	1800	62.50
43	Cork board (180 kg/m ³)	0.045	180	1800	40.00
44	Cork tile (145 kg/m ³)	0.040	145	2207	75.00
45	Cork tile (530 kg/m ³)	0.084	530	1670	102.60
46	Cork tile (540 kg/m ³)	0.085	540	1000	130.21
47	Af/armaflex	0.036	60	1380	8000.00

Table 10 : Meneral Insulations Material for U-Value Calculation.

MENERAL INSULATIONS					
No.	Description	Thermal Cond. W/m °C	Dens-ity Kg/m3	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Fibreglass crown 75	0.040	12	840	8.00
2	Fibreglass gp quilt std grade	0.037	16	840	8.00
3	F/glass gp quilt, sound dead	0.034	36	840	8.00
4	Fibreglass frametherm roll	0.040	12	840	8.00
5	Fibreglass frametherm batt	0.040	12	840	8.00
6	Fibreglass frametherm w/cavity	0.040	24	840	8.00
7	Fibreglass frametherm sleeved	0.040	19	840	8.00
8	Fibreglass factoryliner (34)	0.031	34	840	8.00
9	Fibreglass factoryliner (32)	0.032	32	840	8.00
10	Fibreglass dritherm (21)	0.036	21	840	8.00
11	Fibreglass dritherm (19)	0.036	19	840	8.00
12	Fibreglass dritherm (16)	0.037	16	840	8.00
13	Fibreglass cavity wall slab	0.033	28	840	8.00
14	F/glass cavity wall fill (40)	0.037	40	840	8.00
15	F/glass cavity wall fill (27)	0.039	27	840	8.00
16	Fibreglass rocksil insuln mat	0.040	18	750	8.00
17	Fibreglass rocksil acous sheet	0.034	48	750	8.00
18	Fibreglass rocksil slab UF96	0.034	96	750	8.00
19	Fibreglass rocksil slab UF64	0.034	64	750	8.00
20	F/glass rocksil timberfil (UF)	0.040	18	750	8.00
21	F/glass rocksil timberfil wire	0.034	90	750	8.00

Table 11 : Metals Material for U-Value Calculation.

METALS					
No.	Description	Thermal Cond. W/m °C	Dens-ity Kg/m3	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Alumin	160.000	2800	920	50000.0
2	Copper	200.000	8900	380	50000.0
3	Steel	50.000	7800	500	50000.0
4	Tray ceiling	50.000	7800	500	50000.0
5	Zinc	118.000	7100	396	99999.9
6	Chromium	67.000	7200	452	99999.9
7	Tin	66.000	7320	226	99999.9

Table 12 : Plaster Material for U-Value Calculation.

PLASTER					
No.	Description	Thermal Cond. W/m °C	Dens-ity Kg/m3	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Plaster (dense)	0.560	1300	1000	60.00
2	Plaster (lightwt)	0.160	600	1000	60.00
3	Plaster - gypsum	0.380	1100	840	60.00
4	Plaster - perlite	0.080	400	840	60.00
5	Plaster - sand/cement	0.530	1570	1000	60.00
6	Plaster - vermiculite	0.260	800	840	60.00
7	Plasterboard - gypsum	0.160	950	840	60.00
8	Plasterboard - perlite	0.180	800	840	60.00
9	Perlite aggr plaster (400)	0.079	400	837	57.29
10	Perlite aggr plaster (610)	0.190	610	837	57.29
11	Vermiculite aggr plaster (480)	0.140	480	837	57.29
12	Vermiculite aggr plaster (720)	0.220	720	837	57.29
13	Vermiculite aggr plaster (960)	0.300	960	837	57.29
14	Gypsum/vermiculite bonding	0.218	658	837	57.29
15	Gypsum/perlite browning	0.162	570	837	57.29
16	Gypsum plaster/perlite aggr	0.220	720	1340	57.29
17	Lightweight plaster (448)	0.115	448	837	57.29
18	Lightweight plaster (600)	0.170	600	917	50.00
19	Lightweight plaster (770)	0.201	770	837	57.29
20	Lightweight plaster (900)	0.259	900	837	57.29
21	Cement/sand aggr plaster(1570)	0.530	1570	837	104.17
22	Cement/sand aggr plaster(1182)	0.720	1182	837	104.17
23	Gypsum plaster/sand aggr(1862)	0.577	1862	837	31.25
24	Gypsum plaster/sand aggr(1680)	0.810	1680	837	31.25
25	Plaster (1200 kg/m3)	0.420	1200	837	57.29
26	Plaster (1300 kg/m3)	0.500	1300	837	60.00
27	Plaster (1440 kg/m3)	0.480	1440	837	57.29
28	Plaster (1600 kg/m3)	0.600	1600	837	57.29
29	Lime cement plaster	0.420	1600	837	114.58
30	Plasterboard	0.160	960	837	57.29
31	Cement rendering/mortar (1300)	0.500	1300	769	100.00
32	Cement rendering/mortar (1600)	1.153	1600	1000	114.58
33	Cement rendering/mortar (1778)	1.180	1778	1000	114.58
34	Cement rendering/mortar (1890)	1.730	1890	780	100.00

Table 13 : Roofing Components Material for U-Value Calculation.

ROOFING COMPONENTS					
No.	Description	Thermal Cond. W/m °C	Dens-ity Kg/m3	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Asphalt (1600 kg/m3)	0.430	1600	1000	5208.33
2	Asphalt (1700 kg/m3)	0.500	1700	1000	5208.33
3	Asphalt, heavy	1.220	2240	1000	5208.33
4	Asphalt, 20% grit (1920 kg/m3)	0.580	1920	1000	5208.33
5	Asphalt, 20% grit (2320 kg/m3)	1.150	2320	840	5208.33
6	Bitumen	0.160	1055	1000	4166.67
7	Roofing felt (960 kg/m3)	0.410	960	1000	6770.83
8	Concrete tiles, uncoloured	1.100	2100	837	177.08
9	Concrete tile, black	1.100	2100	837	177.08
10	Concrete tile, brown	1.100	2100	837	177.08
11	Slate, grey	2.000	2700	753	250.00
12	Slate, blue-green	2.000	2700	753	250.00
13	Slate, silver-grey/light	2.000	2700	753	250.00
14	Clay tile, red/brown	0.850	1900	586	72.92

Table 14 : Sheeting Material for U-Value Calculation.

SHEETING					
No.	Description	Thermal Cond. W/m °C	Density Kg/m ³	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Chipboard	0.150	800	1000	500.00
2	Fibreboard	0.060	300	1400	40.00
3	Fire retardant boarding	0.100	800	1000	80.00
4	Glass hollow block	0.680	1000	830	50000.0
5	Glass sheet	1.050	2500	830	50000.0
6	Hardboard medium	0.080	600	2000	600.00
7	Hardboard standard	0.130	900	2000	600.00
8	PVC rigid sheet	0.160	1350	1250	1000.00
9	Polystyrene	0.030	25	1000	1000.00
10	Woodwool slab	0.100	500	1000	20.00
11	Fibre board (240 kg/m ³)	0.053	240	1400	20.00
12	Fibre board (270 kg/m ³)	0.049	270	1423	20.00
13	Fibre board (290 kg/m ³)	0.060	290	1420	20.00
14	Fibre board (300 kg/m ³)	0.060	300	1000	20.00
15	Fibre board (300 kg/m ³)	0.050	300	2335	40.00
16	Fibre board (320 kg/m ³)	0.059	320	1670	20.00
17	Fibre board (350 kg/m ³)	0.069	350	1400	20.00
18	Fibre board (400 kg/m ³)	0.060	400	1400	20.00
19	Fibre board (480 kg/m ³)	0.060	480	1400	20.00
20	Fibre board (720 kg/m ³)	0.090	720	1400	20.00
21	Fibre board (800 kg/m ³)	0.101	800	1400	20.00
22	Fibre board (880 kg/m ³)	0.144	880	1400	20.00
23	Particle board low density	0.078	593	1300	20.00
24	Particle board medium density	0.135	800	1300	20.00
25	Particle board high density	0.170	1000	1300	20.00
26	Hardboard	0.200	900	2444	598.96
27	Hardboard (tempered)	0.180	960	2000	557.29
28	Plywood (513 kg/m ³)	0.124	513	2000	520.83
29	Plywood (530 kg/m ³)	0.140	530	2760	520.83
30	Plywood (544 kg/m ³)	0.115	544	1214	520.83
31	Plywood (650 kg/m ³)	0.140	650	2308	520.83
32	Plywood (fireproofed)	0.150	560	2000	520.83
33	Resin bonded plywood	0.140	650	2000	666.67
34	Chip board (480 kg/m ³)	0.110	480	1590	500.00
35	Chip board (700 kg/m ³)	0.110	700	1570	500.00
36	Chip board (800 kg/m ³)	0.150	800	2090	500.00

Table 15 : Timber Material for U-Value Calculation.

TIMBER					
No.	Description	Thermal Cond. W/m °C	Density Kg/m ³	Speci. Heat J/Kg°C	Vapor Res. GNs/Kgm
1	Hardwood	0.150	700	1200	60.00
2	Mahogany	0.155	700	1200	60.00
3	Oak	0.160	770	1200	60.00
4	Pine	0.140	660	1200	500.00
5	Plywood	0.150	560	2800	1000.00
6	Softwood	0.130	500	2800	60.00
7	Teak	0.170	700	1200	60.00
8	Softwood (500 kg/m ³)	0.140	500	1760	60.00
9	Softwood (630 kg/m ³)	0.130	630	2760	59.48
10	Hardwood (650 kg/m ³)	0.160	650	2300	60.00
11	Hardwood (700 kg/m ³)	0.150	700	1420	59.48
12	Timber (12% moisture)	0.144	560	1420	59.48
13	Timber (20% moisture)	0.144	480	1420	59.48
14	Timber smooth planed	0.144	560	1420	59.48
15	Wood	0.147	640	1420	59.48
16	Beech, across grain, 15%	0.167	700	1420	187.50
17	Cypress, across grain	0.097	465	1420	59.48
18	Deal, across grain 12%	0.125	610	1420	59.48
19	Deal, along grain 12%	0.220	610	1420	59.48
20	Fir (513 kg/m ³)	0.115	513	1380	59.48
21	Fir (545 kg/m ³)	0.115	545	2720	59.48
22	Fir, across grain	0.109	420	2720	59.48
23	Fir, along grain	0.138	420	2720	59.48
24	Mahogany across grain 10%	0.156	700	1420	59.48
25	Maple (720 kg/m ³)	0.159	720	1256	59.48
26	Maple (640 kg/m ³)	0.173	640	1420	59.48
27	Oak, radial (480 kg/m ³)	0.173	480	2390	59.48
28	Oak, radial (610 kg/m ³)	0.207	610	2390	59.48
29	Oak, across grain	0.166	545	2390	59.48
30	Oak, across grain 14%	0.159	770	2390	59.48
31	Oak, along grain 14%	0.290	770	2390	59.48
32	Pine, white	0.112	500	2805	59.48
33	Pine, yellow, across grain	0.147	640	2805	59.48
34	Pine (15% moisture)	0.138	660	1420	59.48
35	Spruce (12% moisture)	0.105	420	1420	59.48
36	Teak (10% moisture)	0.138	720	1420	59.48

Table 16: Vapor Barrieries Material for U-Value Calculation.

VAPOR BARRIERES		
No.	Description	Vapor Res. GNs/Kgm
1	Aluminium foil	4000.00
2	Building paper	5.00
3	Building paper, foil backed	4000.00
4	Insulation board painted	10.00
5	Insulation board emulsioned	2.00
6	Kraft paper	0.20
7	Plaster painted	8.00
8	Plasterboard foil backed	200.00
9	Plywood painted	8.00
10	Polythene (0.12 mm)	250.00
11	Roofing felt	10.00
12	Vinyl wallpaper	10.00
13	Aluminium foil on paper	1000.00
14	Alum foil bond to kraft paper	877.20
15	PVC unplasticised .0051mm	257.10
16	PVC plasticised .1mm	15.90
17	Polythene 0.05mm	120.60
18	Polythene 0.1mm	217.40
19	Polythene 0.15mm	349.70
20	Water proof paper	0.40
21	Black building paper	103.10
22	Laminated paper	42.00
23	Paper, white	7.70
24	Kraft paper, single	0.20
25	Kraft paper, double	0.30
26	Kraft paper, 3 ply	0.50
27	Kraft paper, 4 ply	0.60
28	Kraft paper, 5 ply	0.60
29	Asphalt coated paper	50.00
30	Asphalt infused sheath paper	2.70
31	Bitumen impregnated paper	11.10
32	Sheathing paper	7.70
33	Waxed paper, medium weight	196.10
34	Waxed paper, heavy weight	158.70
35	Polyethylene 0.0508mm	109.30
36	Polyethylene 0.102mm	218.30
37	Polyethylene 0.152mm	291.50
38	Polyethylene 0.203mm	436.70
39	Polyethylene 0.254mm	581.40
40	Gloss paint average	23.80
41	Interior paints, various 1 ct	29.00
42	Varnishes 0.05mm	5.00
43	Accolade f/glass fissure face	22.00
44	Roofing felt	10.00
45	Felt + hot bitumen	52083.33