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Computer Aided Development Software for Air Conditioning Systems

I. B. Vaisman
Israel

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IGOR B. VAISMAN
ASHRAE and IIR Member

Involving in CAD/CAM consists of involving in computer aided way Functional Design stage that includes solving procedures on optimal set of system components in terms of thermodynamic efficiency and cost. The aim of the paper is to present Computer Aided Functional Design (CAFD) Basis of Air Conditioning Systems with Heat Pumps. CAFD algorithm for development of Air Conditioning Systems with Heat Pumps is shown. Principles of development of CAFD software are presented. Basic structure of the CAFD software developed is described. An example of application of the software is analyzed. Conclusions on the CAFD software are given.

INTRODUCTION

Step by step we move on to Computer Aided Design and Manufacture (CAD/CAM) in Air Conditioning and Heat Pump Industries. Finally we will get the following: an engineer gets a task to develop a new air conditioning system, inputs data ... and gets a set of programs for computer aided manufacture. Another case - a new component should be introduced or price of a component has been changed - and an optimal answer comes at once. This move may be accelerated or decelerated but never stopped. More and more procedures of this long and complicated process will be involved in computer aided way until all this process completely will be managed by the help of computers.

Involving in CAD/CAM consists of involving in computer aided way all stages of production process and is developed by various kinds of experts. For example, the complete CAD system consists of mathematical, hardware, software, information, linguistic, methodology and document management tool supports. One of the production stages concerning only refrigeration and air conditioning field is called Functional Design (FD) and includes solving procedures on optimal set of system components in terms of thermodynamic efficiency and cost. Development of Computer Aided Functional Design (CAFD) Fundamentals is responsibility of refrigeration and air-conditioning experts. The aim of the paper is to present CAFD Basis of Air Conditioning Systems with Heat Pumps.

OPERATING PRINCIPLES

Air Conditioning System with Heat Pump basically includes (Figure 1): compressor *Cm*, air-cooled condenser *CD*,

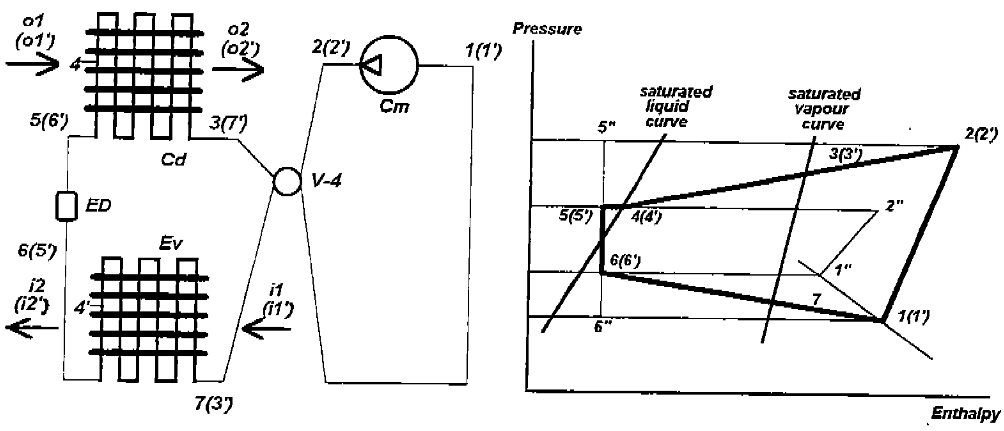

Figure 1. Air Conditioning System with Heat Pump.

expansion device *ED*, cooling air evaporator *Ev*, 4-way valve *V-4* and connecting piping. The system operates in cooling and heating modes.

In the cooling mode the compressor *Cm* sucks vapour flow at pressure p_1. compresses it to discharge pressure p_2 and delivers it through the connecting piping and 4-way valve *V-4* in the condenser *Cd*. In the piping pressure and temperature of the vapour flow are dropped to the lower values p_3 and t_3 respectively. In the condenser the vapour flow is liquefied. gets temperature t_4 and is subcooled to temperature t_5. Pressure is dropped from p_3 to $p_5 = p_4$ (pressure drop of liquid flow is usually negligible). Condensation happens because of thermal contact of the high pressure vapour flow with outdoor (cooling) air flow produced by a fan. The fan pressure head is equal to pressure drop in the cooling air channel. In the condenser the air flow is heated from temperature t_{o1} to t_{o2}. The subcooled liquid flow through the connecting piping enters the expansion device *ED*. Isoenthalpic expansion occurs there and causes appearance of wet vapour. decrease of pressure from p_5 to p_6 and temperature from t_5 to t_6. Then the wet vapour flow through the connecting piping is directed to the evaporator *Ev*. In the evaporator the liquid phase of the wet vapour flow is boiled and at the outlet of the evaporator appears slightly superheated vapour at temperature t_7. Pressure is dropped from p_6 to p_7. Boiling happens because of thermal contact of the low pressure wet vapour flow being boiled with indoor air flow to be conditioned. The air flow is produced by a blower. The blower pressure head is equal to pressure drop in the air channel. In the evaporator the air flow is heated from t_{i1} to t_{i2}. The air flow relative humidity is increased from φ_{i1} to φ_{i2}. After the evaporator the superheated vapour flow is sucked by the compressor through the connecting piping and the 4-way valve and cycle *1-2-3-4-5-6-7-1* is reproduced.

In the heating mode the compressed vapour flow is directed through the connecting piping and 4-way valve into the evaporator and then through the expansion device. condenser. 4-way valve and connecting piping back to the compressor. The Heat Pump thermodynamic cycle way is *1'-2'-3'-4'-5'-6'-7'-1'*. In the evaporator the indoor air flow is heated from temperature $t_{i1'}$ to $t_{i2'}$. In the condenser the outdoor air flow is heated from temperature $t_{o1'}$ to $t_{o2'}$.

FD PRINCIPLES

The Functional Design is intended for creation of description of an air conditioning or refrigerating system being developed as a set of necessary components and interconnections between them. realizing a sequence of physical processes in terms of needed quantity and quality. A sequence of processes in terms of needed quantity and quality is provided if the compressor. evaporator. condenser. 4-way valve. expansion device and piping sizes are properly defined. First of all. there should be produced the sizing of compressor. evaporator and condenser. The processes taking place in these components are described with very complicated mathematical equations and depend on many conflicting parameters. So right sizing may be implemented only through computer aided optimization procedure. Other components may be sized after. Usually they do not cause reconsideration of compressor. evaporator and condenser sizing. although their wrong sizing may influence system performance significantly.

Basic Functional Design Algorithm to be involved in computer aided way (Figure 2) is based on analysis of air conditioning system configuration with a fixed set of components and interconnection between them as shown on Figure 1.

The ***Input of Air Conditioning System Data*** consists of:
- indoor temperature t_{i1} and relative humidity φ_{i1} for cooling mode and indoor temperature $t_{i1'}$ for heating mode.
- outdoor temperature t_{o1} for cooling mode and outdoor temperature $t_{o1'}$ for heating mode.
- cooling capacity Q_0. heating capacity Q_0' and COP levels for the both modes.
- limitations of sizes. noise and cost.

Any set of the ***Thermodynamic Cycle Data*** accords to a unique system with its own cost and thermodynamic efficiency. These data are represented by actual system components and should be subjected to optimization procedure. when FD takes place. The list of them is the following: refrigerant. compressor performance curves. smallest temperature head in condenser Δt_c. heating Δt_{ac} of outdoor air flow. smallest temperature head Δt_g in evaporator. cooling Δt_{ae} of indoor air flow. indoor air flow rate V_0 through evaporator at normal conditions. outdoor air flow rate

1 - *Input of Air Conditioning System Data*

2 - *Input of Thermodynamic Cycle Data*

3 - *Thermodynamic Cycle Calculations*

4 - *Thermodynamic Analysis*

5 - *Input of Evaporator Design Data*

6 - *Evaporator Design Calculations*

7 - *Cost Analysis*

8 - *Input of Condenser Design Data*

9 - *Condenser Design Calculations*

10 - *Cost Analysis*

11 - *Heat Pump Calculations*

12 - *Sizing of the Rest of Components*

13 - *End*

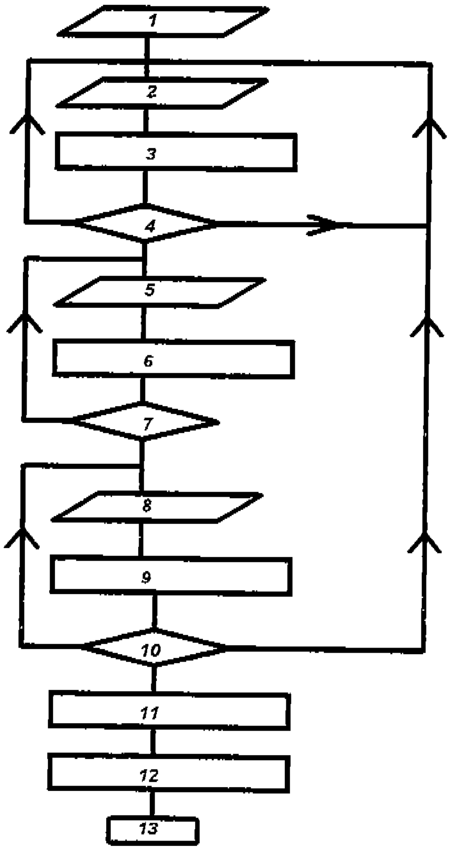

Figure 2. Basic Functional Design Algorithm

V_{cd} through condenser at normal conditions, refrigerant pressure drop Δp_{cd} in condenser, pressure drop Δp_{dis} in discharge line, refrigerant pressure drop Δp_{ev} in evaporator, pressure drop Δp_{suc} in suction line, subcooling Δt_f of liquid in condenser, superheating Δt_0 of vapour in evaporator.

The ***Thermodynamic Cycle Calculations*** defines: temperatures, pressures, densities, enthalpies, and entropies in all thermodynamic states of the cycle; thermodynamic cycle and each component characteristics (heat loads, works, COP).

At the ***Thermodynamic Analysis*** stage thermodynamic performance of the air conditioning system is analyzed. If cooling capacity doesn't fit to the that in the system data, or coefficient of performance is not enough the thermodynamic cycle data are modified and recalculations of the cycle are produced.

The ***Input of Evaporator Design Data*** includes finned tube design parameters and the thermodynamic cycle calculated results concerning evaporator. The design parameters are: inside and outside diameters of the tube, fin sizes, tube pitches, fin pitch, evaporator length, etc. The cycle results are: refrigerant mass flow rate, evaporator air flow rate, thermodynamic parameters of refrigerant at the evaporator inlet and outlet, thermodynamic parameters of the air flow at the evaporator inlet and outlet.

The ***Evaporator Design Calculations*** defines real heat load applied to the evaporator, refrigerant and air flow film coefficients, overall heat transfer coefficient, refrigerant and air flow pressure drops. If deviation of the heat load and the cooling capacity defined in the thermodynamic cycle calculation or deviation of the refrigerant pressure drop calculated from the values assumed in the thermodynamic cycle data is higher than allowable value, then recalculations of the thermodynamic cycle or redesign of the evaporator is produced.

The *Cost Analysis* evaluates cost of the evaporator. If the cost doesn't fit then redesign of the evaporator is produced.

The ***Input of Condenser Design Data*** includes finned tube design parameters and the thermodynamic cycle calculated results concerning condenser. The design parameters are: inside and outside diameters of the tube. fin sizes, tube pitches. fin pitch. condenser length. etc. The cycle results are: refrigerant mass flow rate. condenser air flow rate. thermodynamic parameters of refrigerant at the condenser inlet and outlet. thermodynamic parameters of the air flow at the condenser inlet and outlet.

The ***Condenser Design Calculations*** defines real heat load applied to the condenser. refrigerant and air flow film coefficients. overall heat transfer coefficient. refrigerant and air flow pressure drops. If deviation of the heat load and the condenser capacity defined in the thermodynamic cycle calculations or deviation of the refrigerant pressure drop calculated from the values assumed in thermodynamic cycle data is higher than allowable value. then recalculations of the thermodynamic cycle or redesign of the condenser is produced.

The *Cost Analysis* evaluates cost of the condenser. If the condenser cost doesn't fit then redesign of the condenser is produced.

The ***Sizing of the Rest of Components*** evaluates cost of the rest of components that are in accordance with the data stated in the Input of Thermodynamic Cycle Data. If system cost appears far too high. the thermodynamic cycle data are modified and recalculations are produced.

The ***Heat Pump Calculations*** checks performance of the air conditioning arrangement in heating mode keeping the same sequence of operations and the same components that were sized in the above air conditioning calculations.

SOFTWARE MAIN BUILDING PRINCIPLES

The Software developed is based on the following main six principles: System Approach. Intention for User as a Refrigeration or Air Conditioning Engineer. Integration with Complete CAD/CAM System. Interface with the Existing Software. Self-developing System and Developing System.

System Approach

The system approach considers an air conditioning system as a set of the system components and interconnections between them. Any system component descriptions (subroutines realizing mathematical models of the system component. help information for data input. application information. Data Base information in data files or data strings) should be independent to descriptions of other system components on the one hand and take into account standing rules of integration into complete air conditioning system on the other hand. The system approach is applicable to all tool supports of CAD/CAM System. including mathematical and software tool supports of the CAFD stage. Each component may be replaced. updated or added without influence on any descriptions of other components.

Intention for User as a Refrigeration or Air Conditioning Engineer

It means that the software should consist of interactive mode with all necessary help information for the CAFD. The interactive mode should be easy for operation and implements diagnostics of each input datum and of all set of input data. If input is wrong the software must make error warnings. System of error communications should be included in calculation algorithm if a set of parameters is defined out of computing or operating range. Output of data should include all necessary information for the current and next stages.

Integration with Complete CAD/CAM System

The CAFD stage is a unit of complete CAD/CAM procedure that will be built and developed in the future. It means that the CAFD software should consist of all necessary resources to absorb data from the previous stages (for example, marketing research results of air conditioning system components in terms of performance data and cost) and prepare data in appropriate format for the next stages (for example. description of evaporator design for a designer or for available drawing software in accordance with specific format of the drawing software).

Interface with the Existing Software

The computer software should be developed taking into account the existing software being applied in air conditioning developments. For example. interaction with LOTUS will give an opportunity to build graphs for analyses and optimization procedures or prepare writing presentations and reports.

Self-developing System

The most possible number of data concerning the CAFD calculations should be placed in special data files. Appearance of new components. disappearance of old ones. changes in cost or rates of currency exchange should not cause any changes in the CAFD Software. The software itself must update information using its own resources.

Developing System

Appearance of more accurate equations of state. heat and mass transfer equations. pressure drop equations: appearance of new refrigerants. new types and models of heat exchangers or compressors: addition of new procedures (for example. noise analysis of expansion devices) should not lead to redevelopment of the existing CAFD software. The old components or procedures should be replaced or deleted and new components or procedures should be added without any influence on descriptions of other Software components.

SOFTWARE STRUCTURE

The basic Software is based on the above principles and consists of the following programs:

- ***Thermodynamic Cycle Calculations*** for implementation of stages 2 and 3 of the CAFD Algorithm.
- ***Evaporator Design Calculations*** for implementation of stages 5 and 6 of the CAFD Algorithm.
- ***Condenser Design Calculations*** for implementation of stages 5 and 6 of the CAFD Algorithm.
- ***Control Program*** for implementation of the CAFD Algorithm itself.

Structure of each calculating program includes: data input in interactive mode. data input from data files. diagnostics of input data. calculations in accordance with the above mentioned CAFD algorithm needs. output data on computer screen or in specified files. The output data files may be used as interface with other programs. For example. some data from output data files of ***Thermodynamic Cycle Calculations*** program is used as a part of input data of ***Design Calculations*** programs. Each program is built as a main program interacting with different subroutines. The subroutines are kept in the libraries in accordance with their functions. There are 4 libraries: thermodynamic and transport properties library. heat transfer and pressure drop library. component performance library and general purpose library.

The Software interacts with Refrigerant Data Base (consists of data files with polynom coefficients of various refrigerants and updating software). Compressor Data Base (consists of data files with polynom coefficients of compressor performance and updating software). Finned Tube Design Data Base (consists of data files with design parameters of finned tube heat exchangers and updating software) and Input @ Output Data Base (consists of input and output data files for different applications).

CAFD APPLICATION EXAMPLE

Let us consider an air conditioning system that operates at outdoor temperature of 35^0C. indoor temperature of 27.6^0C and indoor relative humidity of 55%. Compressor of the air conditioning system is Copeland Compressor CR36K6 with current frequency of 50Hz. Indoor air flow rate is of 750 scfm. Evaporator is a finned tube heat exchanger with counterflow arrangement, staggered bundle. rifle area inside tubes. raised lance fins, 4 tube rows in depth, 12 tube rows in height and 700 mm in length. Tube external diameter is of 9.525 mm (3/8"); tube pitch in depth is of 22.23mm (7/8"); tube pitch in height is of 25.4mm (1"). Fin thickness is of 0.12mm; fin pitch is of 2.117 (12 FPI). Number of circuits is varied and may be of 2, 3, 4, 6, 8 or 12. Influence of the number of circuits on the air conditioning system performance is studied by the help of the CAFD Software. Figure 3 presents the results calculated.

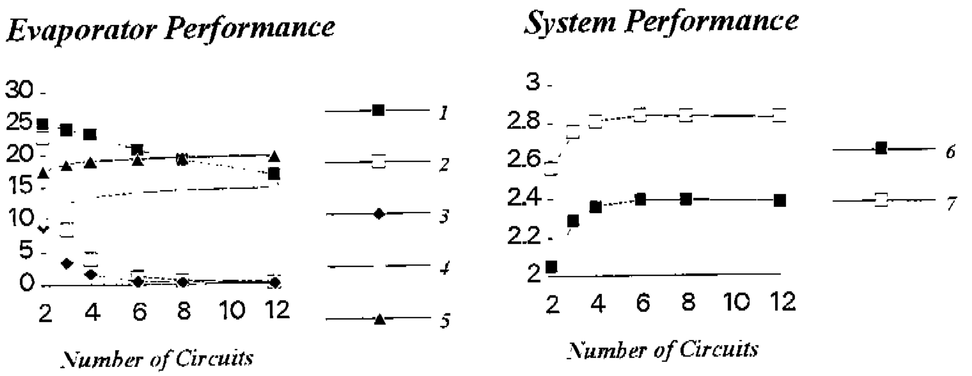

Figure 3. Evaporator and system Performance on Number of Circuits. *1 - Film Coefficient of Boiling Refrigerant,* $10\cdot\frac{kW}{m^2\cdot K}$; *2 - Refrigerant Pressure Drop, psi; 3 - Refrigerant Temperature Drop, K; 4 - Temperature Head at Refrigerant Inlet, K; 5 - Mean Logarithmic Temperature Difference, K; 6 - Cooling Capacity,* $10^{-4}\cdot Btuh$ *; 7 - COP.*

The more the numbers of the circuits are the lower the boiling refrigerant film coefficient appears because of the lowering velocity of boiling refrigerant inside the tube. The coefficient is decreased from $2503\frac{W}{m^2\cdot K}$ at 2 circuits to $1680\frac{W}{m^2\cdot K}$ at 12 circuits. On the other hand the lower velocity decreases refrigerant pressure drop from 22.78 psi at 2 circuits to 0.17 psi at 12 circuits. As a result of the pressure drop reduction, refrigerant pressure at the evaporator outlet is slightly increased and pressure at the evaporator inlet is slightly decreased. The refrigerant pressure drops accord to temperature drop of 8.96K and 0.06K respectively. Finally, available temperature head at the refrigerant inlet of the counterflow evaporator is increased from 9.81K to 14.8K. This leads to the higher mean logarithmic temperature difference that is changed from 17.645K to 19.762K.

Decrease of the film coefficient on the one hand and increase of the mean logarithmic temperature difference on the other hand lead to better performance of the system with more circuits. Air conditioning system with 2 circuits show cooling capacity of 20531 *Btuh* and COP of 2.56. System with 6 circuits shows cooling capacity of 23955 *Btuh* and COP of 2.84. If there are 8 or 12 circuits then system performance is even slightly reduced because of drastic decrease of film coefficient of boiling refrigerant. In addition more circuits requires higher manufacture expanses, so in this case the smallest number of 6 circuits is optimal value.

CONCLUSIONS

In the paper there are presented Computer Aided Functional Design Basis of Air Conditioning Systems with Heat Pumps. The Basis takes up operating principles of the systems being involved in computer aided way and concerns the Computer Aided Functional Algorithm, Software Main Building Principles and Software Structure. The Software developed is applicable for searching optimal solutions on optimal set of air-conditioning system components in terms of thermodynamic efficiency and cost.