

Computer Simulation of Automotive Air Conditioning – Components, System, and Vehicle: Part 2

Timothy C. Scott
University of Virginia

Dhananjay S. Joshi
Chrysler LLC

Frank Chianese
Chrysler LLC (Retired)

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ABSTRACT

In 1972, the first SAE paper describing the use of computer simulation as a design tool for automotive air conditioning was written by these authors. Since then, many such simulations have been used and new tools such as CFD have been applied to this problem. This paper reviews the work over that past 35 years and presents several of the improvements in the basic component and system models that have occurred. The areas where “empirical” information is required for model support and the value of CFD cabin and external air flow modeling are also discussed.

INTRODUCTION

The first published computer simulation of automotive air conditioning systems was given by Davis [1] in 1972. Since then, a number of similar computer models have been created and applied to both transient and steady state air conditioning problems. Computer fluid dynamic (CFD) now provides details of interior air flows. Many models also employ human thermal simulations for occupant comfort.

There have been other contributors to this field who did similar work in the 1970s. One who has received little recognition is R.A. Farr. Farr was originally with McQuay and later with R&R Supply Co. Farr created models of evaporators and condensers and coupled them with catalog data on compressors to create a computer simulation of commercial and residential air conditioning systems. This was used to assist customers in selecting components for such systems. Since Farr published no papers on the models, he has not received much credit for his work. His methods and advice, however, assisted others in the succeeding years. The

method of accounting for condenser subcooling and condenser and evaporator superheat through simple multipliers on the effectiveness proposed by Scott [2] came from Farr's methodology. These have been used in simulations by this author since 1978 [3]. Hopefully this will give Farr some of the credit he has missed.

While a few similar computer models emerged in the 1970s and 1980s [4,5], (See [6] for a summary), most models in use today were developed since the late 1990s [7-14]. These models have also been extended to the thermal comfort simulation [15-17]. The ability to do detailed simulations is largely due to the availability of CFD programs and a number of other generalized simulation packages.

In what follows, we will describe some of the types of models being used. We will also discuss the kinds of skills the analyst needs in order to build and use these models. Finally, we will argue that a model on the order of the original one [1] or simpler is quite adequate for much of the simulations needed. We also stress that the seasoned AC engineer with years on task, a solid knowledge of moist air processes, heat exchangers, and one-dimensional transient thermal modeling, and supported by a database of experimental studies that delineate valuable “rules of thumb” relating design variables to system performance is gone forever. The types of models we choose to support design decisions is a strong function of our personal abilities (or lack of same). Thus while simple models generally work just fine, there simply are no engineers left who are able to use them or run the special tests necessary to support them. It appears, then, that large complex models will be the tools of the future.

REQUIRED USER/DEVELOPER SKILLS

AC system analysis is not easy to do because it involves topics not normally treated in depth in undergraduate engineering education. As a result, the creators of AC system models are academics, industrial research engineers, or for-profit software developers.

The people who need to use these models are component developers/suppliers, advanced development groups, academic researchers, and the automotive system designer.

Quite typically, the automotive system designer has the task of selecting, from a limited number of components, a system that will provide sufficient cooling for a vehicle under development. This person will rarely remain in such a job for a time sufficient to understand the details of any models he/she might be using or developing. The problem we continually face is how to get such people to use AC system and component models. Indeed, people with advanced degrees and experience in two-phase flow modeling, etc. are rarely occupied with the task of system component selection.

The work that culminated in the model described in [1] was started in 1969 by a person transferred up from the Chrysler Space Division who had done the thermal modeling of the Apollo capsule (Davis), one person doing graduate work in two phase flow and heat exchangers (Scott), a mixture of people with many years of experience in vehicle air conditioning (Chianese and others) and a mandate from management to "do something" to improve the performance of the system so as to gain a competitive and cost advantage.

All of the system components (evaporator, condenser, compressor) were built in-house through the Chrysler Airtemp division. This meant that we had access to all the dimensions and specifications of the components as well as test facilities at Airtemp. Our own laboratory in Highland Park Mi. also had evaporator and compressor test tunnels as well as a compressor calorimeter. Further, our department had control of the climate test cell where vehicle cooldowns were performed.

This was an ideal situation for the development of a computer simulation. Still, most system design engineers could not understand or run the simulation and relied on us to do studies for them.

This issue is still important today. And since few people spend more than a few years in any specific function at most U.S. automotive companies, it will probably not get resolved.

So while the number of models that have been developed is significant, and the accuracy of most are quite sufficient, the degree to which they are consistently used in the product design stage is less than the published papers would lead one to think.

In order to increase the use of these models, a number of software suppliers have created products that are easier to use. The hope is that applications engineers will not have to spend a lot of time learning about two-phase flow heat transfer, moist air processes, and non-linear system modeling in order to use the models.

In this paper we discuss some of the present modeling methods. We also present perhaps the simplest workable model based on fundamental principles.

COMPONENT MODELS

There are three basic levels of component models

Simple models use lumped heat exchanger analysis or curves fit to supplier or tested performance data. Uniform air flows are assumed with, perhaps, a "maldistribution" or similar multiplier. For evaporators and condensers, the different regions of single and two-phase flow are lumped. This method is based on the early techniques that were developed before significant computer power was available [18,19,20] and follow the classic treatment by Threlkeld [21]. This is also the method used in the ASHRAE exchanger test standard [22]. Other examples are [23-26].

For compressors, a table of flows and efficiencies may be used directly or fit with simple equations. Expansion devices are modeled as constant enthalpy or the evaporator superheat is specified.

Expansion devices are simply modeled as constant enthalpy and/or fixed evaporator superheat controllers.

Simple models are the easiest to use but require some knowledge of basic heat exchanger and moist air processes if one is to understand them.

Detailed or "distributed" models divide heat exchangers up into single and two-phase flow regions. Correlations for refrigerant side and air side convection and pressure drop are used. These are necessary in order to delineate the boundaries between single and two-phase regions. Air side velocity and temperature variations may also be simulated. [27-29] These models require detailed information about exchanger dimensions and circuiting. As such, they are more commonly used by evaporator and condenser suppliers because such geometric information is often difficult for others to access.

Detailed models tend to use two-phase flow orifice models for expansion devices as there are a number of these available [30-32]. They may also incorporate control system models and models for piping, accumulators, and the like. Simple models, however, are normally still used for compressors.

A detailed model is a useful tool for the component manufacturer since it can evaluate circuiting configurations and the effects of design changes on pressure drops and other performance parameters. Several software package providers have incorporated these detailed models into whole system simulators. The volume of information required by the user is considerable, however. An automotive manufacturer who does not make the components must then engage the suppliers to provide much of this information in order to do a system simulation.

“Embedded” models are models that operate within a larger simulation environment.. These make use of standardized “blocks” for heat exchangers, pumps, piping, etc. or their parts and modify them so that they may be applied to two-phase flows and moist air processes. In this way, an AC system simulation can be run on a software product also used for fuel system plumbing, engine cooling, and other applications. The modeling tool may be a commercial product such as Flowmaster [12,33], Kuli, etc. or a specific software package designed for this kind of problem such as e-Thermal [34]. Some of these models use actual representations of the components while others may create “pseudo” or equivalent components. For example, a condenser is modeled as a straight tube without fins using “multipliers” to account for the increased area and fin efficiency. Such “pseudo” models allow one to use a smaller number of standard modeling blocks but require actual component performance data in order to determine the values of the multipliers.

All of the recent models are part of the ongoing effort to create tools that are easy to use so that more people will make use of system simulation and thus create better designs with less effort. Thus far, however, those using the models must still have a considerable amount of knowledge.

Interestingly, the ability of these three different modeling methods to simulate actual performance is about the same. Garcia[35] has shown that the detailed models of the processes within evaporators and condensers yield good agreement with experiment. Oskarsson[36] also found that predictions of models that simply divided the exchanger into 2-phase and single phase regions were as good as detailed finite element models. And since simple models and pseudo-models all required actual component test information as their base, they are of equal accuracy. In fact, Chwalowski [37], in comparing several levels of analysis sophistication showed that they are all essentially equal in their ability to predict the installed capacity of evaporators. And this ability was not as good as one would like. Typical errors of up to 10% are common when prediction by models is compared with installed performance. This is a point we shall return to shortly.

AC SYSTEM OPERATING POINT

The system operating point problem is to find the evaporating and condensing temperatures when the information shown in Figure (1) is given..

In the simplest case, the condenser subcooling and evaporator superheat are specified. Then system “balance” point for a constant compressor speed can be obtained by a graphical procedure. This procedure is commonly used with residential and commercial units and is outlined in the ASHRAE Handbook [38]. Further discussion is provided by Stoecker [39]

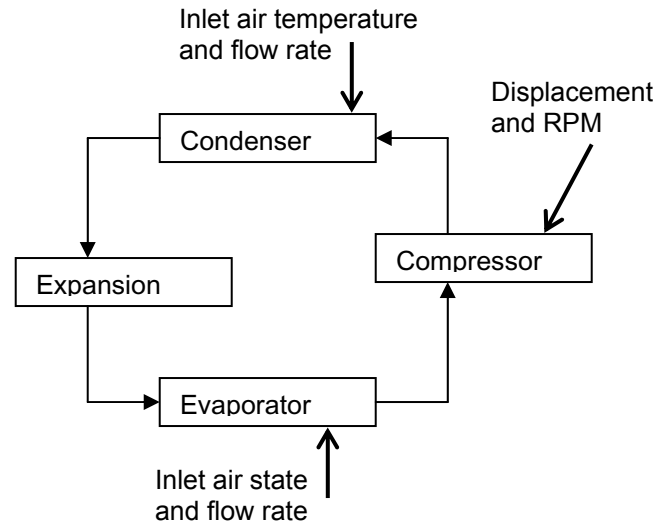


FIG. 1: The System Balance Point Problem

In automotive applications, the process is not this simple, especially when we consider the wide range of operating conditions a vehicle AC system encounters.

The evaporating and condensing temperatures may be found by requiring the mass flow rate through each exchanger to equal those of the compressor. The simplest procedure is to set the evaporator superheat and condenser subcooling. Then the solution process is essentially as illustrated in [1]:

1. Guess an evaporating temperature
2. Guess a condensing temperature
3. Determine the compressor mass flow rate and outlet superheat from a compressor model
4. Compare the condenser heat transfer required to satisfy the specified subcooling from the condenser model with the heat transfer given by the mass flow rate times the condenser enthalpy difference
5. Adjust the condensing temperature until the above is satisfied
6. Now compare the evaporator heat transfer from the evaporator model with the heat transfer given by the mass flow rate times the evaporator enthalpy difference.