

User interface design considerations

EESCoolTools - a collection of simulation models for refrigeration applications

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Abstract

When designing a user interface for a simulation model there are several important issues to consider: Who is the target user group, and which a priori information can be expected. What questions do the users want answers to and what questions are answered using a specific model?

When developing the user interface of EESCoolTools these issues led to a series of simulation tools each with a specific purpose and a carefully selected set of input and output variables.

To allow a more wide range of questions to be answered by the same model, the user can change between different sets of input and output variables. This feature requires special attention when designing the user interface and a special approach for controlling the user selection of input and output variables are developed. To obtain a consistent system description the different input variables are grouped corresponding to the phenomena they describe and the user can select only one input variable per phenomena. This method ensures that all phenomena are described - i.e. the equation system is non singular.

Numerical robustness of the model is assured by applying a so-called cycle-cored numerical structure, which has the consequens that the user does not have to specify any start guesses, etc.

The design approach developed have resulted in a number of simulation tools which allow users with limited theoretical knowledge about refrigeration systems, mathematical models and simulation to use them while the expert users still have a lot of flexibility in choosing input variables and in assigning values of parameters.

Background

EESCoolTools [1] is a selection of simulation tools aimed at the refrigeration industry. Today, a lot of people do not use any kind of simulation tools when designing or modifying refrigeration systems. They rely on rules of thumb and the use of component selection tools from the different manufactures. To design more energy efficient refrigeration systems energy consultants and engineers could benefit from using simulation tools.

The name EESCoolTools is a combination of the three words EES, Cool and Tools:

- **"EES"** refers to the name of the program used to develop the simulation models (Engineering Equation Solver - EES) by F-Chart [2].
- **"Cool"** refers to that the programs are related to the area of refrigeration.
- **"Tools"** refers to that the programs are thought to be tools enabling you to make faster and more detailed system design and energy analysis.

EESCoolTools is a part of the software collection CoolPack [1], [4].

The design goal of EESCoolTools has been to develop simulation tools that are easy and fast to use. The users should not encounter any numerical problems. This has demanded careful attention on both the numerical parts of the tools and the user interface.

The easy way to make a simulation tool numerically robust is to limit the freedom of the user. This could be to limit the number of inputs to the model or to use a single input output structure. But this is not a very satisfying way of solving the problem as it constrains the use of the simulation model severely.

Users

The target user group for EESCoolTools is very broad. This could be developers and designers of refrigeration systems, energy consultants and engineers at the R&D departments of companies that produce components for refrigeration systems. All of these different users are interested in a broader view of how the whole refrigeration system is working. But they want this knowledge for different reasons. The system designer wants to know the different temperatures, pressures and capacities that enable him/her to dimension the different components in the refrigeration system. The component developer wants to know the environment (boundary conditions) in which his/her component are working in e.g. the different temperatures, pressures, mass flows for the expansion valve. The energy consultant is mostly interested in the overall energy consumption and wants to know how he can reduce it.

All these people have two things in common:

- limited knowledge about energy system modelling in general
- limited experience or knowledge about solving numerical problems

The user background has a significant impact on two elements when developing simulation tools.

1. The users limited knowledge about the numerical problems demand that the user do not have to struggle with start guesses and other things related to making the model converge.
2. The user probably does not know what information is needed to describe the different phenomena in a refrigeration cycle consistently.

Both of these problems are addressed in EESCoolTools. The first issue is only touched briefly in this paper while the second issue is discussed in detail since it has a great impact on the user interface of the simulation tools.

Another important matter that involves the users is what a priori information does they possess. The very sophisticated simulation tool that can simulate a refrigeration system in every detail is not very useful if the user is not able to provide the large amount of input information this tool might demand. There can be two major reasons why the user does not have the information:

1. The user does not know enough about refrigeration systems and do not understand what information the tool requires.
2. The user is not able to make reasonable assumptions about input values for which he does not have information.

This has led to a careful selection of input and output variables based on what can be expected from the users and from the feedback that has been received during testing of tools. The difficult task is to make the tools easy to use without making them too restricted or trivial.

Numerical considerations

When the development of the simulation tools for CoolPack was started some critical decisions were taken regarding which mathematical models should be used.

Model structure

A tool in which the user could build a mathematical model of any refrigeration system by selecting the necessary components from libraries and connecting them afterwards has always been a dream among engineers simulating energy systems. First of all because the connections represent the flow of fluids in pipes between the different components and therefore is a very intuitive way of modelling. The idea about a component oriented tool is a very appealing thought. Mainly because it gives “unlimited” freedom in system designs but this tool is also a very difficult task to implement in a way that allows other than experts to use it.

The user of such a tool has to be familiar with the numerical problems that can arise when connecting the different components.

Mathematically, the connections between the different component models are established through a fixed set of coupling variables. The most common numerical problems are related to start guesses for these and other variables as well as problems related to generation of an inconsistent equation system. The user described in the previous paragraph does not know enough about these mathematical phenomena to solve them himself without using a significant amount of time or seeking help elsewhere.

Because of the problems with the component oriented method and considering the present target user group, a different approach was adopted in EESCoolTools. Instead of one large tool it was decided to build several specific tools. Each tool simulates a typical refrigeration system. By doing this some flexibility in system configurations is lost. But most of the flexibility is regained through a more numerical robust model that allows a wider application range.

The models are all based on a so-called cycle-cored structure as described by B.D. Rasmussen & A. Jakobsen [3]. As the name indicates this method is focusing on how the components are connected to the underlying refrigeration cycle instead of how the components are connected together.

A core of equations is determining which processes or phenomena the cycle consists of – compression, expansion, and so on. The individual processes are all described by

general variables like thermal efficiency, isentropic efficiency, subcooling and superheating. All of the general variables describing the cycle are basically insensitive to the mass flow and choice of refrigerant. This means that it is easier to make general valid start guesses for these variables, which will fit a model of a refrigeration system, whether it has a large or small refrigeration capacity.

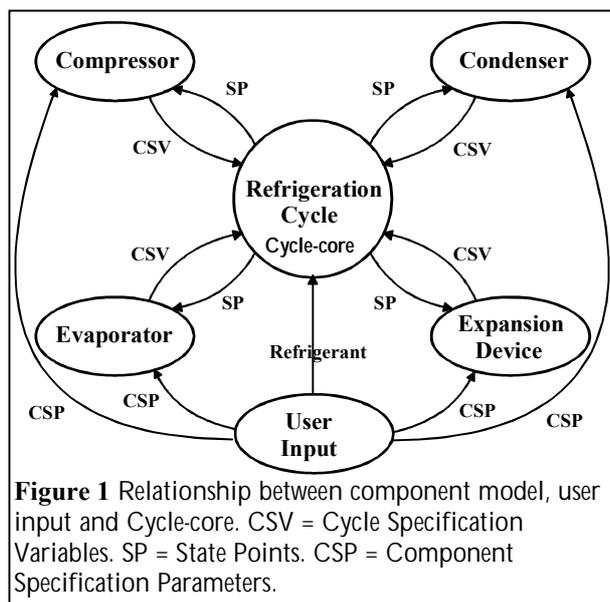
The cycle-core generates the state point array of the refrigeration cycle that is one of the simulation goals. The state point array holds information about temperature, enthalpy, pressure, and density for every state point.

Separate models are used to calculate the general cycle specification variables for the cycle-core. These models can vary in detail and could be a very complicated and detailed model of the compressor for example. The cycle specification variables can also be input directly from the user interface. For example the user could give the superheating of the refrigerant leaving the evaporator as input. Figure 1 is describing the connection between the different elements in the model.

The cycle-cored structure has made it possible to make user interaction unnecessary regarding start guesses. This includes the possibility to use the same tool for domestic refrigeration systems with a refrigeration capacity as low as 10 W and for large refrigeration system with capacities as high as 10 MW. Furthermore, it has shown that this method is numerically robust enough to allow different input and output structures to be used.

Input/output problems

One of the large problems when simulating energy systems is to describe all phenomena consistently. If this is not done, singularities will occur. For example, the user can not use both the isentropic efficiency and the power consumption as inputs for the phenomenon compressor performance, without making the equation system singular. A model with only one input/output structure is an easy way to avoid this problem because the developer can make sure that the all phenomena are consistently described. But this also limits the application range for a given model. If the user



does not have information about one of the inputs for the model but instead has information about one of the outputs, he/she typically is using the tool backwards – iterating. An example could be the compressor performance. The user knows the isentropic efficiency of the compressor, but the simulation tool has the power consumption of the compressor as input. To use the tool, the user has to guess a value of the power consumption then simulate and see if the resulting isentropic efficiency matches the desired value. This is not a very attractive way to get around this problem.

EES

The graphical user interface, GUI, and the mathematical models are often implemented in separate software. This separation happens because the mathematical models and user interface are implemented in software each optimised for these two tasks. The user interface is then mostly seeing the mathematical model as an external program with a fixed input/output structure, see figure 2.

Both the numerical solver and the user interface of all EESCoolTools are built-in in the simulation software called EES. EES is a user-friendly steady state simulation tool with built-in thermodynamic and property functions for a wide range of natural and synthetic

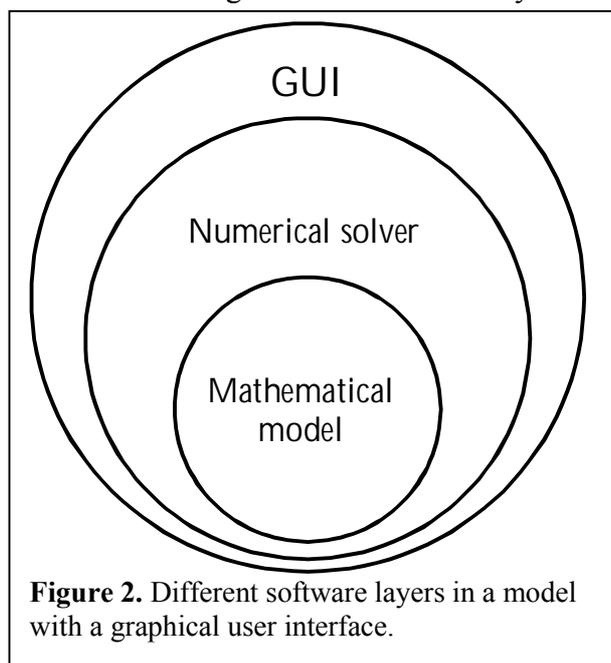


Figure 2. Different software layers in a model with a graphical user interface.

refrigerants. EES is also capable of generating an executable version of a model that may be freely distributed. The executable is nearly a full version of EES but the user can not load another model and some of the variable options are also disabled.

Numerical implementation

EES has all the features needed to implement the models described above e.g. procedures, functions, logical structures and access to third party DLLs. Depending on the refrigeration system the implementation will be a combination of equations written directly in EES and external procedures. The cycle-cored structure is implemented in a single procedure. Component models are also implemented in procedures.

Before solving the equation system EES is compiling all equations. During compilation EES is blocking the equations according to the way they depend on each other. This way the explicit and implicit parts of the equation system are separated and the CPU-time needed for solving the equation system is greatly reduced. The compiling is done each time the user solves the model even if there is no changes in the equation system. One of the prerequisites for changing the input/output structure of the model is the compiling of equation system. In a numerical solver that does not compile the equations there has to be a new version of the equations for each new input/output structure. When the number of input/output structures are growing it is no longer an operational approach. Instead the solver has to compile the equation system each time it is changed.

To help the solver finding a solution EES allows the user to specify upper and lower limits for all the variables as well as start guess values. This capability is very useful for variables like isentropic efficiency because the developer knows beforehand that they are only allowed to have values between 0 and 1. This feature in combination with the cycle-cored structure has made the chance of finding a solution nearly 100% as long as the user provides physically meaningful inputs.

User interface in EES

EES has an advanced user interface design capability that will be briefly described. A user interface in EES consists of a main diagram window. From the main diagram window there can be access to several subdiagram windows through buttons or hot areas. In each window the graphical part can be generated with the built-in graphic tools and/or by pasting a bitmap. There is access to all variables used in the model and these can either be configured as input or output variables.

By using some of the built-in logic in EES it is possible to change the input/output structure of the models without changing the user interface. Since EES is always compiling all

equations before solving them, this has no impact on the CPU-time.

Layout of user interface

The layout philosophy of the user interface has been developed through a combination of knowledge about which questions the mathematical models can answer and what knowledge and information the users have available and need.

The interfaces that will be described in the following paragraph are all for cycle-oriented tools. Tools that are more component oriented are basically using the same user interface philosophy.

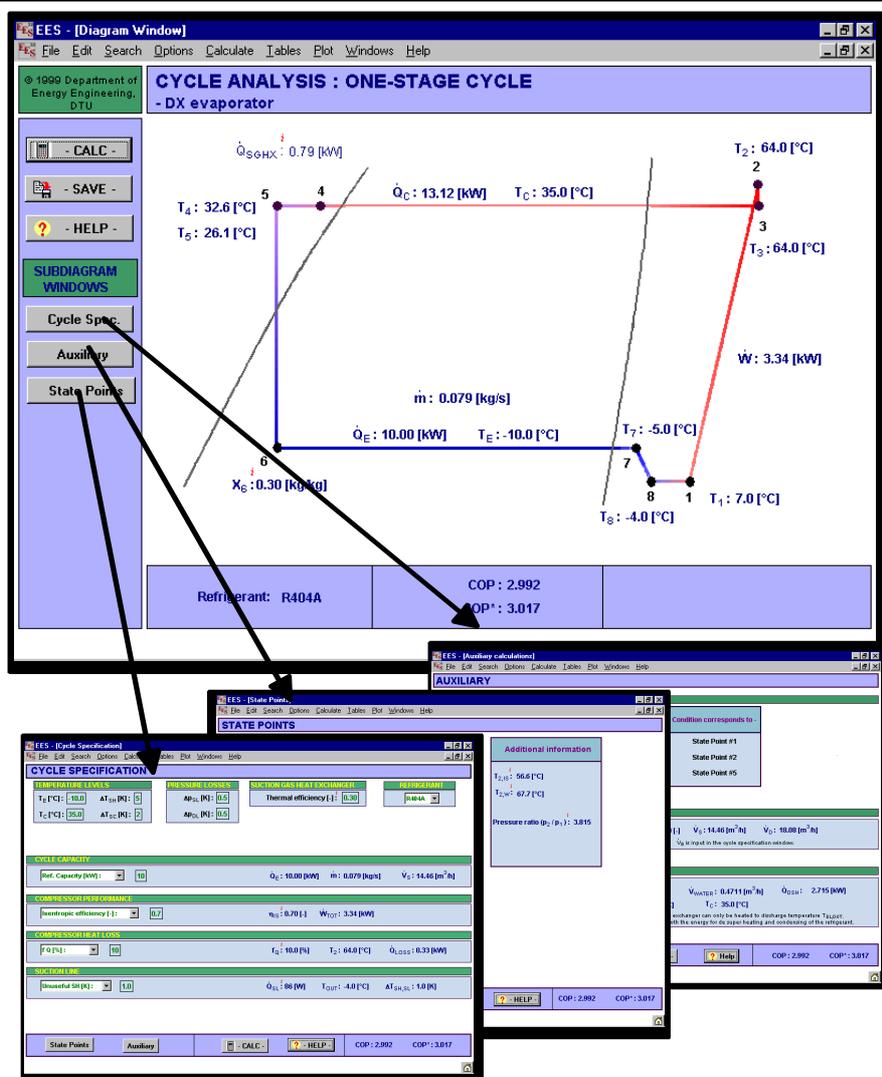


Figure 3. The Diagram windows in a typical EESCoolTool are a main diagram window from which there is access to the following subdiagrams: Cycle Specification, State Points and Auxiliary.

General layout of diagram windows

The user interface consists of several diagram windows. A main diagram window with several subdiagram windows - See figure 1. The main diagram window has several tasks. One is to give the user an introduction to the objective of the specific tool. In figure 3 the main diagram window shows a $\log(p),h$ -diagram of a simple one-stage cycle. This picture serve as a fast way to indicate what the tool is simulating as well as a fast way to display a selection of the main outputs from the simulation model. Furthermore, the picture shows how the different state points in the refrigeration cycle are numbered.

From the toolbar to the left there is access to the following three subdiagram windows: Cycle Specification, State Points and Auxiliary.

In all subdiagram windows there is a toolbar that has the same possibilities as the one in the main diagram window.

The graphic capabilities of EES have been widely used to help the user separate the different input and output variables. And the same four colours have been used in all tools to symbolise different topics.

Cycle Specification window

A refrigeration cycle consists of several phenomena that must be described by the user. The number of phenomena depends on the level of detail of the simulation model of the cycle. The phenomena involved in a refrigeration cycle could be the isentropic compression of the refrigerant or the refrigeration capacity of the cycle. The user must describe each phenomenon in the model so that the equation system remains consistent. To assist the user in entering all inputs related to the cycle specification variables these are all placed in one subdiagram window – Cycle Specification - see figure 4. Based on the description of the different phenomena in the

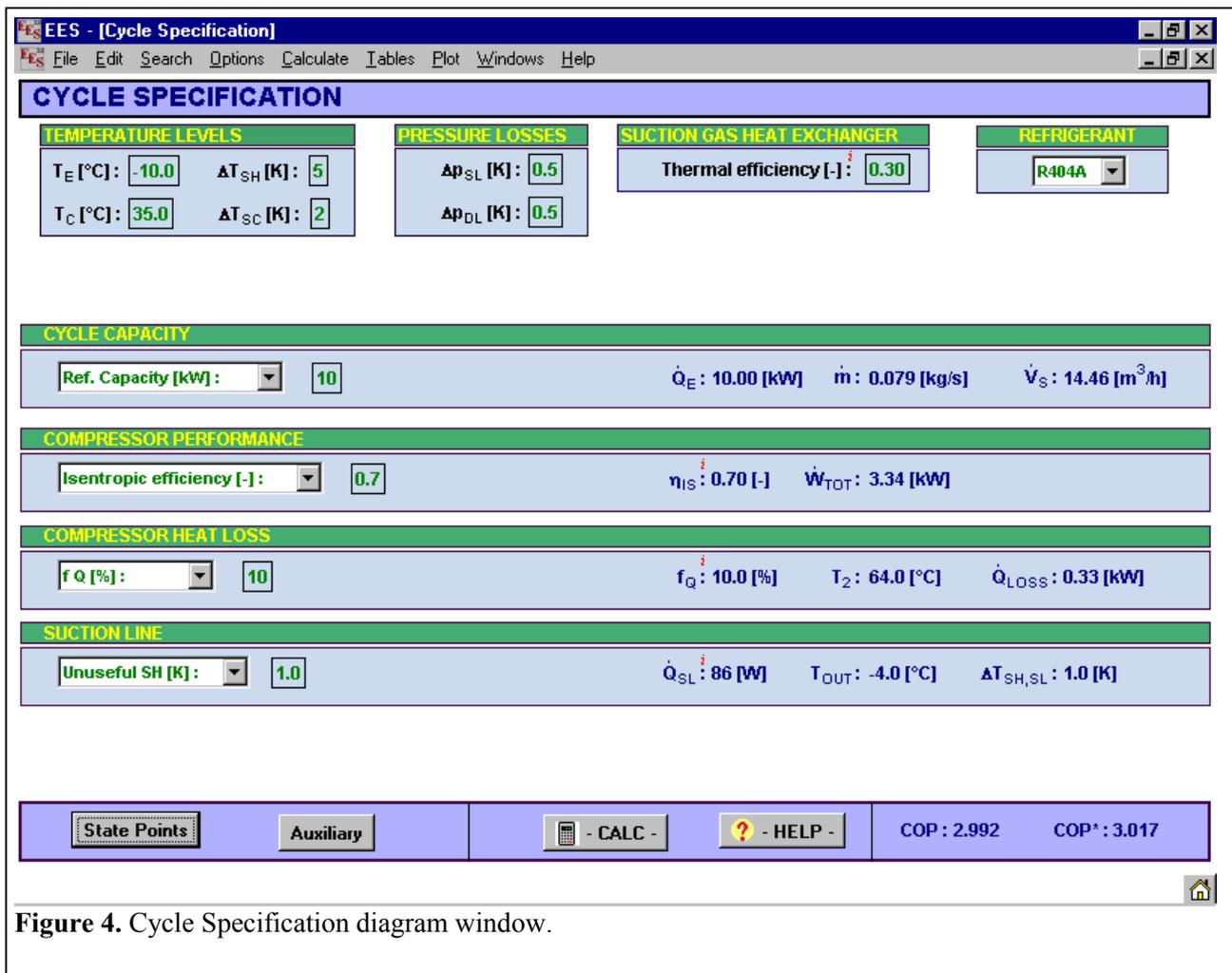


Figure 4. Cycle Specification diagram window.



Figure 5. The figure shows the available input/output variables of the phenomenon compressor performance.

model the complete state point array is generated.

Figure 5 shows how the phenomenon compressor performance is handled in EESCoolTools. As seen in figure 5 all inputs and outputs related to a phenomenon is described within a box to show which outputs are related to which inputs.

To the left in figure 5 the user chooses the input variable he wants to use to describe the phenomenon. The selection is done using a drop down menu. To the right in figure 5 the outputs from the model are displayed. The input variable is echoed as well. This implementation ensures that each phenomenon is described by the relevant variables.

It is not possible to select the same input variable more than once in the cycle specification window. This way the user can not select the same variable twice and make the model singular.

State Points

This diagram window contains the resulting state point array from the model as well as some additional information about some of the state points, see figure 6. With the information available in this window the user can do further calculations that is not covered in the tool.

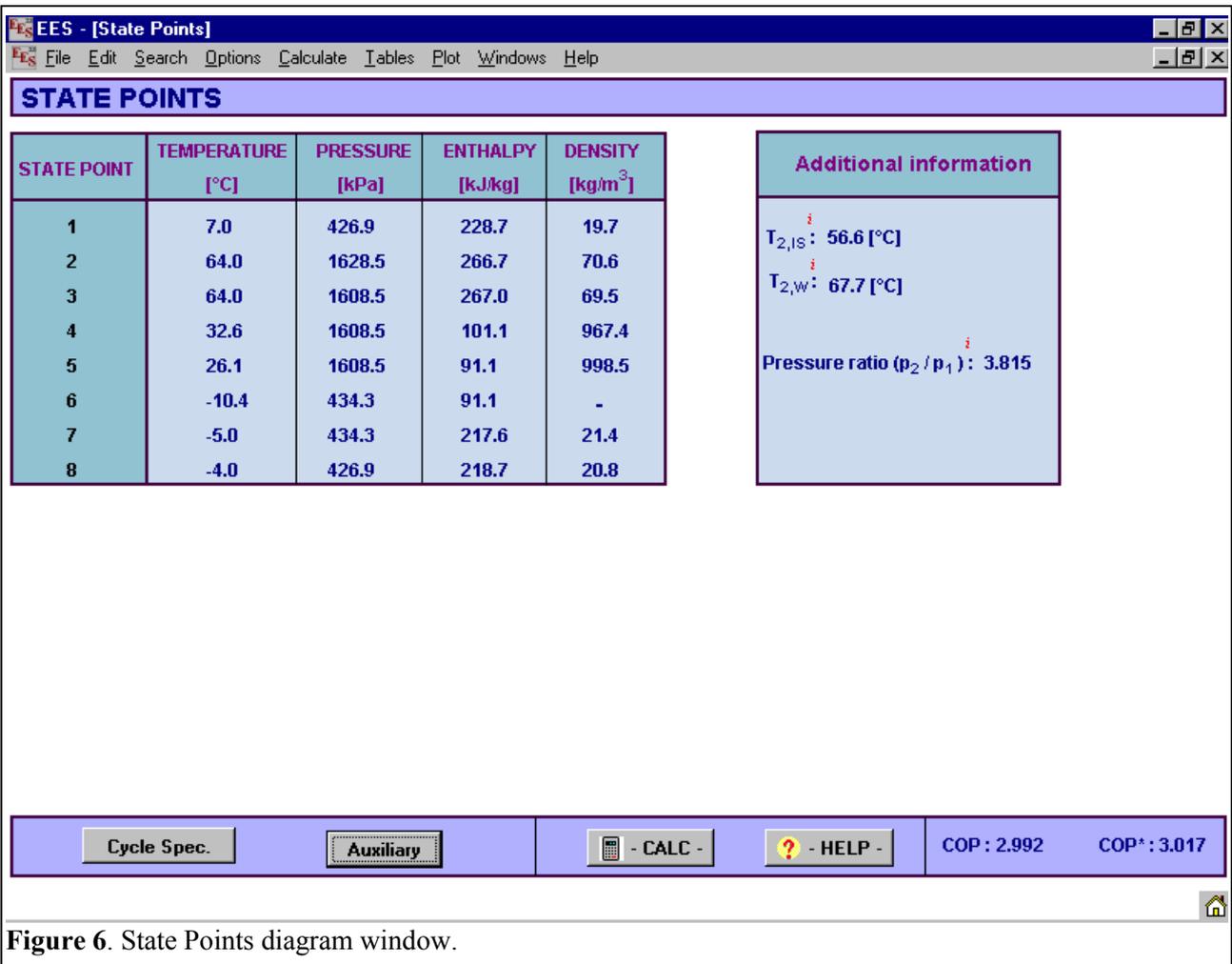


Figure 6. State Points diagram window.

Auxiliary

As mentioned in the description of the cycle specification window there is a part of the equations that describe the refrigeration cycle and generate the state point array. Based on the state point array additional calculations can be added. An example of such calculations could be a simple calculation of the pipe diameter given a desired velocity of the fluid. The calculations will take the information about density from the relevant state points together with the mass flow and then calculate the pipe diameter. Another example could be calculation of the displacement or volumetric efficiency of the compressor. Based on the state point at the inlet of the compressor the suction volume can be calculated if either the displacement volume or volumetric efficiency is used as input.

The input and outputs for this kind of calculations is all placed in the Auxiliary calculation window, see figure 7.

An input variable in the Auxiliary window has only effect on calculations that are related to outputs in the same graphical box in which they are input.

Discussion

When the development of the user interface for EESCoolTools was started the capabilities of EES were not as numerous as they are today. There was just one window and only input and output variables were allowed. Such restrictions made it necessary to be very innovative. This has kept the user interface simple even though the graphical capabilities of EES has now increased a lot

The layout of the user interface for all simulation software depends very much on the software tools used to build them. This might make it difficult to transfer the strategy used in one simulation model to another but some of the ideas used in EESCoolTools should work in general.

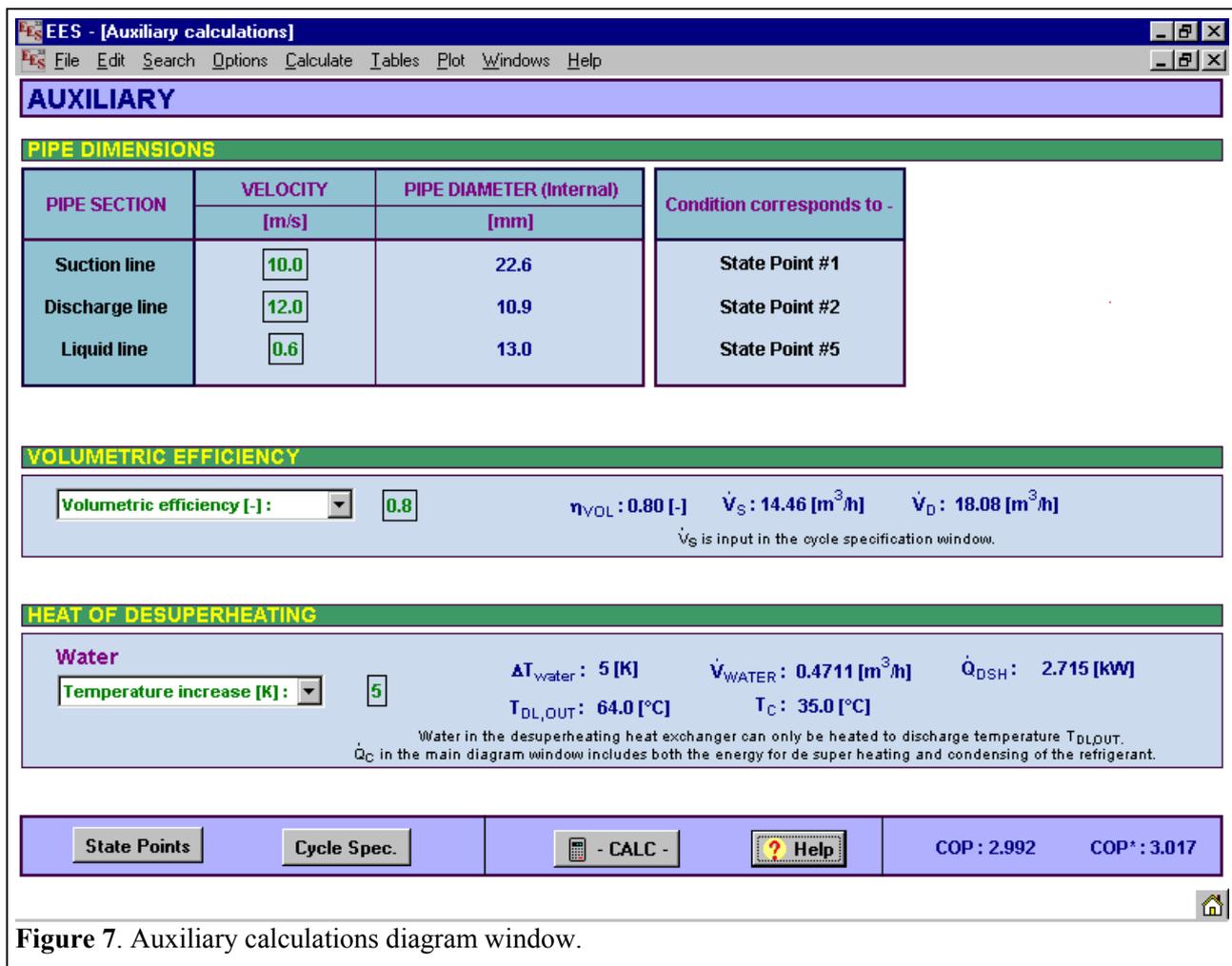


Figure 7. Auxiliary calculations diagram window.

The strategy of separating the user interface for the input variables that defines the refrigeration cycle from the rest of the input variables can be used in any energy system simulation. This also applies to using graphics to indicate which input and outputs are related to a specific phenomenon.

The strategy of grouping choice of input variables and corresponding phenomena that ensures a consistently described system could also be used in other simulation environments.

Further work

So far all the models in EESCoolTools are individual tools and can only be used as such. There is a great potential in using the information generated in one tool as basis for further calculations in other tools. To do this effectively both EES and EESCoolTools will have to be prepared for this.

Acknowledgement

The mathematical models used in EESCoolTools are developed in connection with the research project called SysSim. The aim of SysSim is to develop simulation tools to be used in connection with energy optimization in refrigeration systems. Project SysSim and EESCoolTools are financed by the Danish Energy Agency.

The developers would like to thank Professor S.A. Klein at University of Wisconsin for a fruitful dialog that has been beneficial for both EES and EESCoolTools.

References

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