Introduction of Room Air Conditioner System Simulation Platform

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Content

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Function of the software

AC System simulation Platform

System Type:
- Cooling Only
- Cooling & Heating

Refrigerant:
- R410A
- R290
- R22
- R32

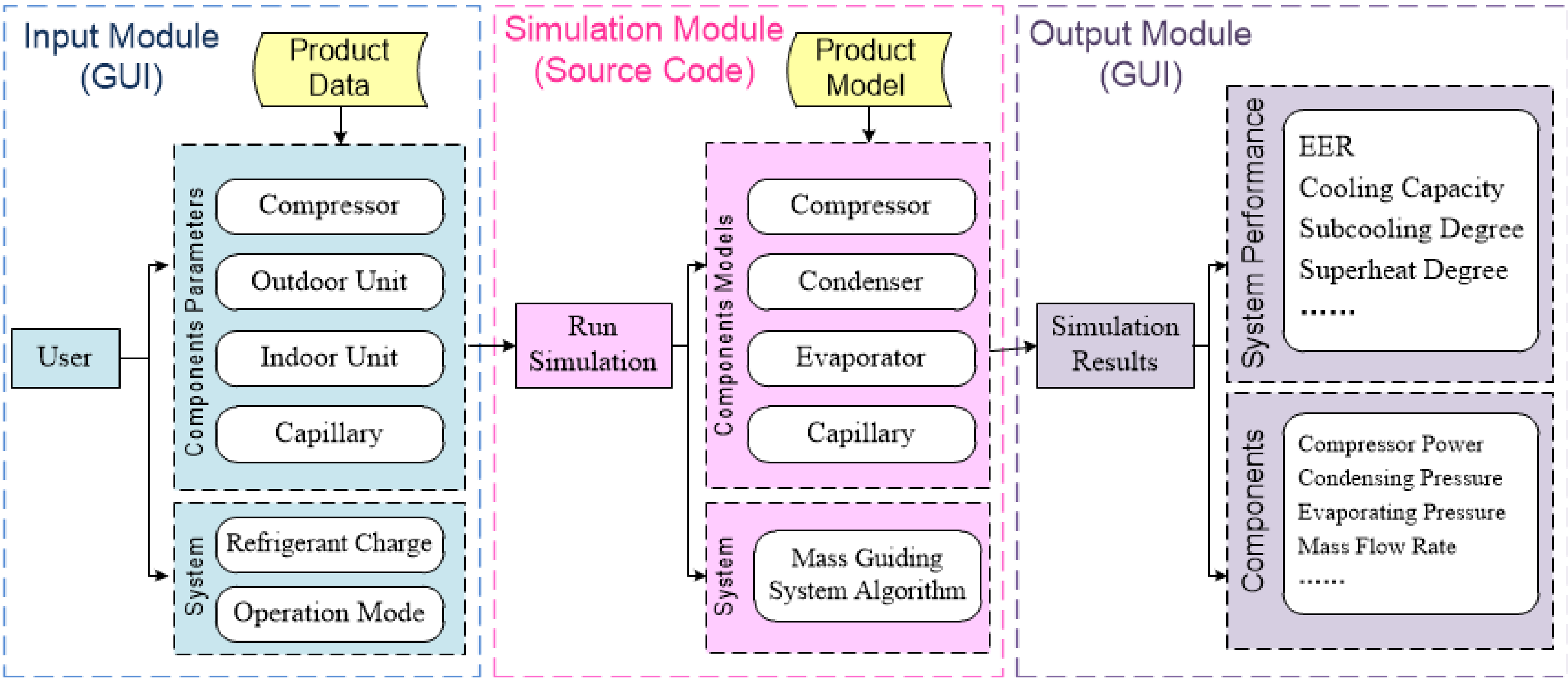
- Compressor Data Import
- Confidential Data Protection

- Performance Simulation
- Analysis for performance parameters

Unit Setting:
- SI
- English

Operating Systems:
- Win 7 & Win 8
- Chinese & English

Architecture of the software



The software is able to employ user's compressor data in the simulation process, and the data can be imported as a DLL file.

Content

Mathematical model and Algorithm

Compressor | Capillary | Heat Exchanger | System

Existing Problems

1) General model can not reflect the compressor specific performance

2) Ten coefficient model doesn’t fit for the system simulation progress

3) The confidential data of the compressor can not be easily obtained

Solution — Developing a Product Data Interactive Model

1) Using product data to reflect the compressor characteristics

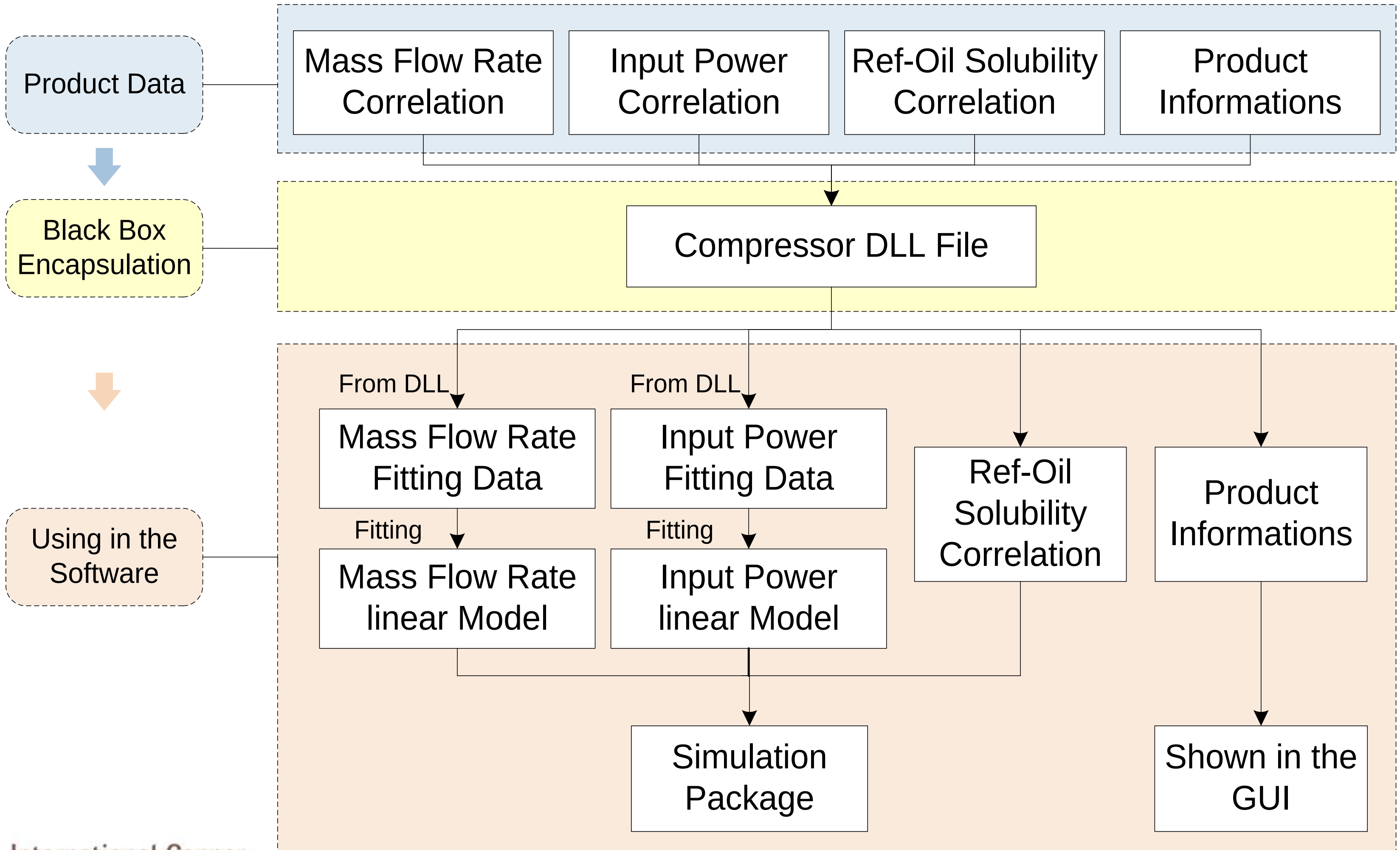
2) Having wide application range to fit system simulation progress

3) Protect product confidential data

Mathematical model and Algorithm

Compressor | Capillary | Heat Exchanger | System

— Technical Roadmap



Mathematical model and Algorithm

Compressor | Capillary | Heat Exchanger | System

— Mass Flow Rate Equation

变频压缩机质量流量产品数据（20系数模型）

$$\dot{m} = \sum_{n=1}^{20} c_n T_e^i T_c^j f_r^{3-i-j},\quad 其中\ i \ge 0, j \ge 0, i + j \le 3$$

将频率项线性化

引入质量流量理论模型

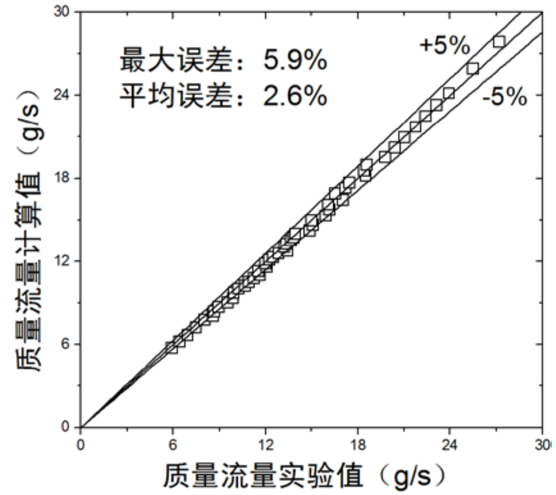
$$\dot{m} = \frac{\dot{V}}{v_i} f\left(a + b\frac{p_o}{p_i}\right),\quad 其中\ a = F_1(f), b = F_2(f)$$

将系数线性化

基于理论的变频压缩机线性化流量模型：

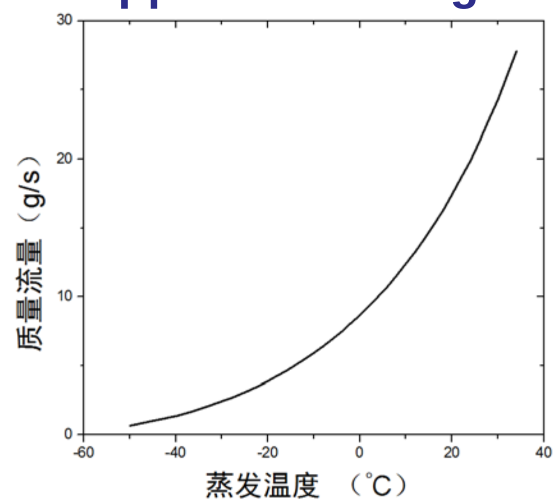
$$\dot{m}_x = \frac{\dot{V}}{v_i}\left(C_0 + C_1 f_x + C_2 \frac{p_o}{p_i} + C_3 f_x \frac{p_o}{p_i}\right)$$

Accuracy Validation



- Maximum Error:5.9%
- Average Error:2.6%

Application Range



Applicable in large range (Te: from -30 ^{o}C to 30 ^{o}C)

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Mathematical model and Algorithm

Compressor | Capillary | Heat Exchanger | System

— Input Power Equation

功率计算理论模型：

$$\dot{W}_e = c + d\dot{W}_{th}$$

$$\dot{W}_{th} = \dot{m}\cdot p_i \cdot v_i \cdot \left(\frac{n}{n-1}\right)\left[\left(\frac{p_o}{p_i}\right)^{\frac{n-1}{n}} - 1\right]$$

令 $x_1 = \dot{m}\cdot p_i \cdot v_i$, $x_2 = p_o / p_i$, $a = (n-1)/n$

代入整理得：

$$\dot{W}_e = c + \frac{d}{a}\left(x_1 x_2^{a} - x_1\right)$$

令 $x = x_1 x_2^{a} - x_1$　$y = \dot{W}_e$, $b = d/a$

代入整理得：

$$y = c + bx \qquad a = \ln\left(\frac{x + x_1}{x_1}\right) / \ln x_2$$

选 取 3 n 组 工 况 ， 记 为 $\{x_{1k}\}_n$、$\{x_{2k}\}_n$，其中k=1、2、3，n≥2。

变频压缩机功率产品数据：

$$\dot{m} = \sum_{n=1}^{20} c_n T_e^{i} T_c^{j} f_r^{3-i-j},$$

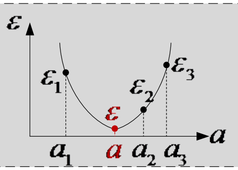
其中 $i \ge 0, j \ge 0, i + j \le 3$

计算出的功率记为$\{y_k\}_n$

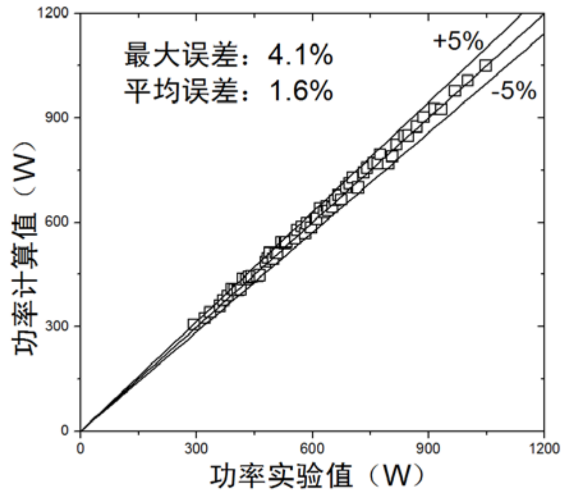
引入残差 $\varepsilon = \sum\left(y' - y\right)^2$

采用求解残差极小值法实现线性拟合

拟合得到模型系数a、b、c



☐ Accuracy Validation



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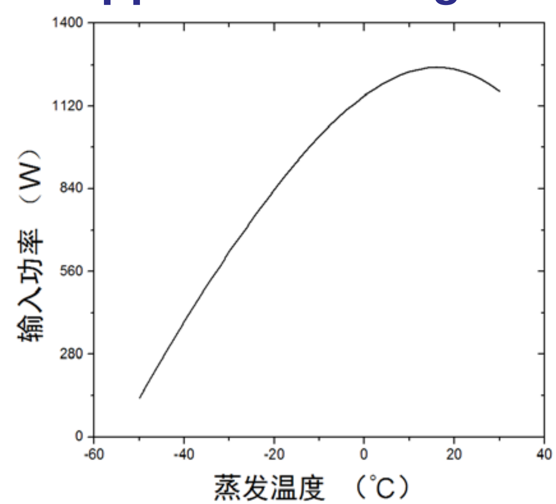
☐ Application Range



Applicable in large range (Te: from -30 ºC to 30 ºC)

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Mathematical model and Algorithm

Compressor | **Capillary** | Heat Exchanger | System

Basic Equation

- The continuity equation: $m = \frac{\pi}{4} D^2 G = \text{const}$
- The energy equation: $h = \text{const}$
- The momentum equation: $-\mathrm{d}P = G^2 \mathrm{d}v + \frac{1}{2}\frac{f}{D} v G^2 \mathrm{d}L$

Adiabatic capillary

- Superheated
- Two-phase
- Subcool

Superheated refrigerant in the capillary

$$L_{sh} = 2D\left[\frac{p_{sh1}^2 - p_{sh2}^2}{\left(p_{sh1}v_{sh1} + p_{sh2}v_{sh2}\right)} + G^2 \ln\frac{p_{sh2}}{p_{sh1}}\right] \Big/ \left(G^2 f_{sh}\right)$$

Two-phase refrigerant in the capillary

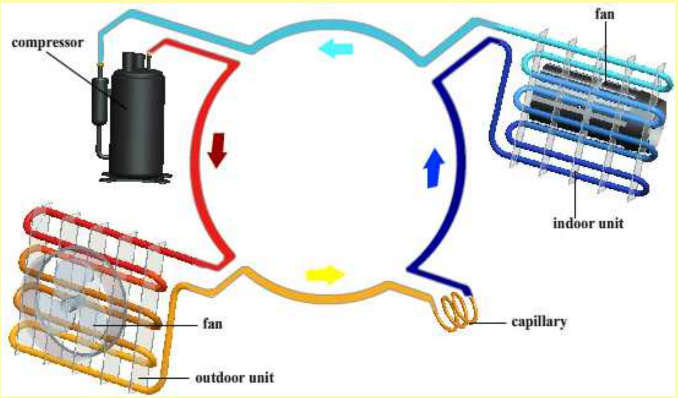
$$L_{tp}^* = \ln\left(\frac{p_{tp2}^*}{k_1 + (1-k_1)p_{tp2}^*}\right) - \frac{1}{k_2(1-k_1)}\left\{p_{tp2}^* - 1 - \frac{k_1}{1-k_1}\ln\left[k_1 + (1-k_1)p_{tp2}^*\right]\right\}$$

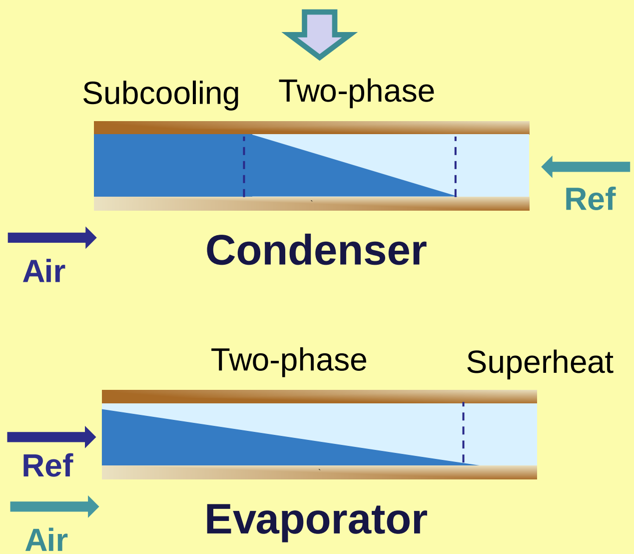
Subcooled refrigerant in the capillary

$$L_{sc} = \frac{2\Delta p_{sc} d}{f_{sc} G^2 v}$$

Mathematical model and Algorithm

Compressor | Capillary | **Heat Exchanger** | System





□ Refrigerant side:

$$Q_{\mathrm{r}} = H_{\mathrm{r,in}} - H_{\mathrm{r,out}} = \alpha_{\mathrm{r}} \cdot A_{\mathrm{i}} \cdot \left(T_{\mathrm{r}} - T_{\mathrm{wall}}\right)$$

$$\Delta p_{\mathrm{total}} = \Delta p_{\mathrm{f}} + \Delta p_{\mathrm{acc}}$$

□ Air side:

$$Q_{\mathrm{a}} = H_{\mathrm{a,in}} - H_{\mathrm{a,out}} = \alpha_{\mathrm{a}} \cdot A_{\mathrm{o}} \eta_{\mathrm{o}} \cdot \left(T_{\mathrm{a}} - T_{\mathrm{wall}}\right)$$

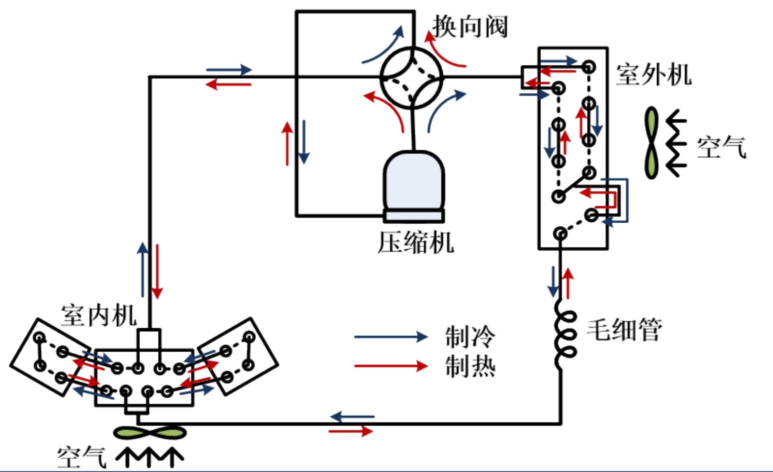
□ Energy equation:

$$Q_r = Q_a$$

Mathematical model and Algorithm

Compressor | Capillary | **Heat Exchanger** | System

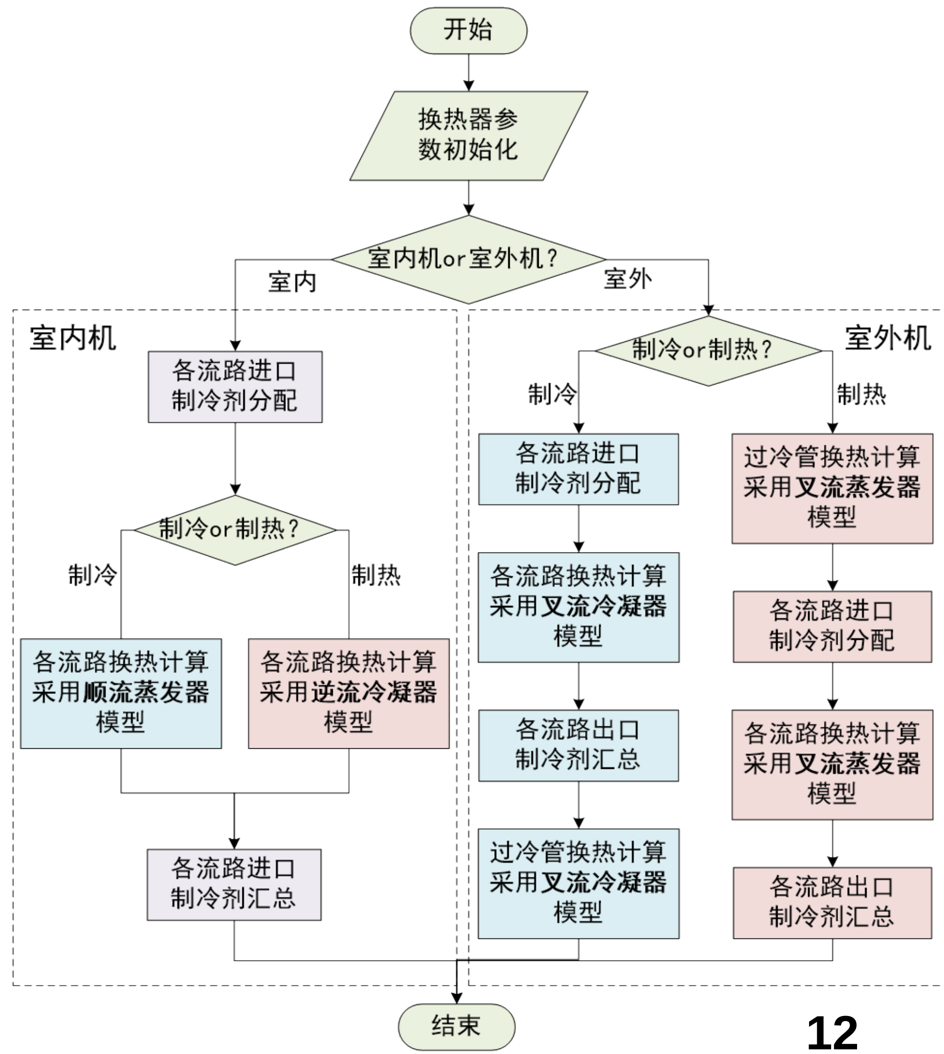
Refrigerant flow direction changes when operation mode switches



Problems

- Indoor Unit
  - Cooling Mode: Down-flow Evaporator
  - Heating Mode: Reverse-flow Condenser
- Outdoor Unit
  - Cooling Mode: Cross-flow Condenser
  - Heating Mode: Cross-flow Evaporator
- Outdoor Unit has subcooling tubes, which makes refrigerant split at different point in different operation modes.

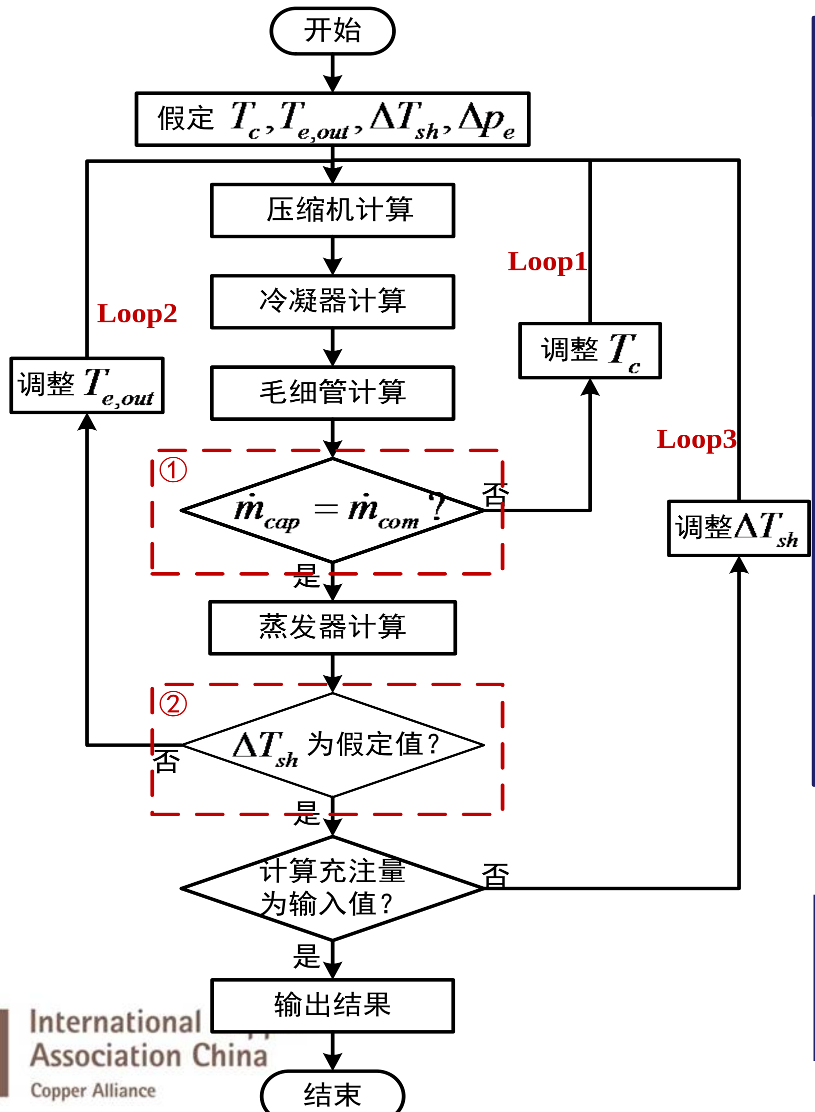
Developed model considering multi-path flow circuitries and multi-operation modes



Mathematical model and Algorithm

Compressor | Capillary | Heat Exchanger | **System**

— Existing System Simulation Algorithm



Shortcomings of Existing Algorithm

I. High demands for capillary and compressor matching, while engineers may input random parameters which will result in calculation divergence

II. The refrigerant in the evaporator outlet must be superheated, while NOT all the AC systems meet this requirement

III. Three coupled iteration loops result in SLOW computing speed

Developing new algorithm is necessary

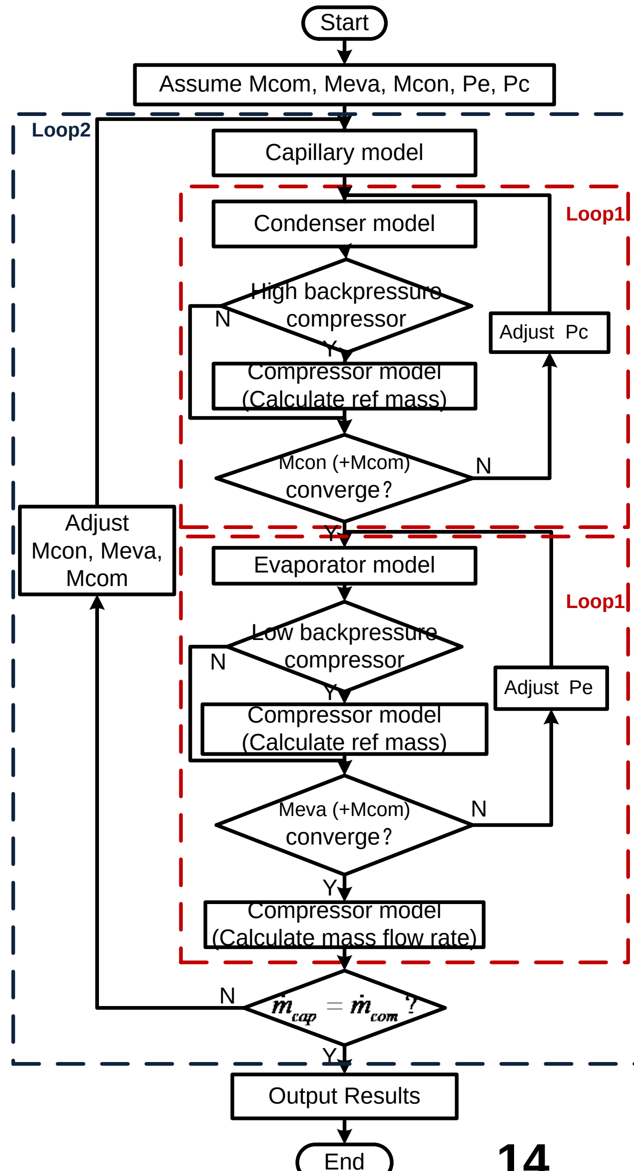
Mathematical model and Algorithm

Compressor | Capillary | Heat Exchanger | **System**

— Developed System Simulation Algorithm

Key Technique

- ☐ Mass-induced Iteration
  - ➢ Adjusting refrigerant mass in each component instead of Tc to balance mass flow rate avoids the possibility of calculation divergence result from capillary and compressor matching
  - ➢ Adopting refrigerant mass as convergent criterion instead of superheat degree avoids the possibility of calculation divergence result from system performance
- ☐ Parallel calculation loop
  - ➢ Using two parallel calculation loops instead of coupled loops increases computing speed



Content

I. Function and Architecture of the Software

II. Mathematical Model and Algorithm

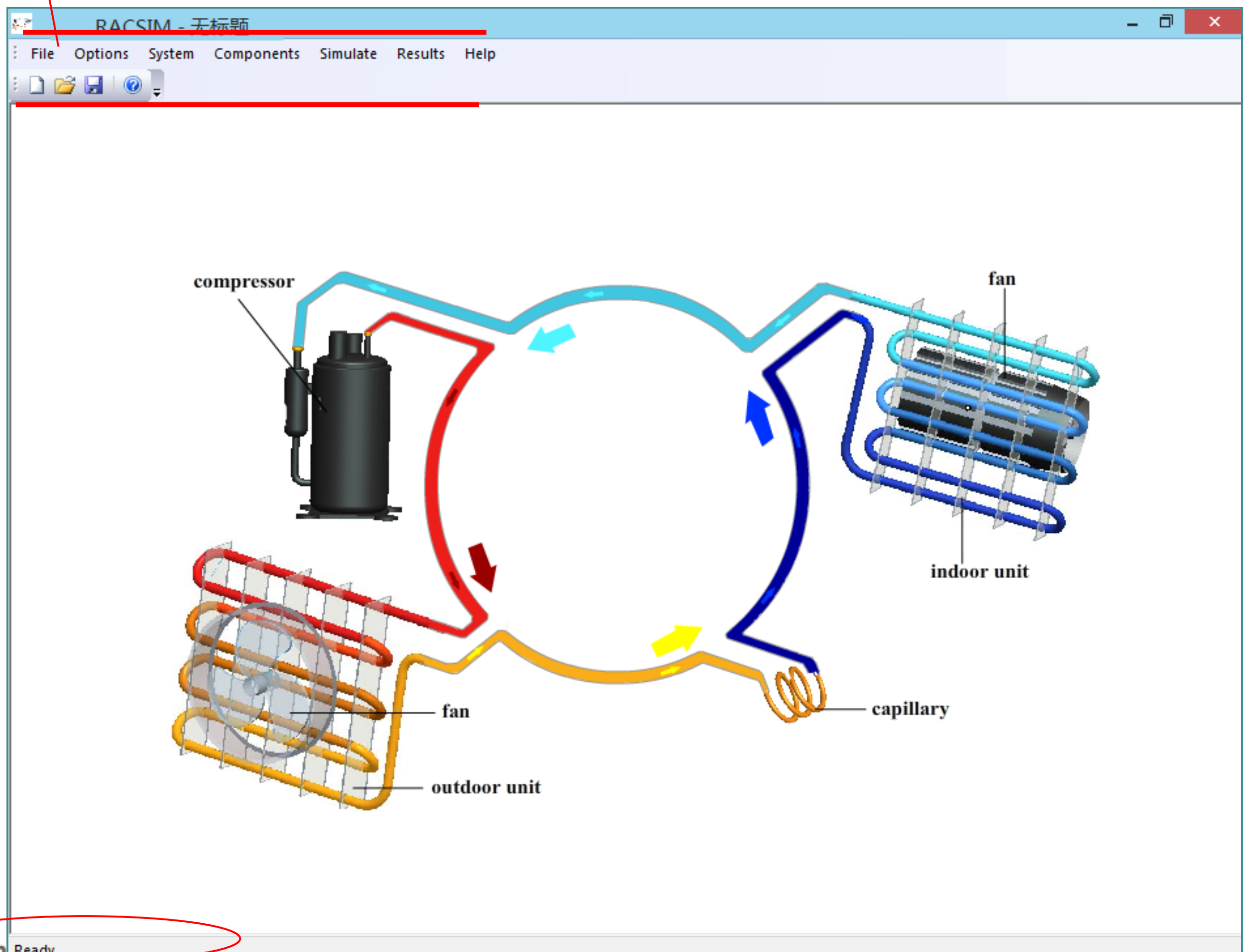
III. Graphic User Interface of the Software

IV. Example for 2600W AC system

V. Proposal for Next Step

Graphic User Interface of the Software

Main menu and toolbar

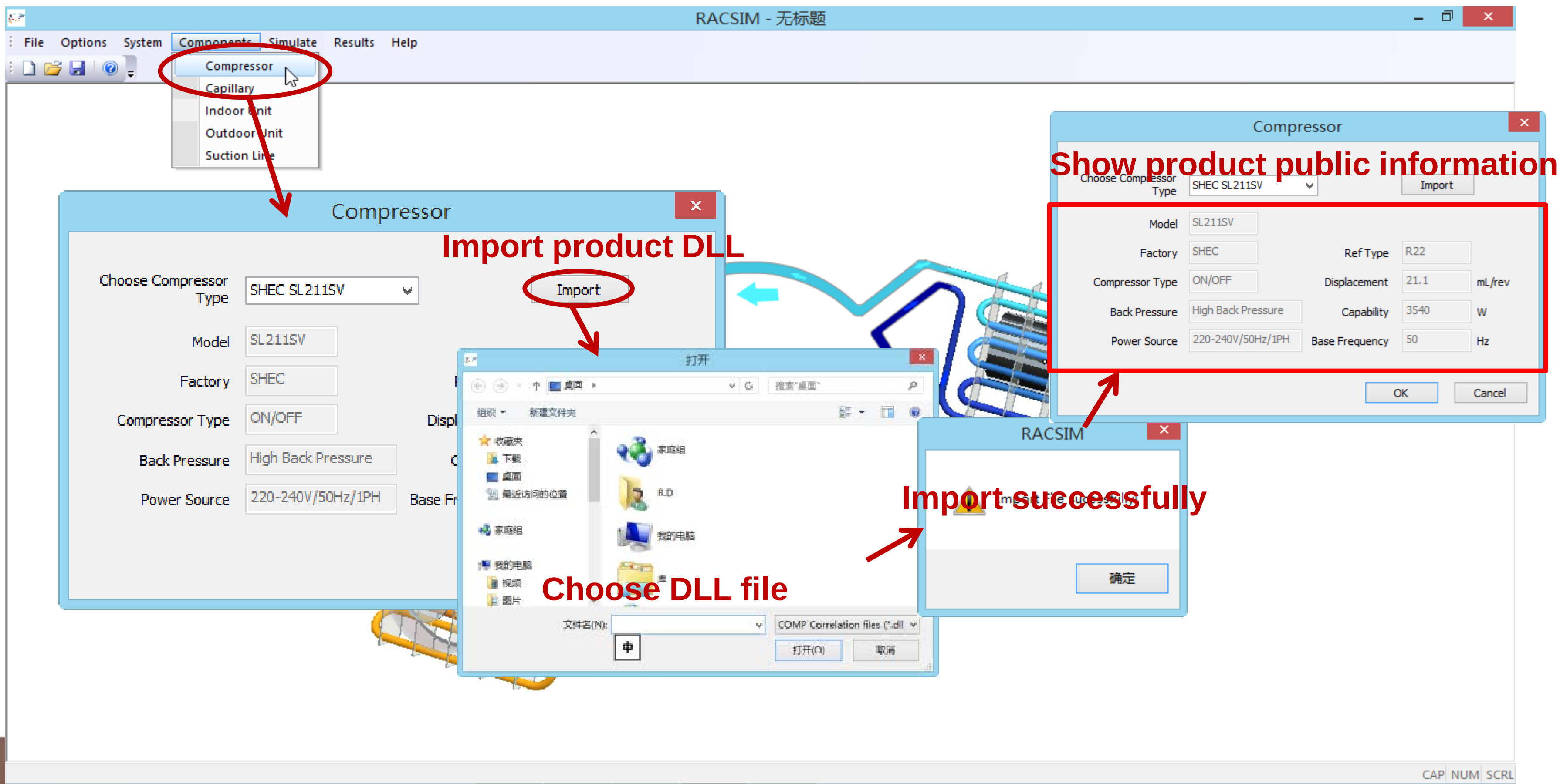


Status bar

Graphic User Interface of the Software

Main Interface | **Compressor** | Heat Exchanger | System Data | Results

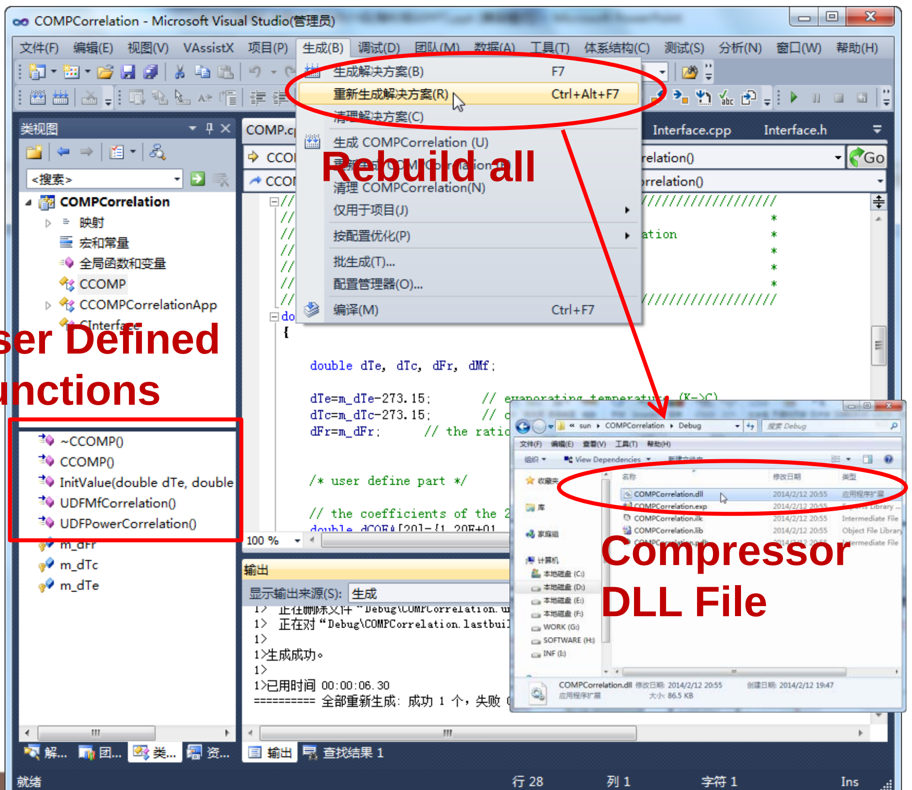
To protect user's confidential data, the compressor data is imported as a DLL file. Only public information is shown in the interface.



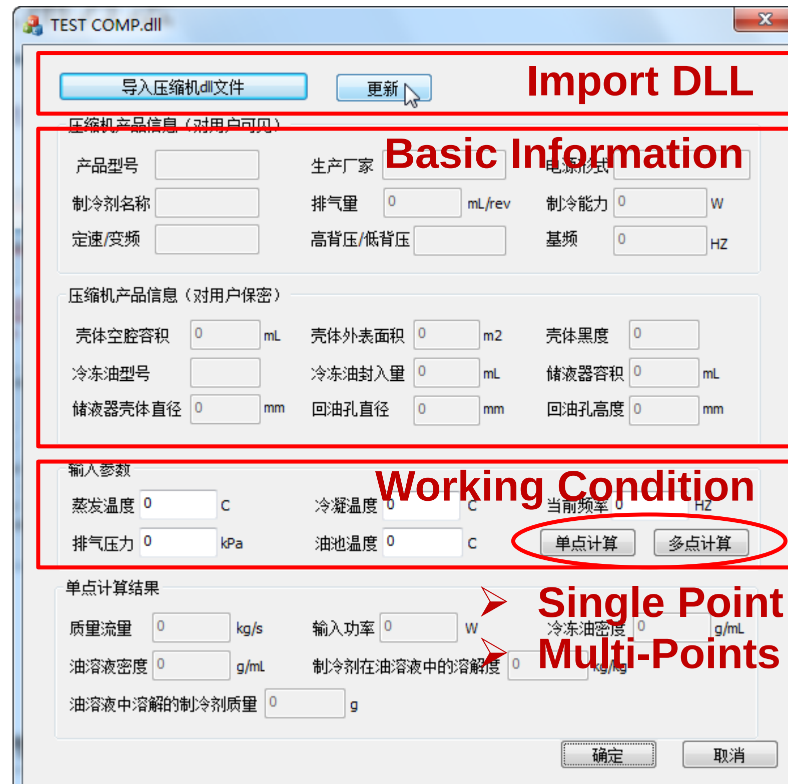
Graphic User Interface of the Software

The compressor DLL file is built through the program template and checked by the test tool provided by SJTU

☐ Program Template



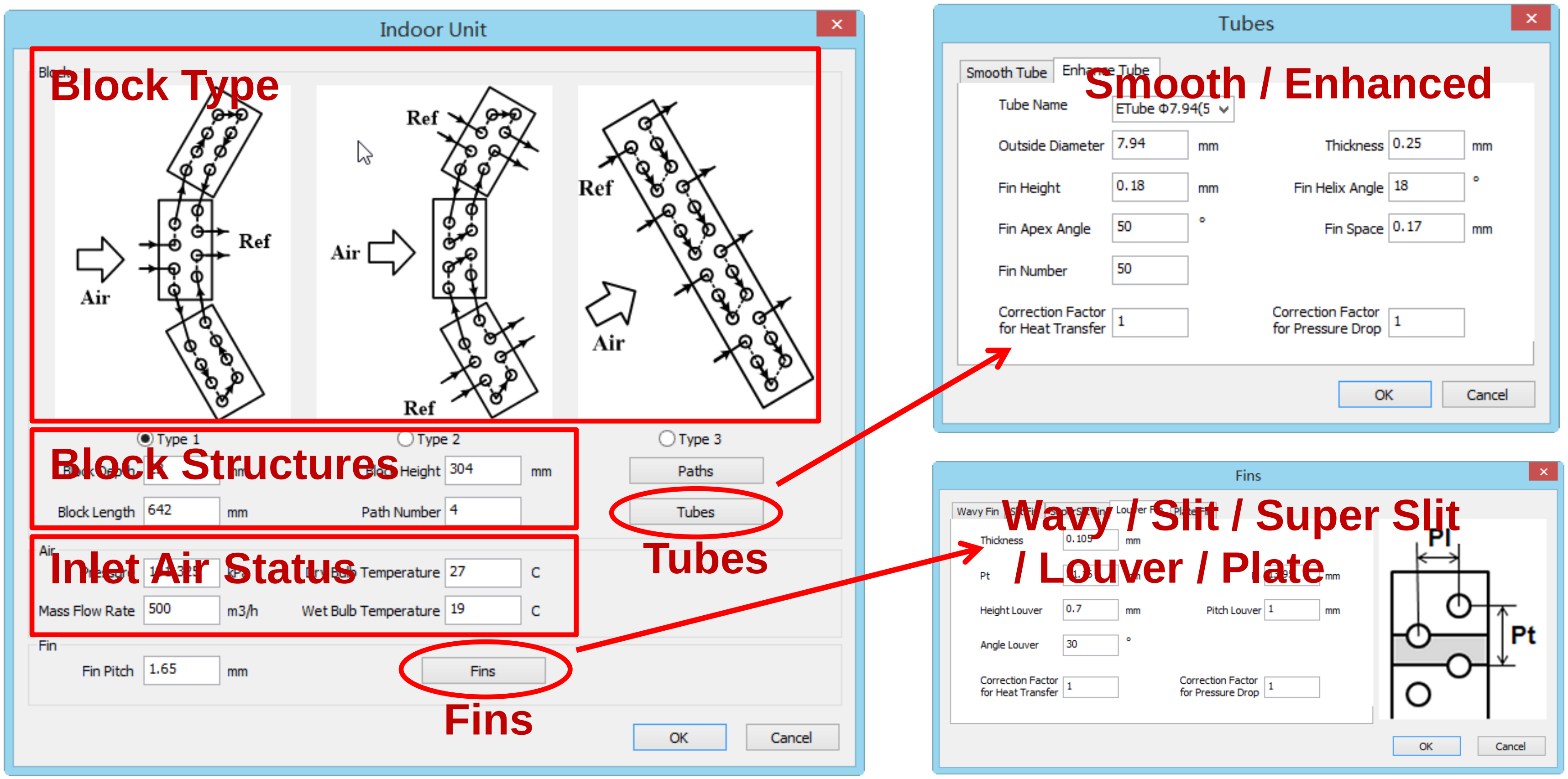
☐ Compressor DLL Test Tool



Graphic User Interface of the Software

Main Interface | Compressor | **Heat Exchanger** | System Data | Results

☐ Indoor Unit



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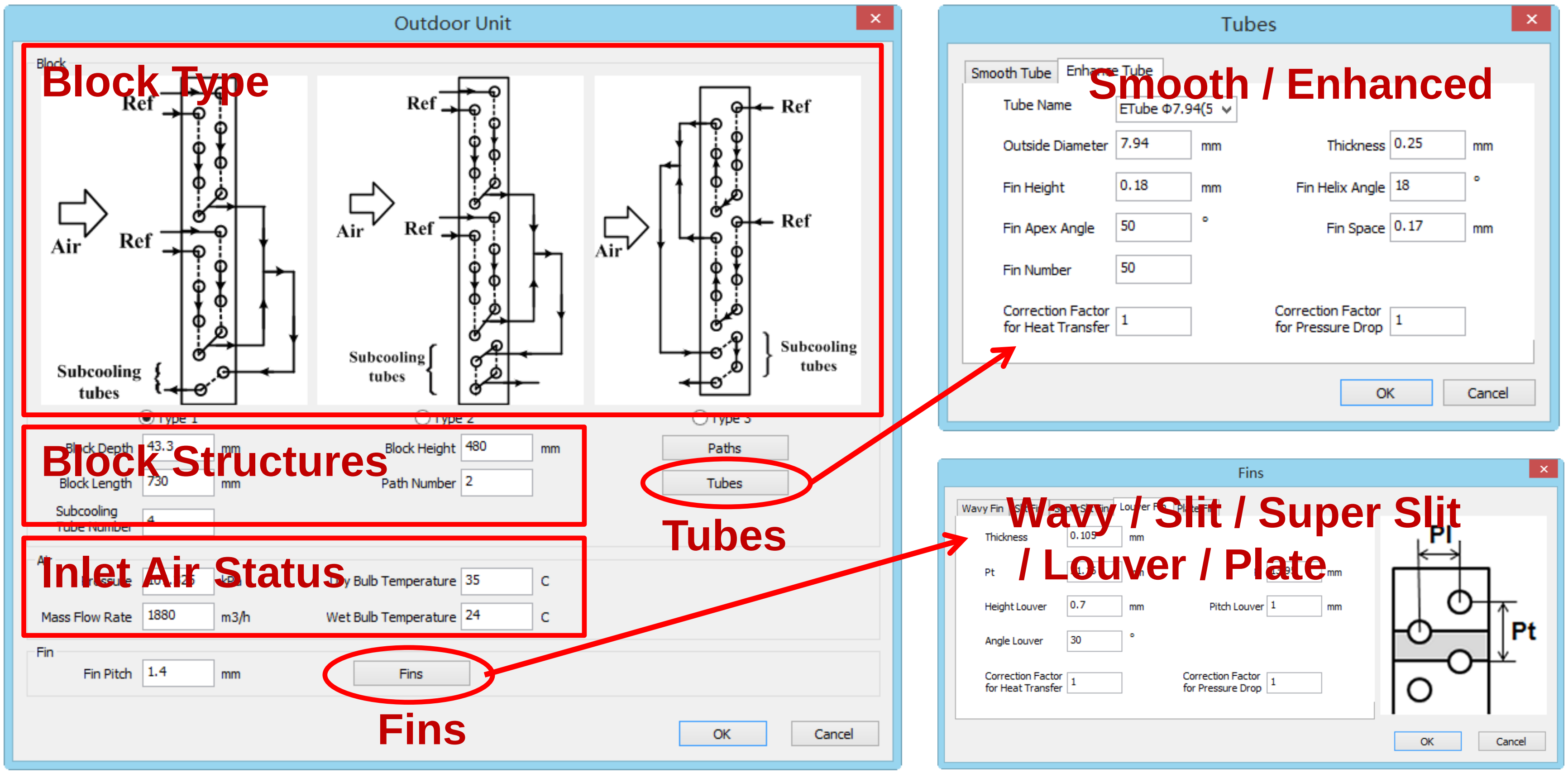
Graphic User Interface of the Software

Main Interface | Compressor | **Heat Exchanger** | System Data | Results

☐ Outdoor Unit

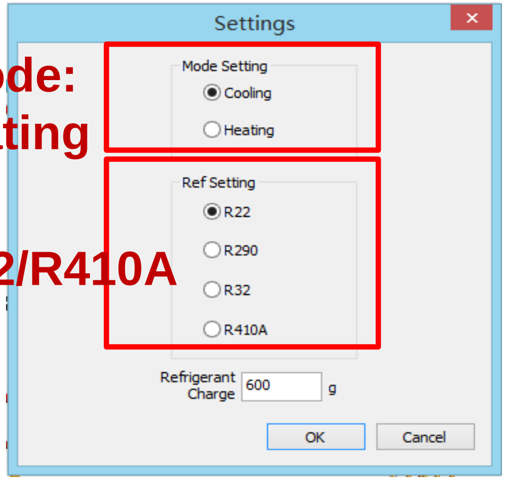


Graphic User Interface of the Software

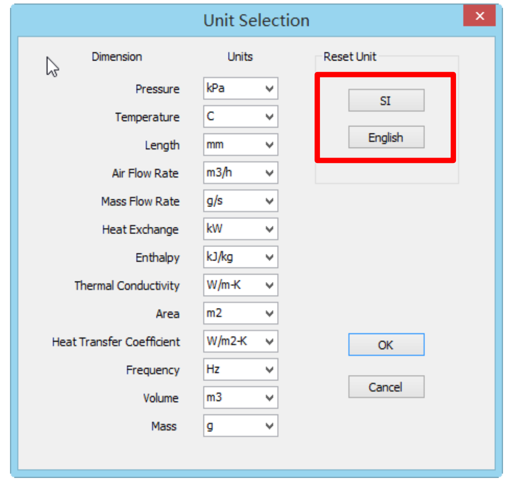
Operation Mode:
Cooling / Heating

Ref Type:
R22/R290/R32/R410A

☐ System Settings

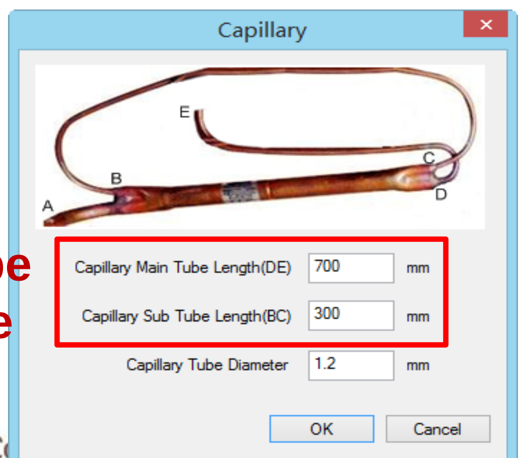


☐ Unit Selection



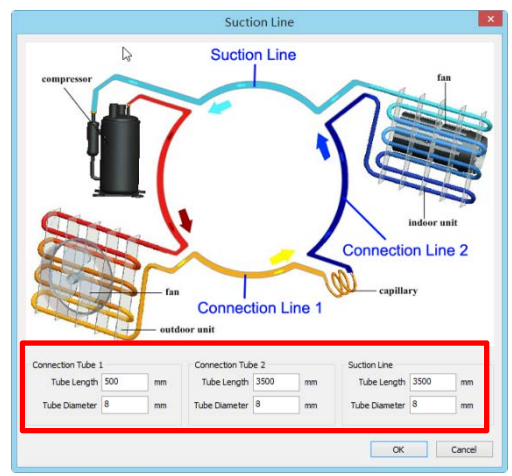
- SI
- English

☐ Capillary



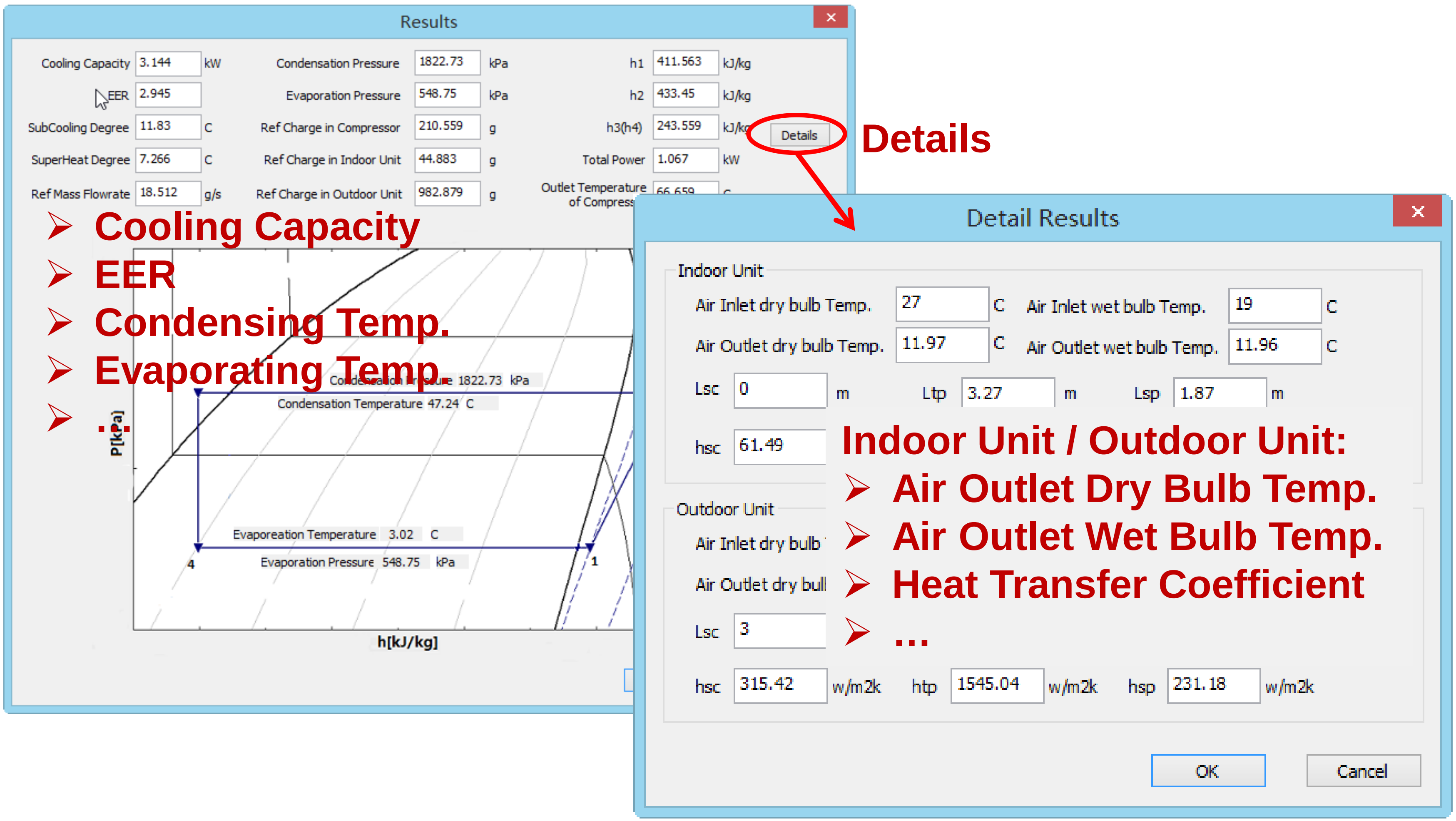
- Main Tube
- Sub Tube

☐ Connection Line



- Connection Line
- Suction Line

Graphic User Interface of the Software



Details

- **Cooling Capacity**
- **EER**
- **Condensing Temp.**
- **Evaporating Temp.**
- **…**

Indoor Unit / Outdoor Unit:

- **Air Outlet Dry Bulb Temp.**
- **Air Outlet Wet Bulb Temp.**
- **Heat Transfer Coefficient**
- **…**

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Example for 2600W AC system

Content

Proposal for Next Step

Development of Multi-Unit AC System Simulation Software

I. Multi-Unit Air Conditioners have been widely used.

II. The use of small diameter copper tube is an effective way to reduce volume of heat exchanger, cost and refrigerant charge.

III. Employing small diameter copper tube in multi-unit AC system is challenged because of much more complex refrigerant distributions and system matching.

IV. Control algorithm of multi-unit system is hard to optimize experimentally.

V. A simulation software to predict system performance is needed.

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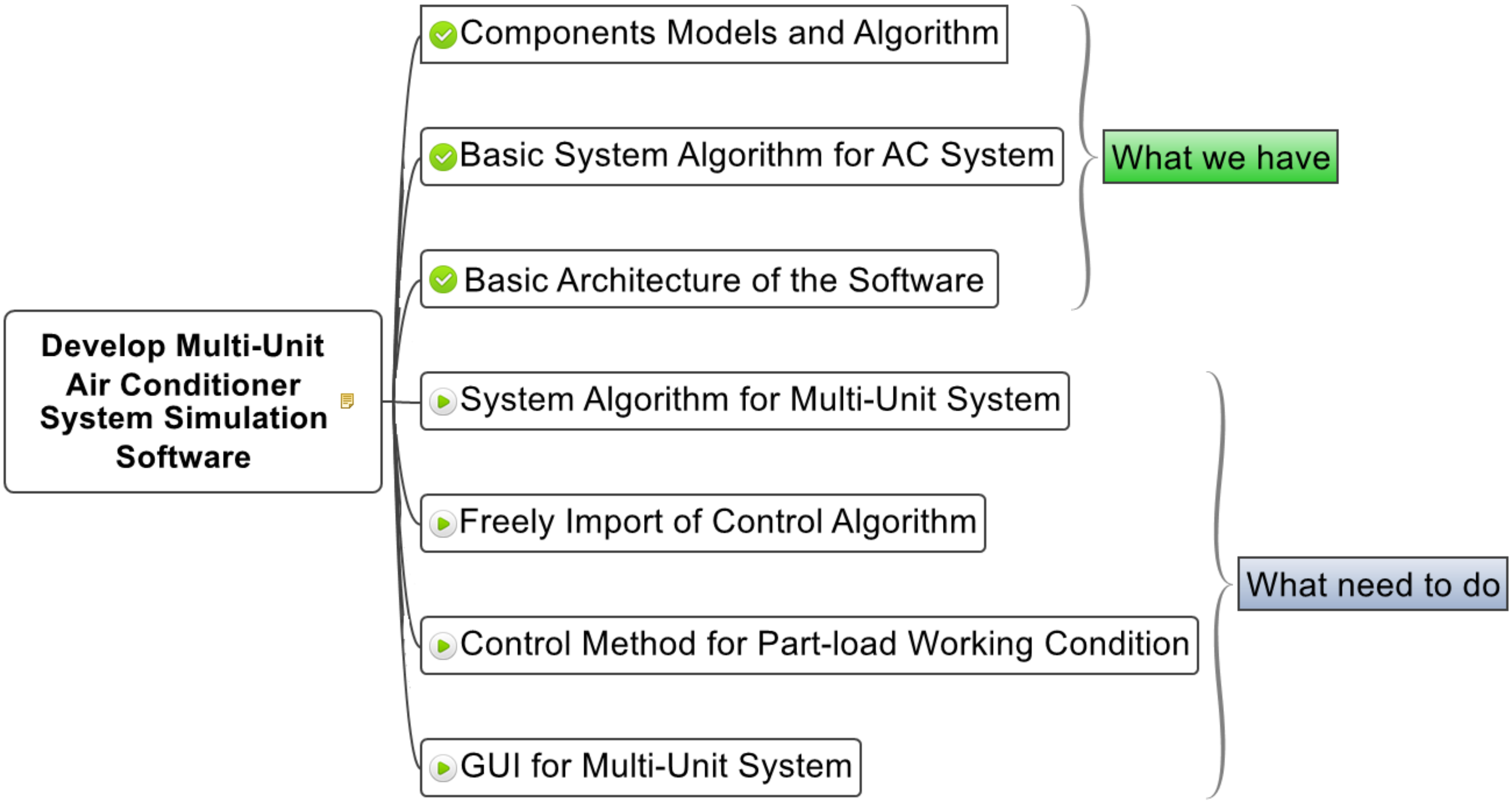
Proposal for Next Step

Technique Requirement



Proposal for Next Step

What need to do

I. **Extend Single Unit System Algorithm to Multi-Unit System**

Multi-Unit AC system has several indoor units, which means more unknown variables in the simulation process, making system simulation algorithm more complex.

II. **Develop method to adopt user's control algorithm**

Multi-Unit AC system has variable control algorithms, which means it is difficult to find a general way to import user's variable control algorithm and to use in the simulation process.

III. **Develop control method for Part-Load Working Condition**

Multi-Unit AC system has more adjustable parameters than single unit system, which makes the control method for part-load working condition is more complex.

IV. **Develop GUI for Multi-Unit System**

Multi-Unit AC system has more input and output parameters, which means the GUI need to be redesigned.

The End

Thank you！

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