General Introduction

DOE/ORNL Heat Pump Design Model (HPDM)

Bo Shen and Keith Rice

Building Technologies Research and Integration Center

Energy & Transportation Science Division

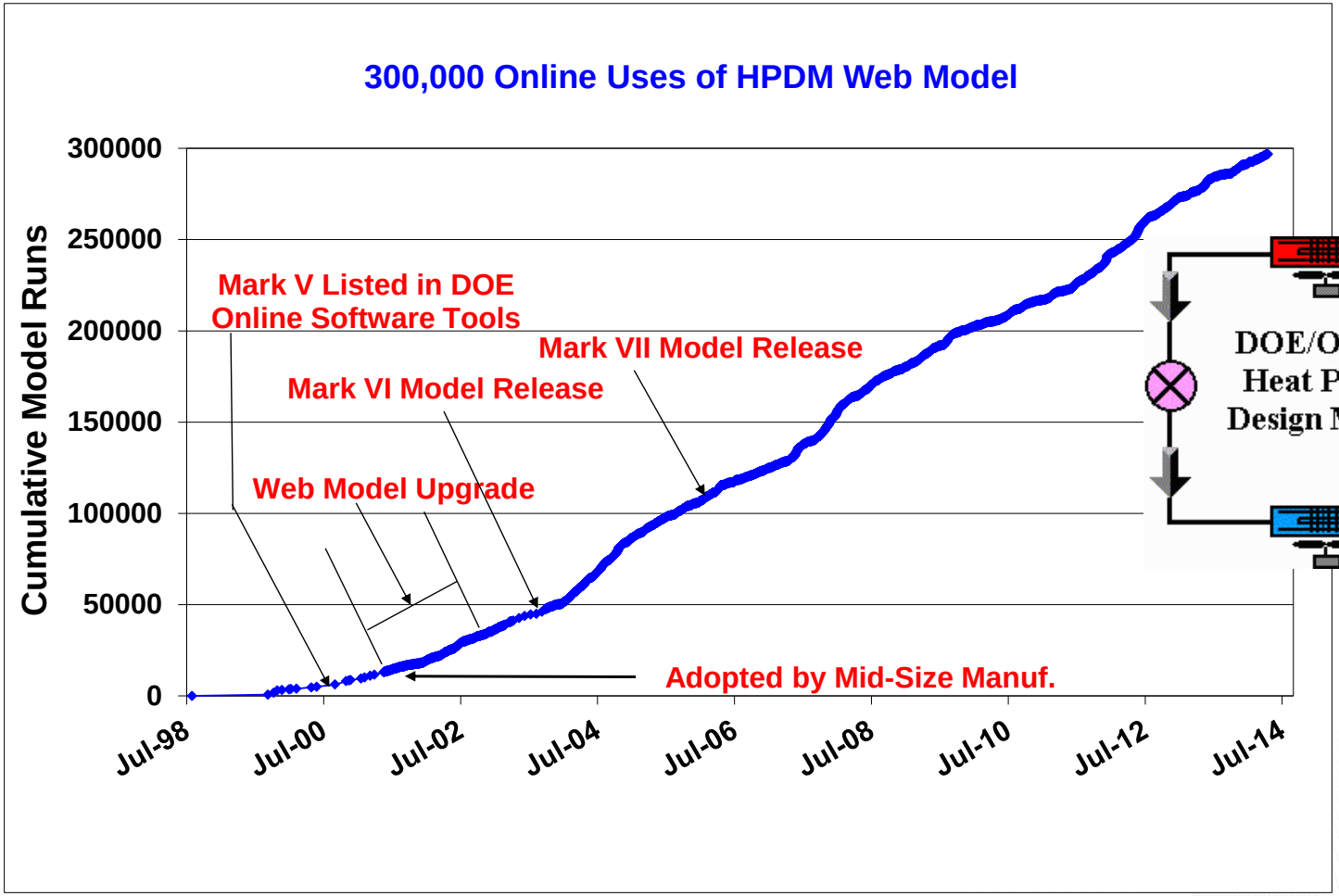
ORNL is managed by UT-Battelle
for the US Department of Energy

OAK RIDGE National Laboratory

Content

1. General features
2. Major compressor and heat exchanger modelling approaches
3. Old version – Mark VII, VI, V
4. New version – HPDMFlex (flexible modeling framework)

1.1 Well Regarded Web-Based HPDM

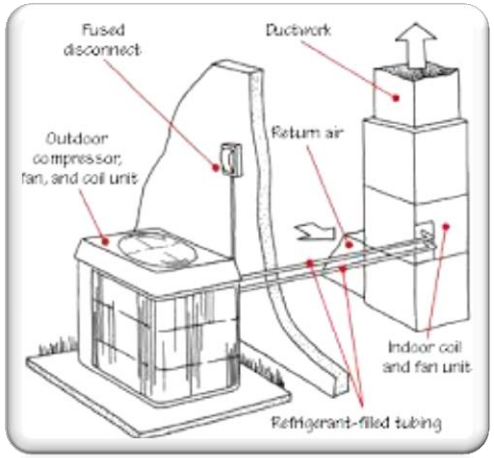


Widely-used building equipment design software, over 30 years of development by Building Equipment Research Group, ORNL.

http://web.ornl.gov/~wlj/hpdm/MarkVII.shtml

1.2 Extensive applications and complex system configurations in HVAC&R

Refrigerator



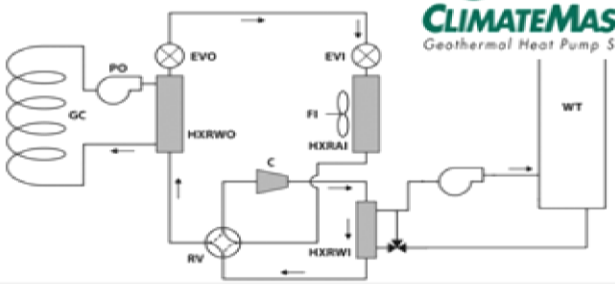
Heat pump

Water heating

Rooftop Air conditioner

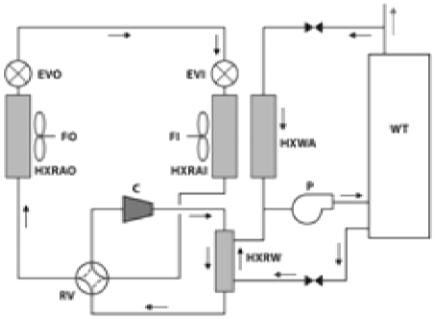
Integrated Heat Pump

V-speed ground-source



CLIMATEMASTER
Geothermal Heat Pump Systems

V-speed air-source



MAYTAG

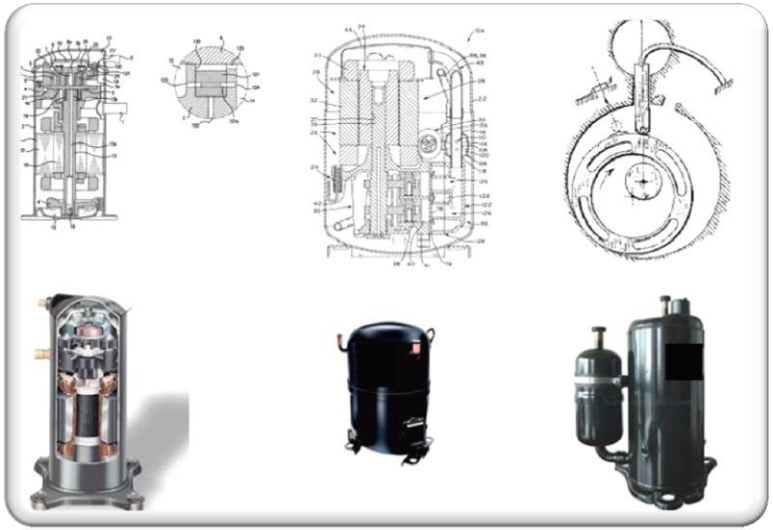
LENNOX

Complex System Configurations

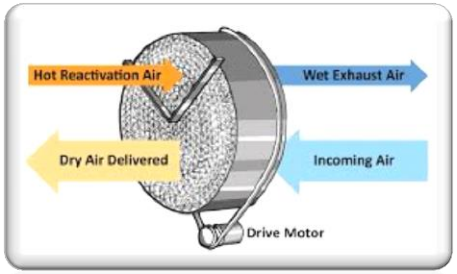
OAK RIDGE National Laboratory

1.3 Numerous types of components

Flow mover: fan or pump

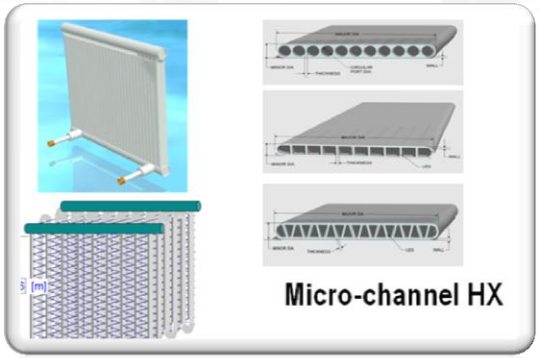


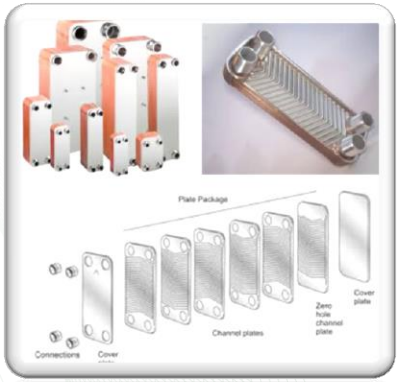
Compressors



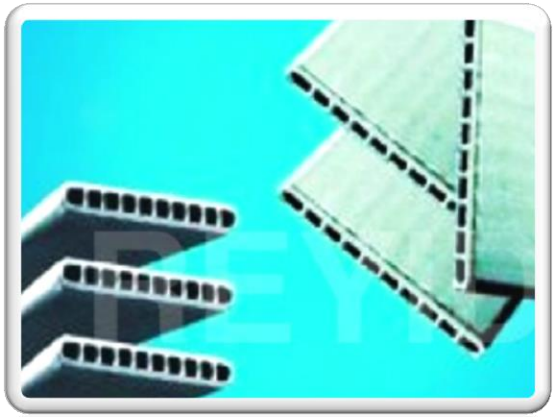
Desiccant

Heat exchangers

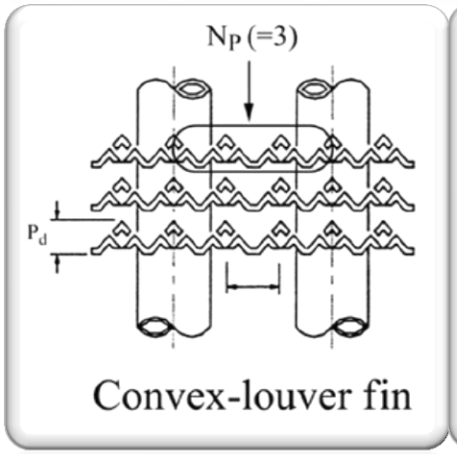


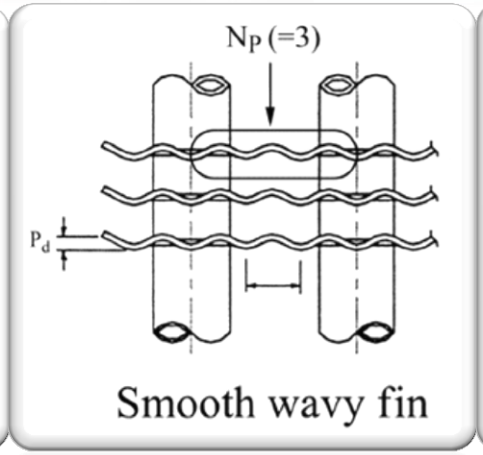


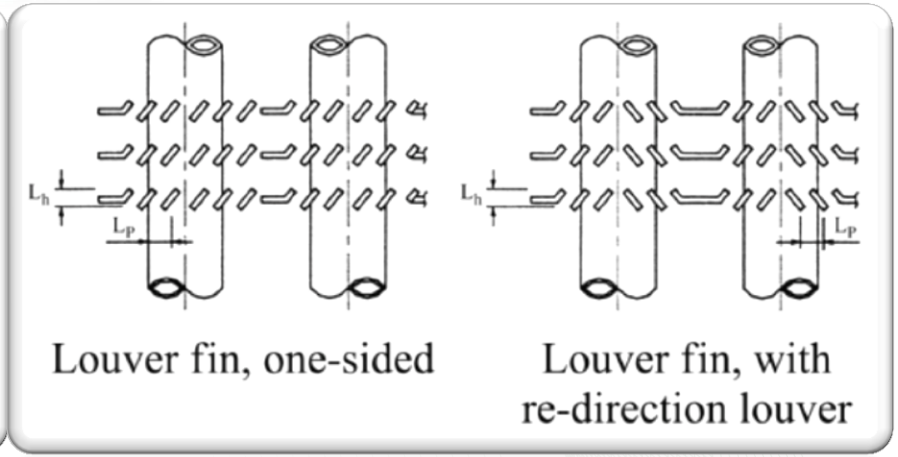
1.4 Plenty of tube and fin types



Various tube types



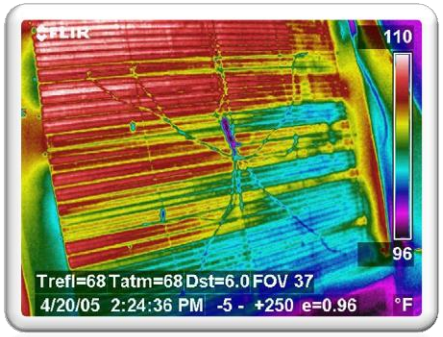




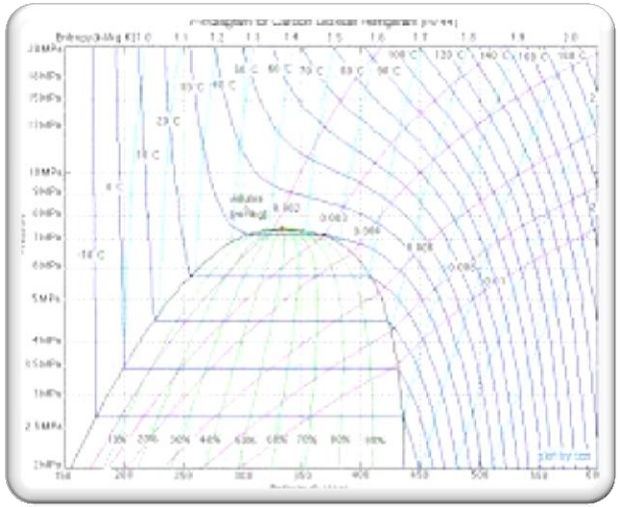
Various fin geometries

1.5 Solutions to Complex Science Challenges

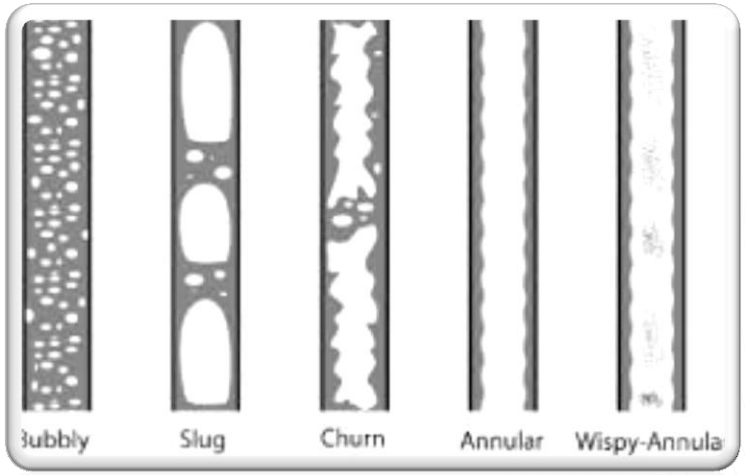
Water condensation



Non-uniform air flow distribution



Refrigerant property

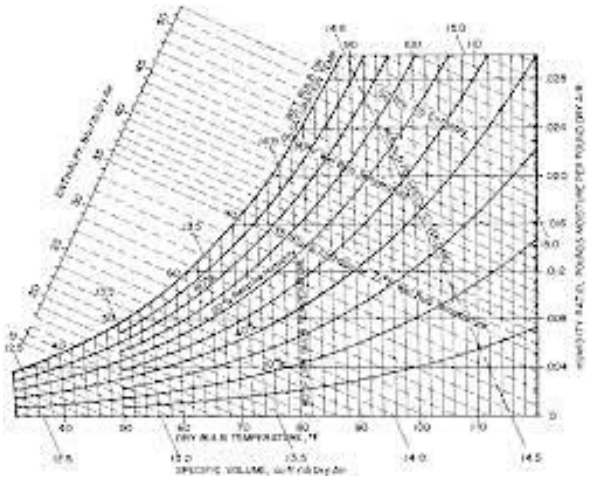


Two-phase flow patterns

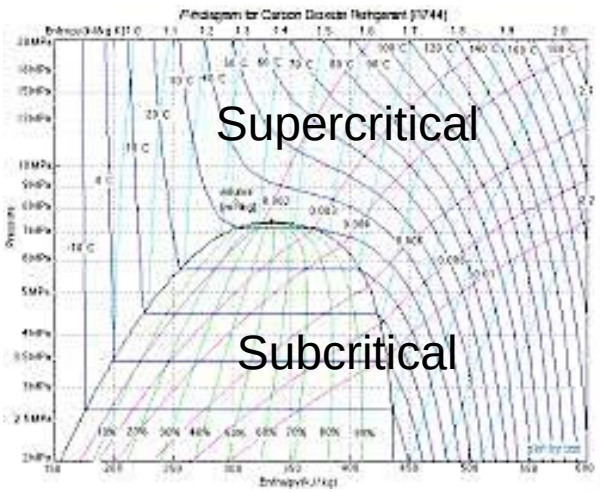
1.6 Universal working fluid property management

-Hundreds of working substances in HVAC&R industry: air, water, glycol, CO2, HFC, HCFC, CFC, HFO, natural substances

Air psychometric chart

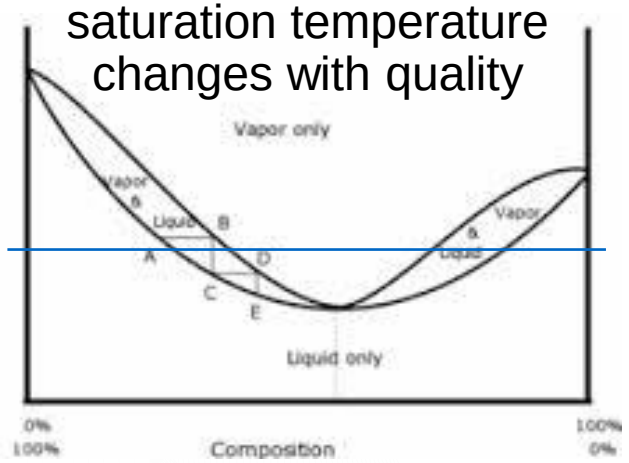


Refrigerant property



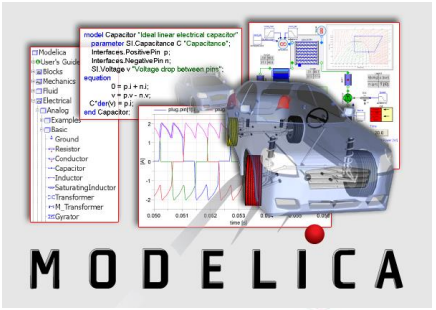
Refrigerant mixture

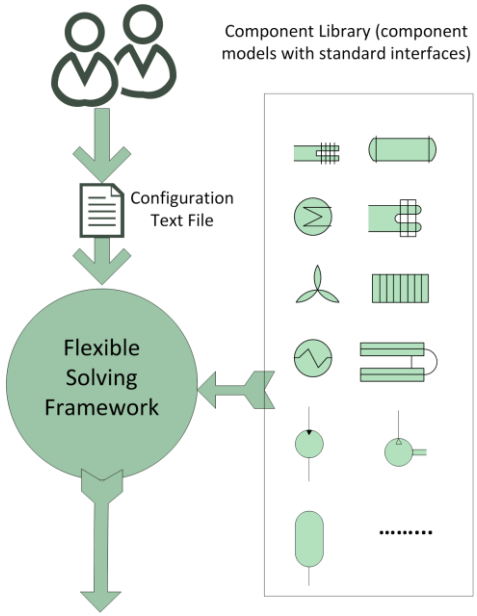
Temperature glide – saturation temperature changes with quality



Next Generation Refrigerants (low global warming - GWP, zero ozone depletion) – detailed system modeling with new refrigerant property, to assess long-term impact using life cycle analysis, provide design guidance based on fundamental study.

1.7 Engineering Analysis Flow – From Concept Design to Life Cycle Analysis





ORNL Building Equipment Model

Set Boundary Conditions

CFD

All connected.

Directly Export Components

Dynamic Link Library

Generate Performance Curves

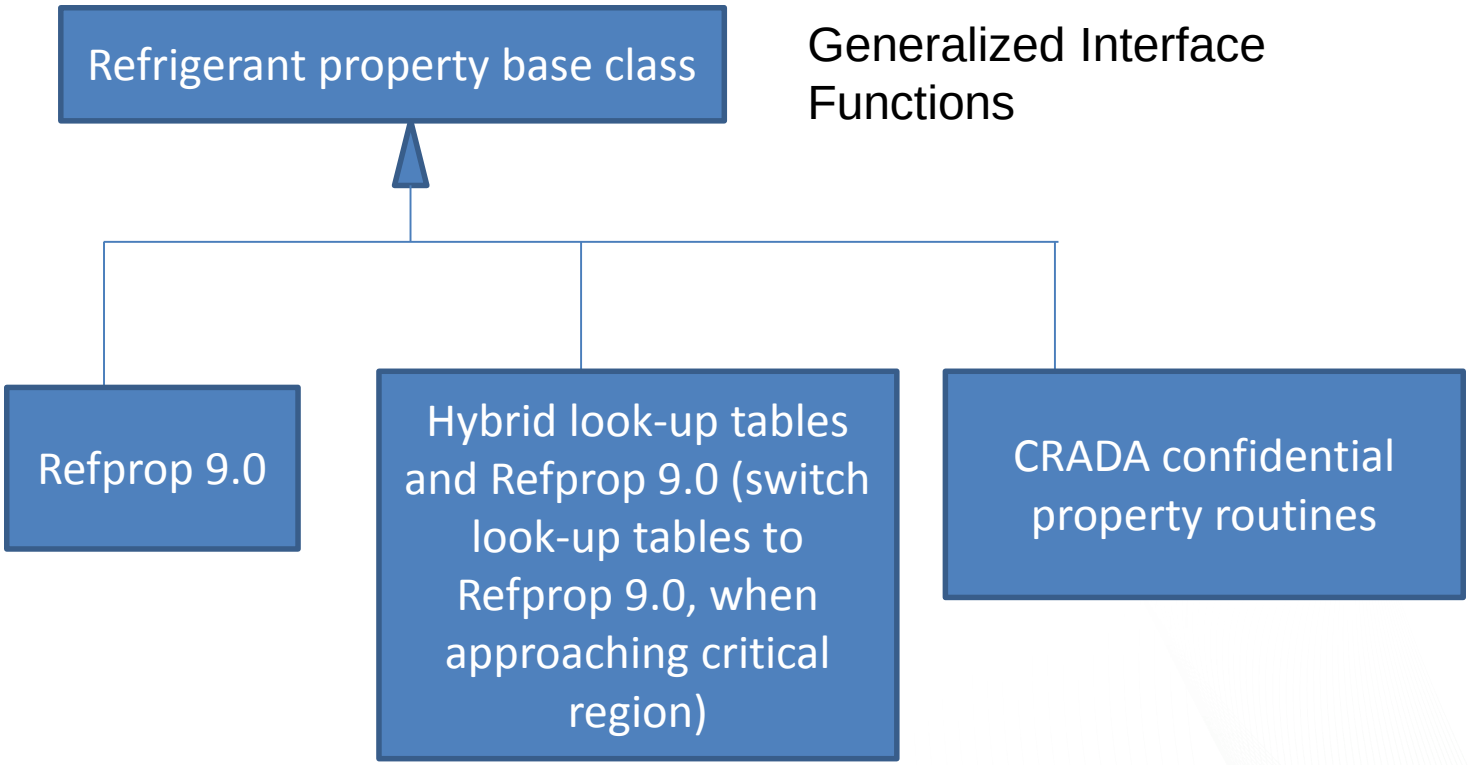
Curve-Fitting Program

Generate Performance Tables

Parametric Runs

OAK RIDGE National Laboratory

1.8 Refrigerant property routines

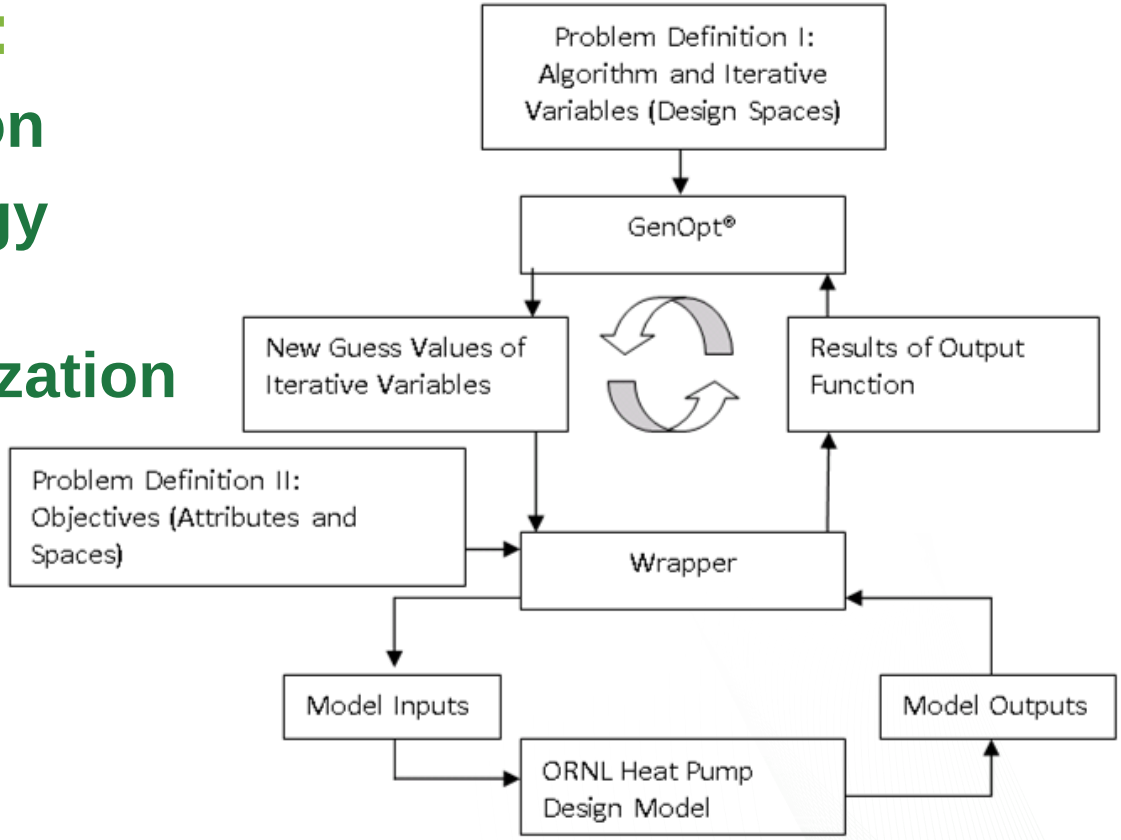


Refprop wrapper codes:
http://www.boulder.nist.gov/div838/theory/refprop/LINKING/Linking.htm

Fairly simple to vary refrigerant type, even the data source and calculation method in all the component and system models

1.9 ORNL Equipment Design Optimization Tools – Multi-Variable Optimization

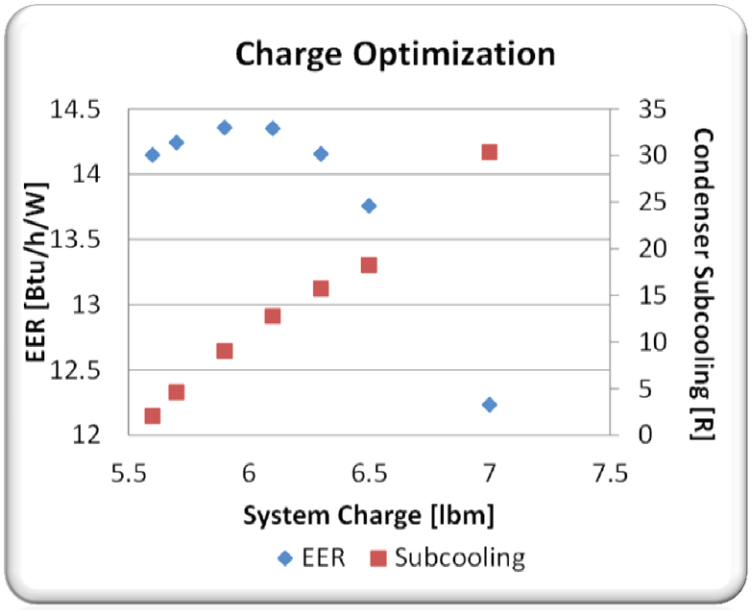
- **Functionalities:**
  - **Auto-calibration**
  - **Control strategy determination**
  - **System optimization**



- Capable of optimizing controls in the entire operation envelope

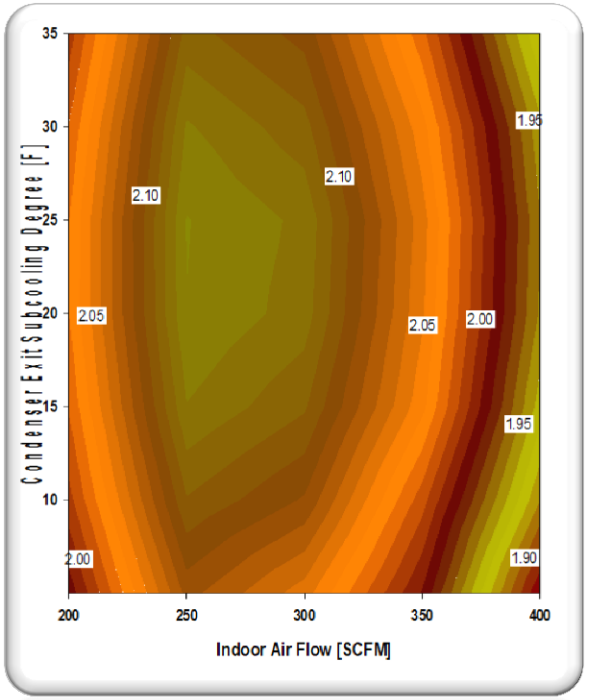
- Optimizer can be open source tools, like GenOpt (LBL).

1.9 Continued

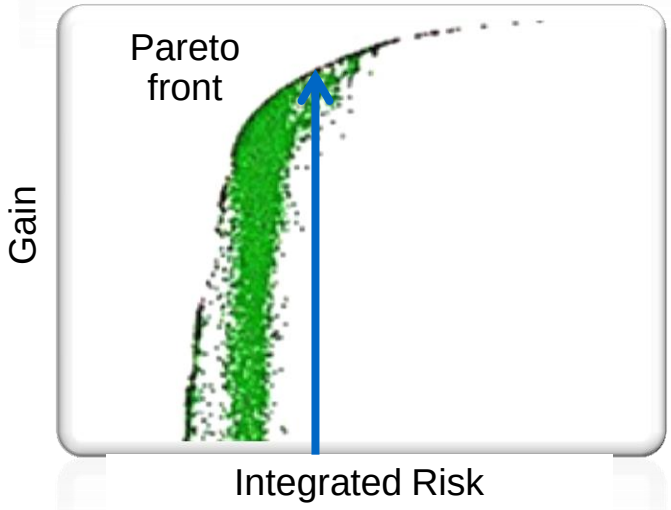


Single-variable optimization

Two-variable optimization energy factor



Multi-variable optimization – Pareto chart



- ***Simulation driven, optimized design → optimum performance with minimum cost.***

2.1 Variable-Speed Compressor Modeling

$$Y = C_1 + C_2 T_e + C_3 T_c + C_4 T_e^{\,2} + C_5 T_e T_c + C_6 T_c^{\,2} + C_7 T_e^{\,3} + C_8 T_c T_e^{\,2} + C_9 T_e T_c^{\,2} + C_{10} T_c^{\,3}$$

→10-coefficient AHRI compressor map at rated inlet superheat; Y can be the compressor mass flow rate and power consumption.

→Linear interpolation between speed levels.

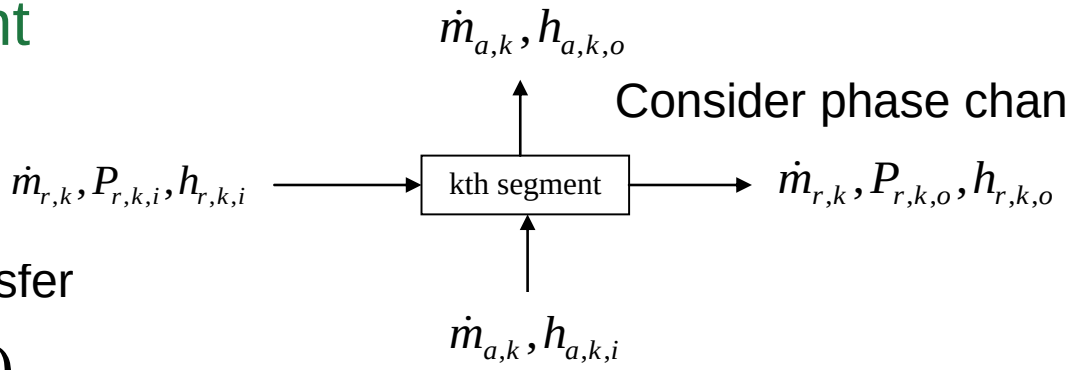
→Mass flow rate adjustment for actual inlet superheat levels.

$$\dot{m}_{ref,actual} = [1 + F_{mass}(\frac{v_{ARI-map}}{v_{act}} - 1)]\dot{m}_{ref,ARI-map}$$

$$F_{mass} = 0.75$$

2.2 Advanced Heat Exchanger Modeling

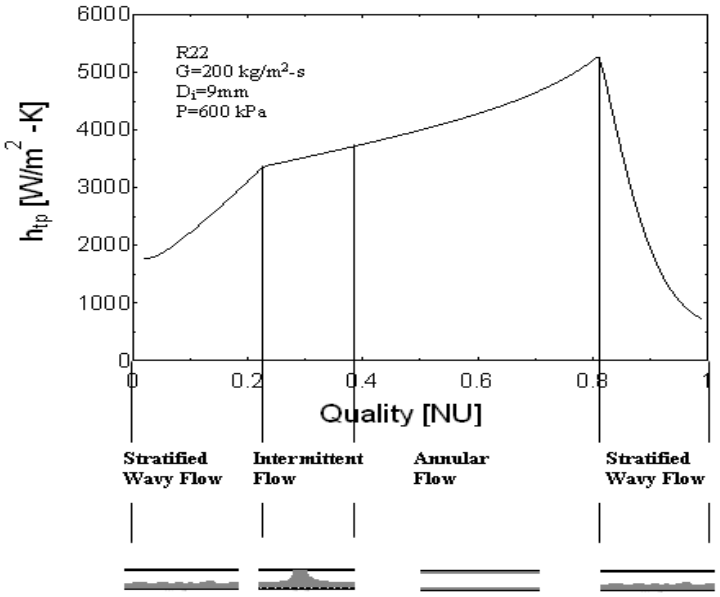
- Segment-to-segment modeling approach



Dry Coil Analysis Heat Transfer

$$\dot{Q}_{\max} = C_{\min}(T_{h,i} - T_{c,i})$$

$$\varepsilon = 1 - \exp(-NTU)$$



Wet Coil Analysis Heat & Mass Transfer

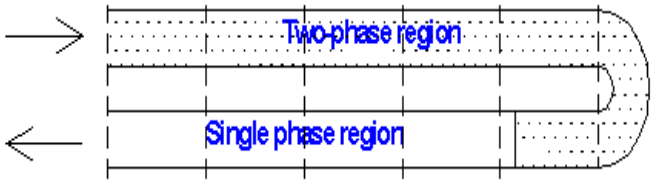
$$\dot{Q}_{\max} = \dot{m}_a (h_{a,i} - h_{s,evap})$$

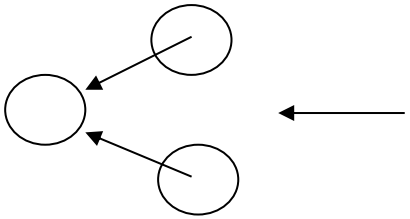
$$\varepsilon^* = 1 - \exp(-NTU^*)$$

Refrigerant side local flow-pattern-specific heat transfer and pressure drop calculation

2.3 Reality Representation: Arbitrary HX Circuitry - Segmented Fin-&-Tube Coil Modeling

1. Tube element:

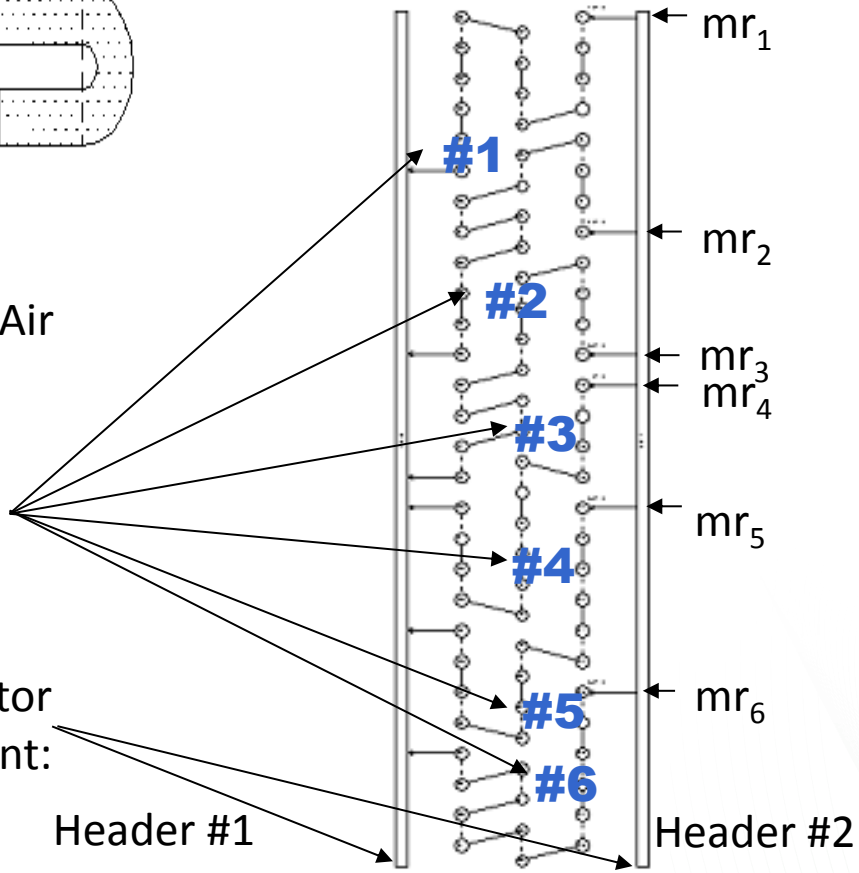




2. Circuit element:

3. Header/Distributor element:

Fin-&-Tube Coil



Air flow distribution

CFD

2-D air side distribution; Independent circuit refrigerant entering conditions; Arbitrary circuitry, provides more accurate real-world heat exchanger performance predictions

3.1 Old version

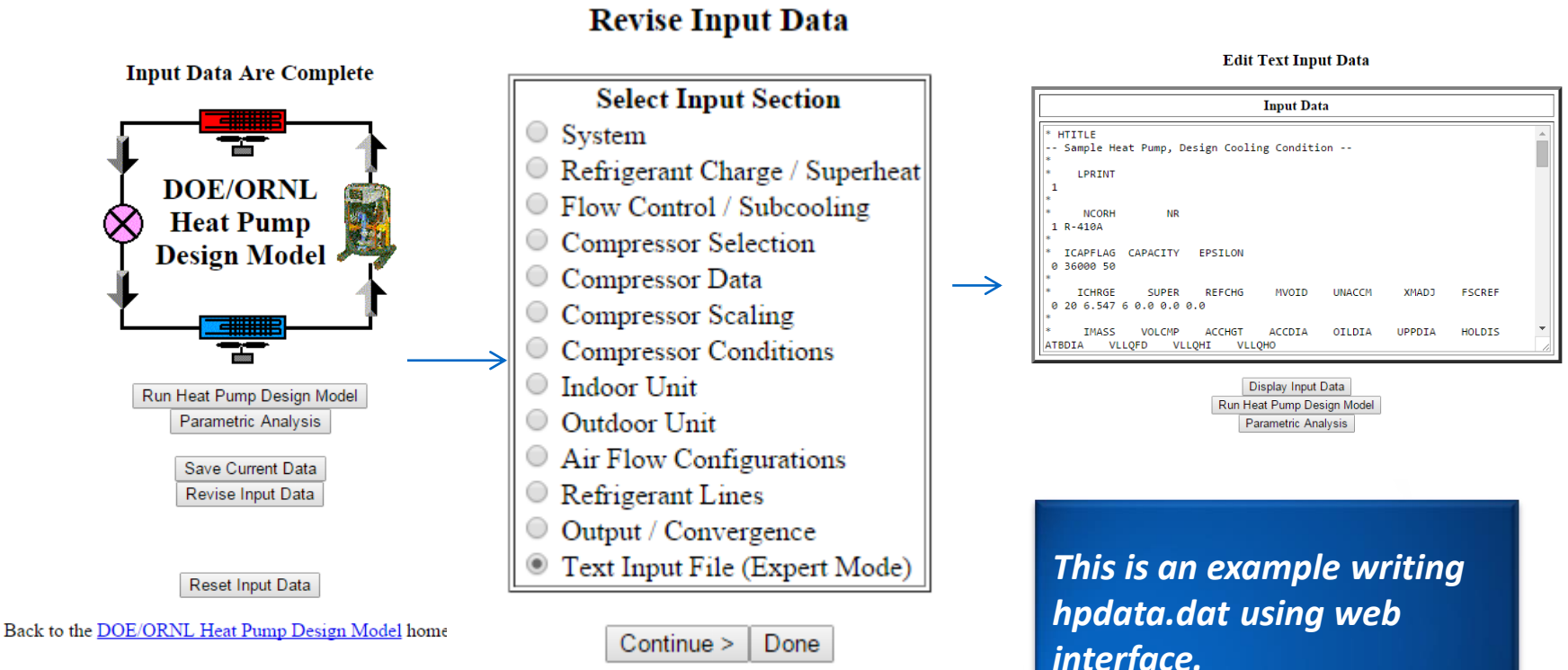
- How we usually run Mark7 – single-point simulations

➢ Web version: http://web.ornl.gov/~wlj/hpdm/MarkVII.shtml.

➢ Emerson's SDS

➢ Desktop version: Excel templates, free from ORNL.

3.2 Web interface of Old Version



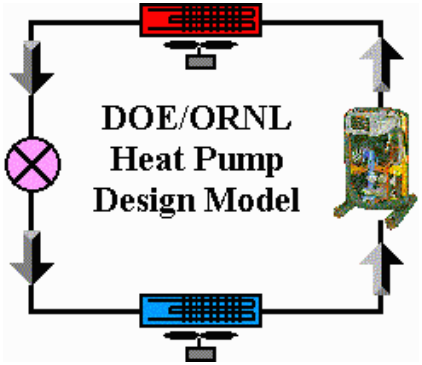
This is an example writing hpdata.dat using web interface.

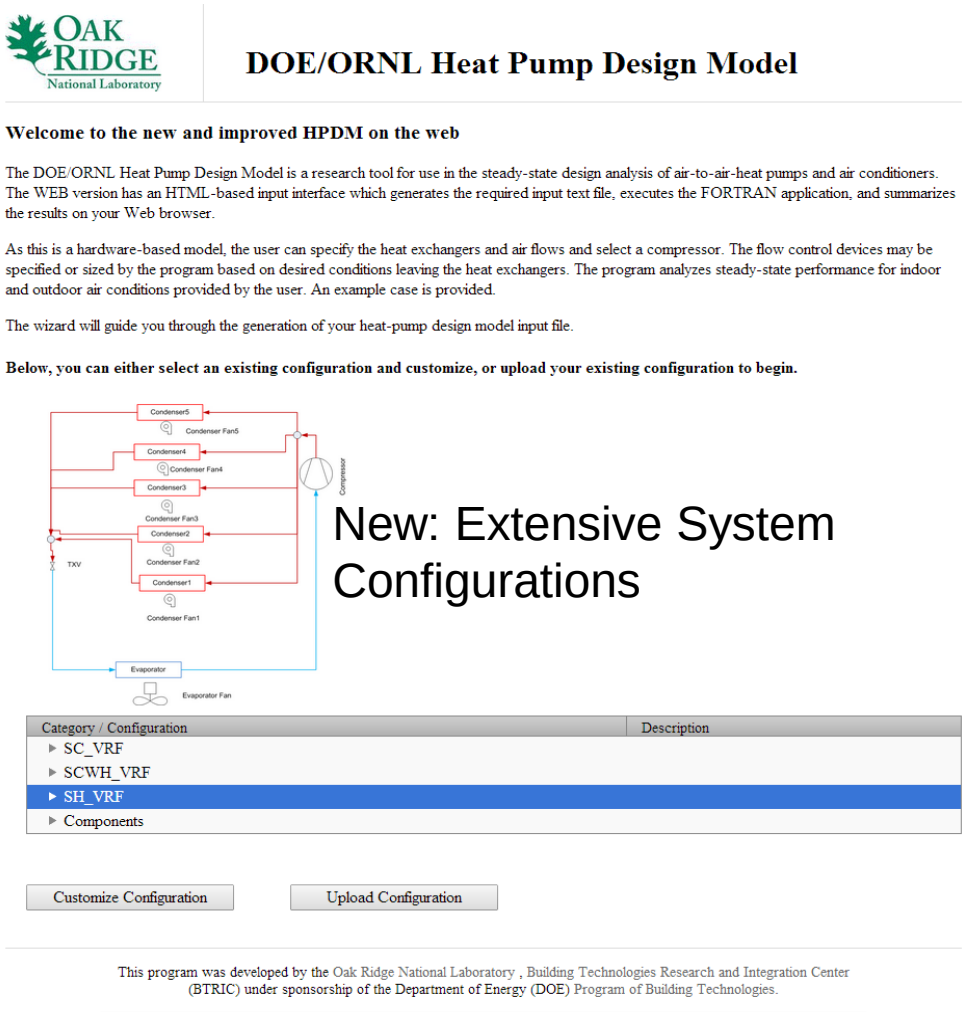
References and documentations linked to the web page.

4.1 New Web Interface

http://hpdmflex.ornl.gov

Previous: Single System Configuration





New: Extensive System Configurations

4.2 Web interface of new version http://hpdmflex.ornl.gov

Quick prototype

1. Extensive HVAC applications, system configurations, and numerous categories, combinations of component models.
2. Hardware-based component models: edit component-by-component.
3. Graphical input and output
4. Informational wizard
5. Fast solving
6. The user controls the product data, by using download and upload buttons (web interface is only a processor).
7. Flexible solving, i.e. parameters, variables with attributes

- ***The Web interface is an extensive collection of examples, which you can download and start with your inputs.***

4.3 Extensive configs + Flexible solving

- Flexible solving enabled by changing the variable attribute:

Required variables (values must be given and checked by the user):

- **i** – input, i.e. constant in a solving process
- **g**- guess, i.e. guess value must be provided

Optional variables (values can be empty, and users don't need to address them):

- **o-** output, i.e. only used for reporting result after each solving process; the attribute can't be changed.
- **r –** regular, i.e. regular solving variable, the attribute can be changed to **g** or **i** with a given value.
- **t** – transfer, i.e. transfer values successively between two NR solving processes.

4.4 Download the desktop version from the web interface (link at the bottom)