UNR's Universal Thermal Model for RA Thermal Rating Verification

Presenter

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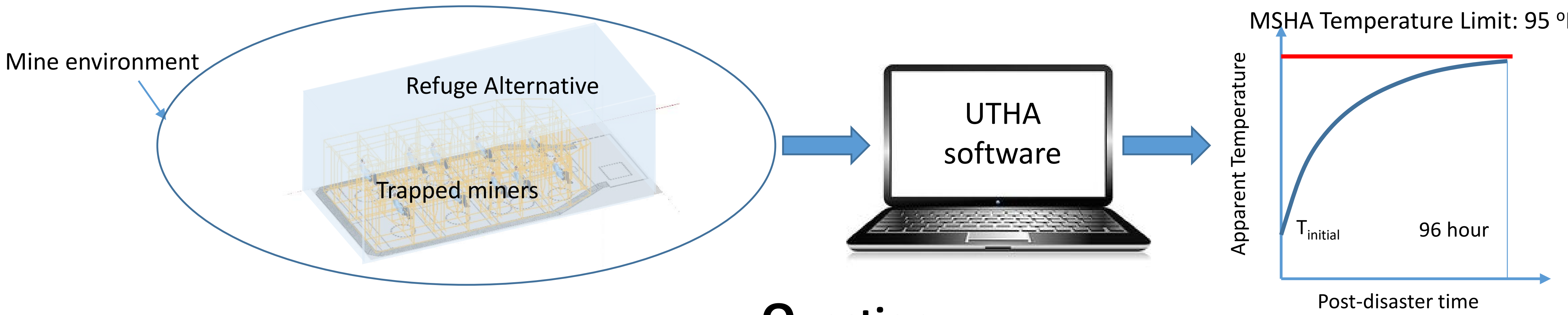
Contributed by

Davood Bahrami, UNR (MULTIFLUX thermal model)
Craig Stewart and Craig Christensen, Chasm (Ventsim GUI integration)
Dave Yantek, NIOSH (GUI review)

NIOSH Partnership Meeting, October 19, 2016

BAA Project: Development of Universal Deployment Technology for Refuge Alternative

Project’s goal: to develop an easy-to-use software tool for mines to check compliance of their RA at the mine site



Question

Will a given RA be compliant with Ta < 95 °F for a mine with a given in situ condition at the RA location?

Answer

Use an approved deployment technology for answering the compliance question (Is the RA Acceptable as-is at full capacity? What can a mine do to pass the RA?

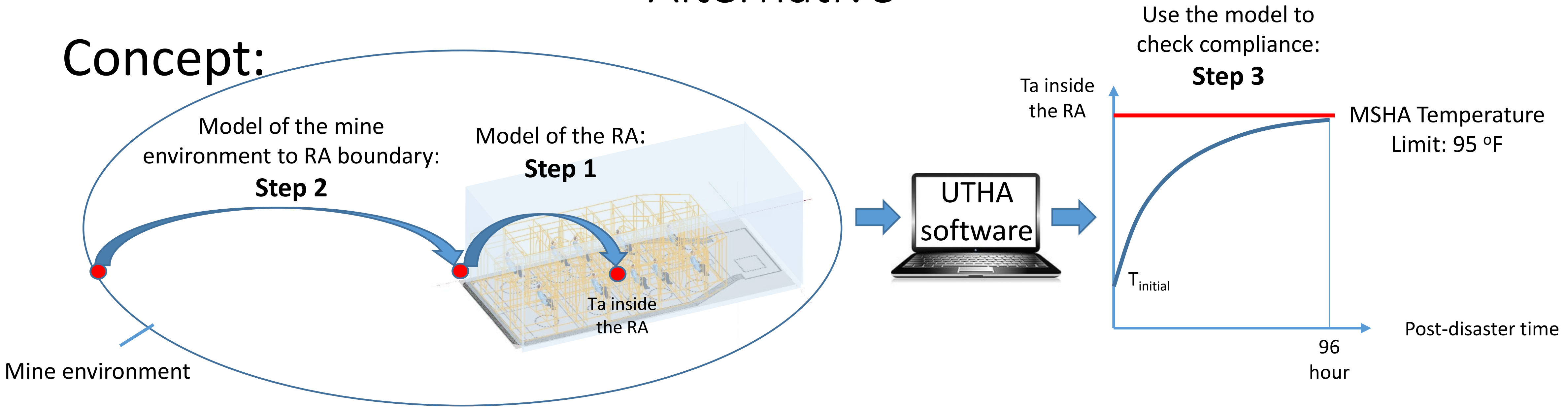
Step 1. Set-up the **Universal Thermal-Humidity-Air model (UTHA)** for the specific RA from easy-to-use Graphical User Interface (GUI); use mitigation techniques in too hot or too cold mines in the input

Step 2. Enter easy-to-access data for in situ ambient conditions at the given mine for the RA; use mitigation techniques in too hot or too cold mines in the UTHA input

Step 3. Run the UTHA model for the mine and check for compliance; mitigate (down-rate, cool, heat, etc.) if needed

Development of Universal Deployment Technology for Refuge Alternative

Concept:



Step 1: Use the UTHA model for the given RA from its boundary walls to the inside air temperature, Ta. The universal RA model must work at any conceivable boundary condition:

- constant temperature ("infinite heat sink" at the wall)
- variable temperature with time and space on floor, ribs, and roof, affected by the heat from the RA
- cooling arrangement outside the RA

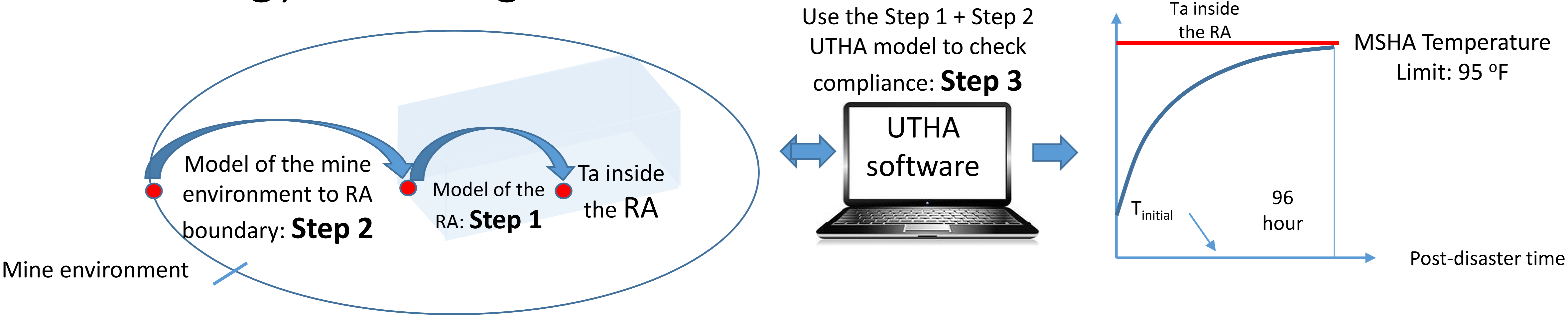
The universal RA model must also work at any conceivable internal arrangement and number of trapped miners:

- type, size and shelter capacity
- type and number of CO_2 scrubber(s): hanger or box-type
- Down-rated, variable shelter capacity for any given RA
- cooling arrangement inside or outside the RA

Step 2: Use the universal mine ambient model supported with some temperature measurements and heat conduction data for the rock strata

Step 3: Use the specified model at the mine for MSHA compliance evaluation; check capacity reduction or cooling techniques if needed for Ta < 95°F

BAA Project: Development of Universal Deployment Technology for Refuge Alternative



Compliance checking technology

Step 1: Use the universal, qualified model of the RA from a software supplier and select the specific RA model of the mine from a Graphical User Interface (GUI) of the software:

Step 1 gives the RA model for the mine from a drop-down menu

Step 2: Take a few measurements at the RA location at the mine and obtain strata thermophysical properties for the mine. Enter the data through the GUI:

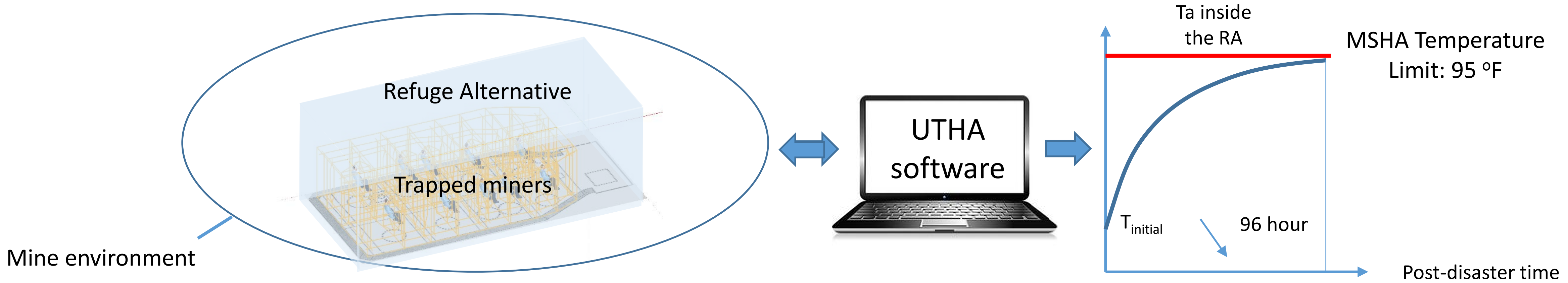
- air temperature at the RA location
- strata wall temperatures at the floor, roof and ribs
- rock heat conductivity, thermal diffusivity and density for floor, roof and ribs
- dimensions of the drift or alcove

Step 2 gives the mine environment for the RA model at the location from a drop-down menu

Step 3: Use the complete (Step 1 + Step 2) model to check compliance with MSHA regulation for maximum inside temperature in the RA in 96 hours with the modeled occupancy at the given in situ mine condition by running software from the GUI:

Step 3 plots the temperature curve to check compliance

Development of Universal Deployment Technology for Refuge Alternative



UTHA Model Development Tasks at UNR, Mackay School

Task 1. Develop UTHA for any RA and make UTHA work at any in situ ambient condition at any mine and in any RA test. This is done in a Computational Energy Dynamics (CED) model (similar to a CFD model)

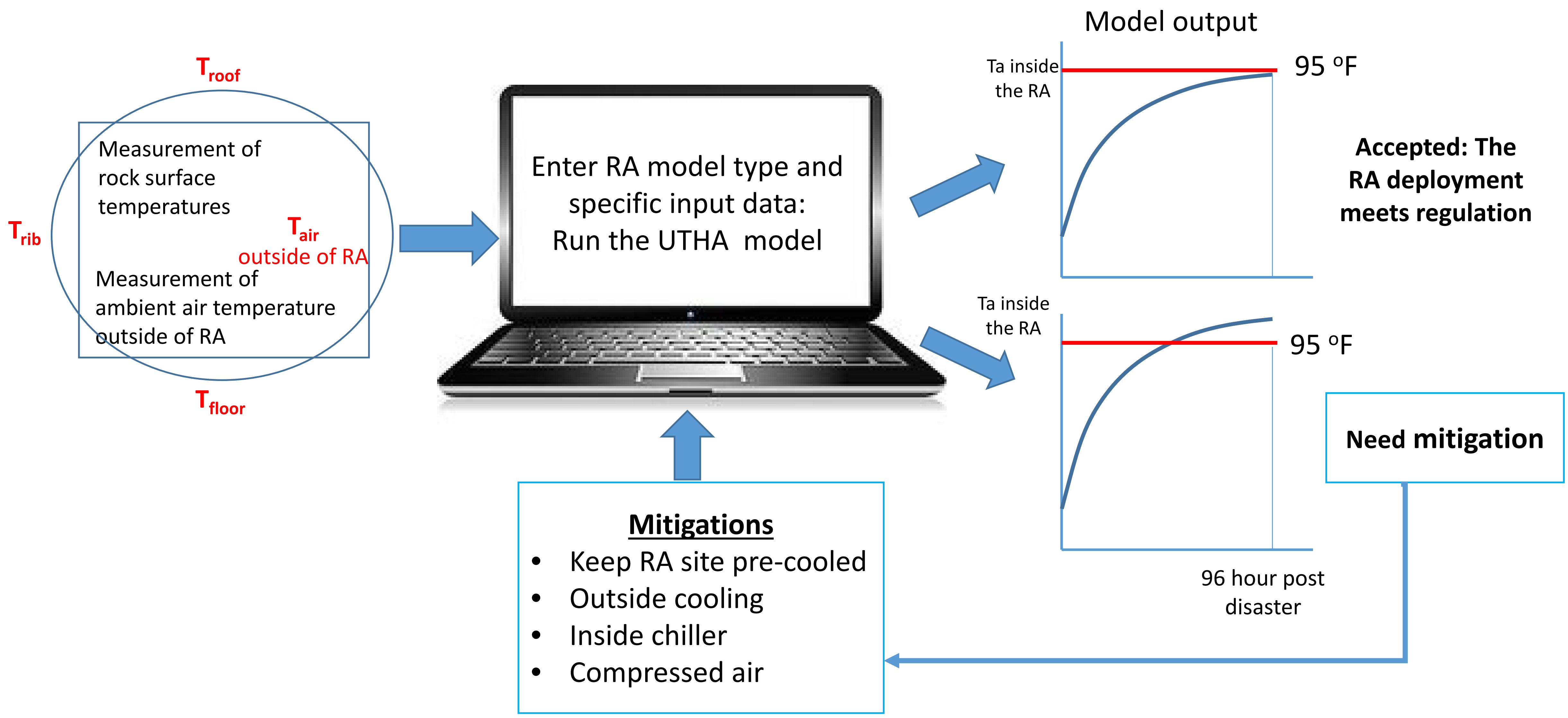
Task 2. Develop and easy-to-use GUI for applying the UTHA model by operating coal mines. This is done in Ventsim Visual

Task 3. Test the UTHA model against experiments conducted at NIOSH by matching internal temperatures in the RAs between model simulation results and measurements using various outside conditions:

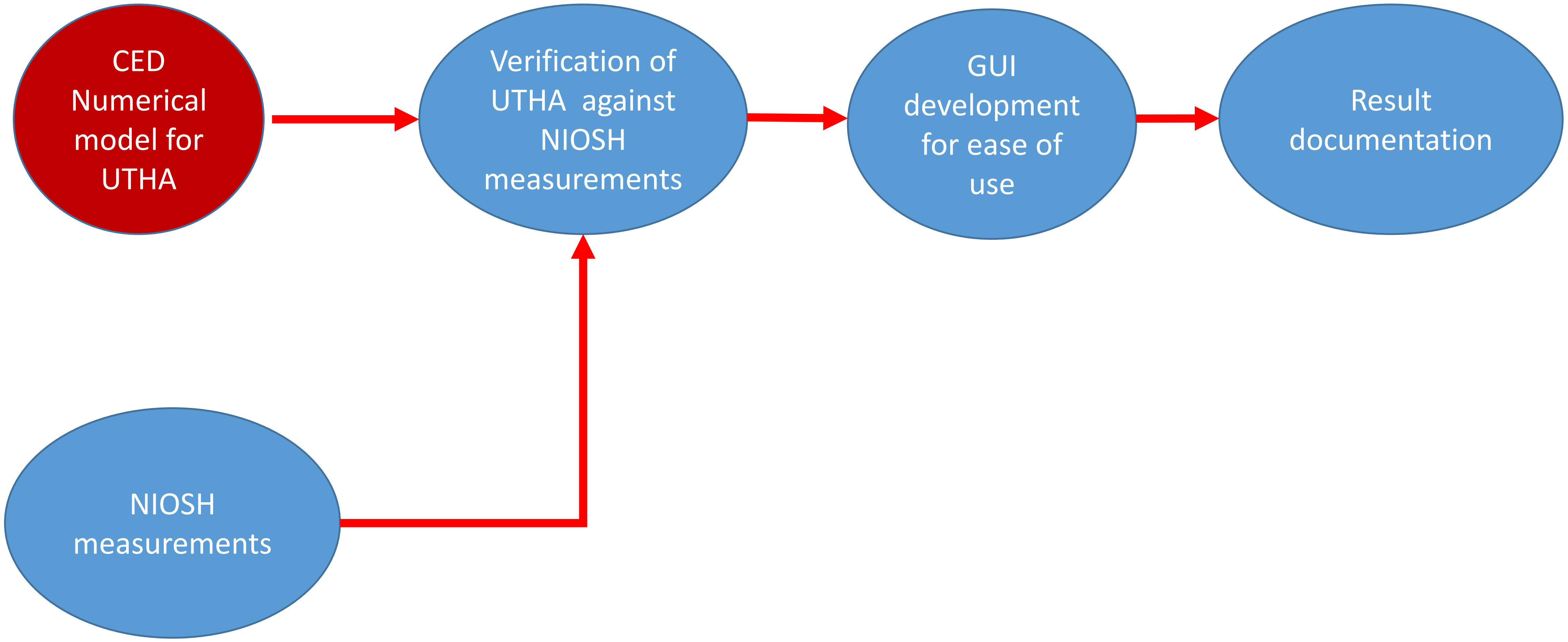
- Outside temperature
- Strata heat flow

Task 4. Find a commercialization partner for qualified distribution of the UTHA model to operating mines

Use of the UTHA Model for RA Compliance Verification



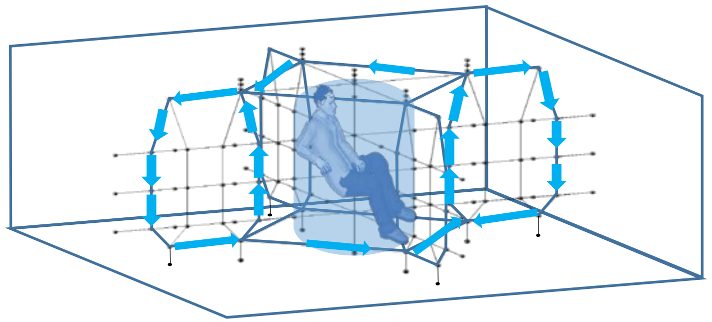
The UTHA Model Development



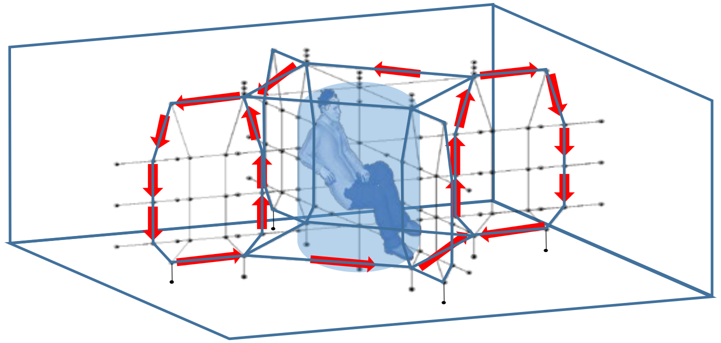
Components of the UTHA model: Human Universal Psychrometric Environment (HUPE) model-elements

(1) mass and heat

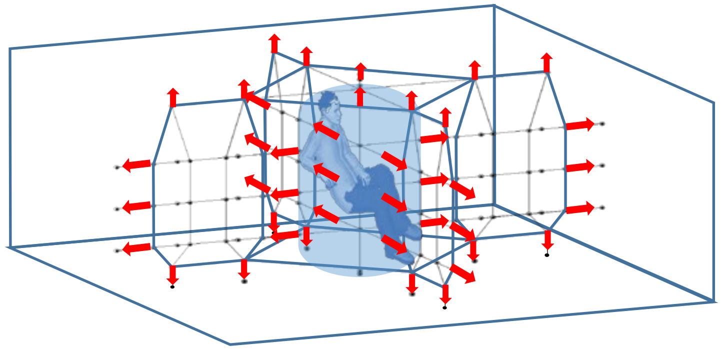
Bouyancy air flow:



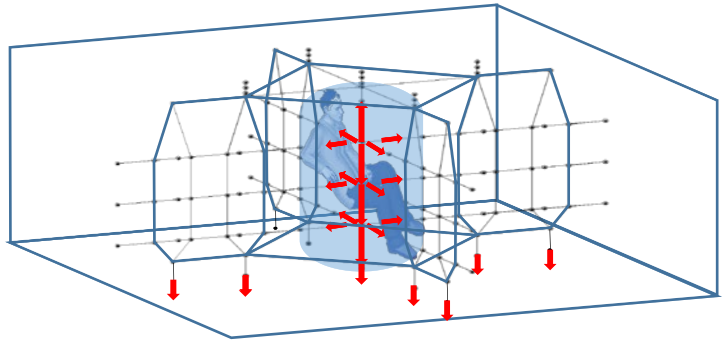
Heat advection



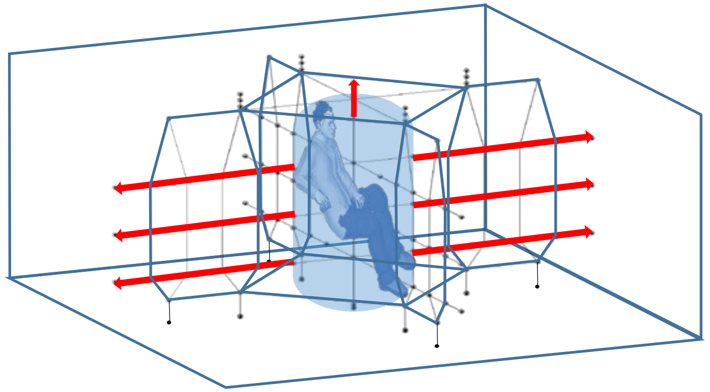
Heat convection:



Heat conduction:

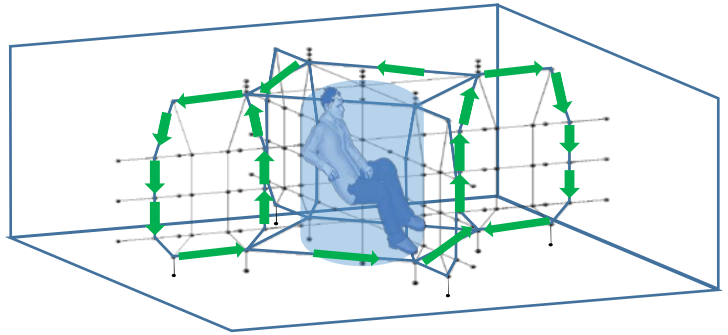


Heat radiation:

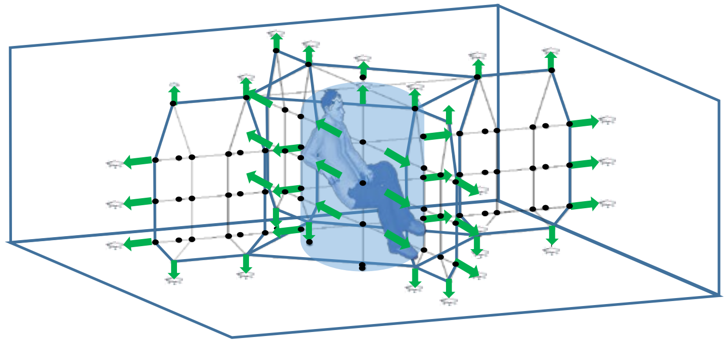


Components of UTHA: the HUPE model-elements
(2) humidity and condensation

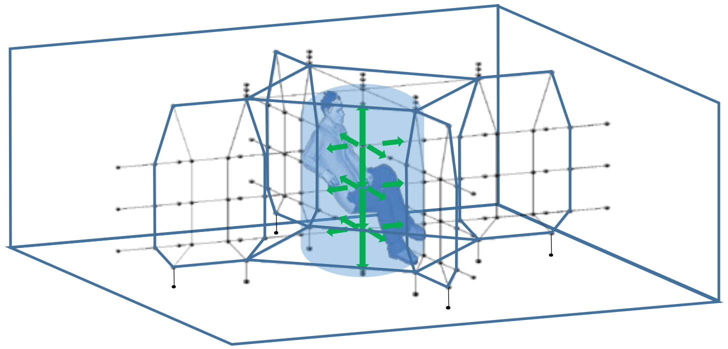
Moisture advection



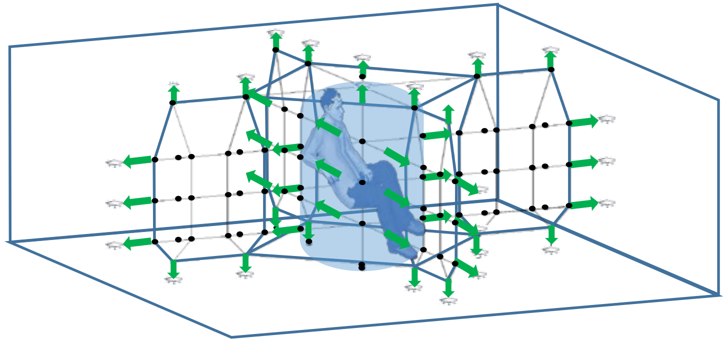
Moisture convection:



Moisture diffusion:

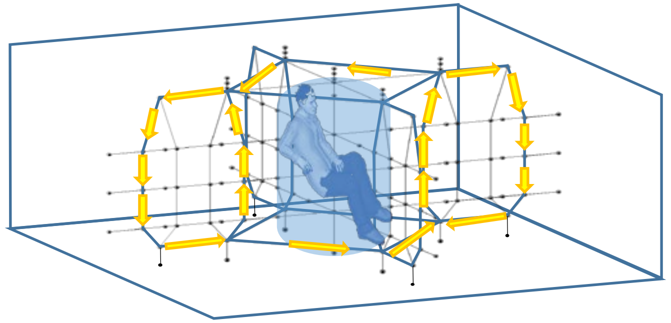


Moisture condensation:

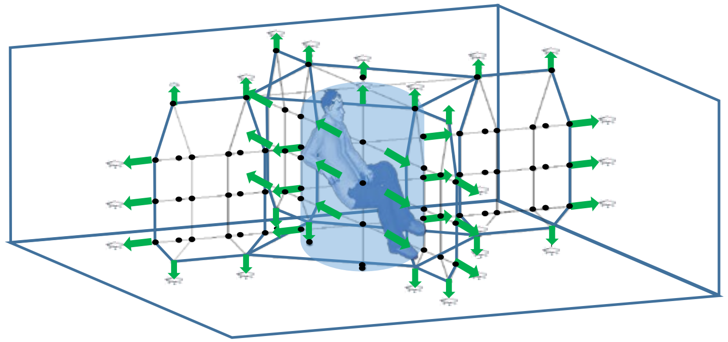


Additional components of UTHA: the HUPE model-elements upon request
(3) breathing air components

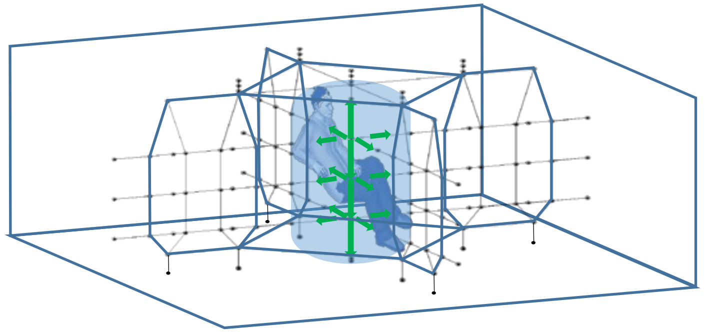
Component gas flow by air circulation:



Gas transport by convection:



Gas transport by diffusion:

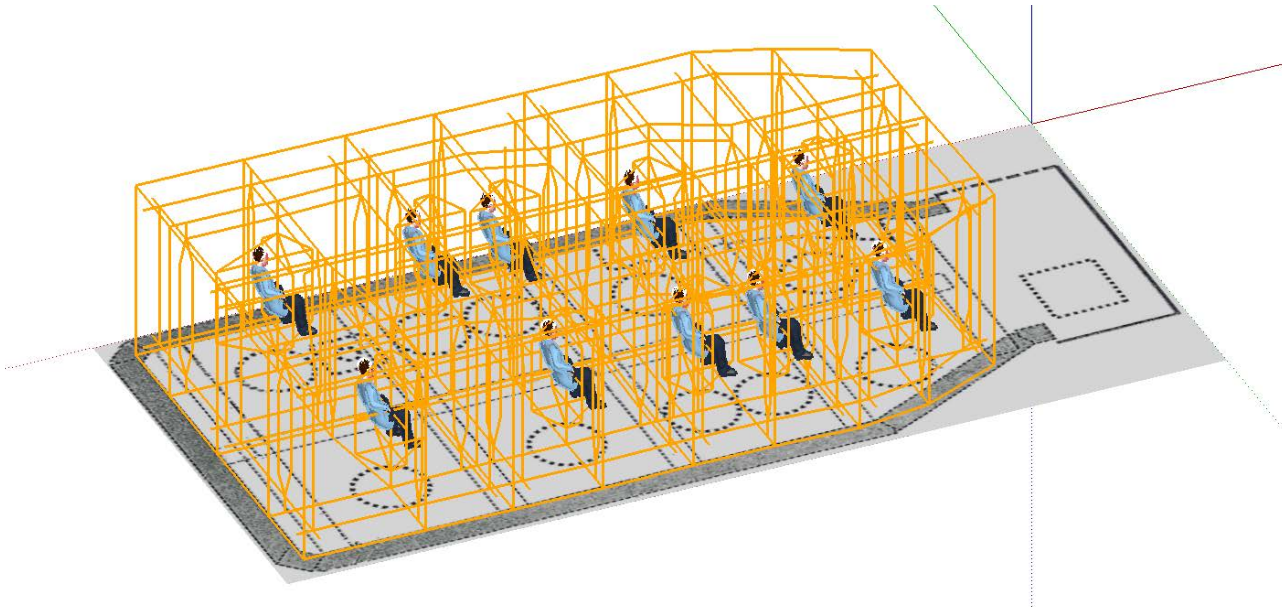


Gas components of interest:

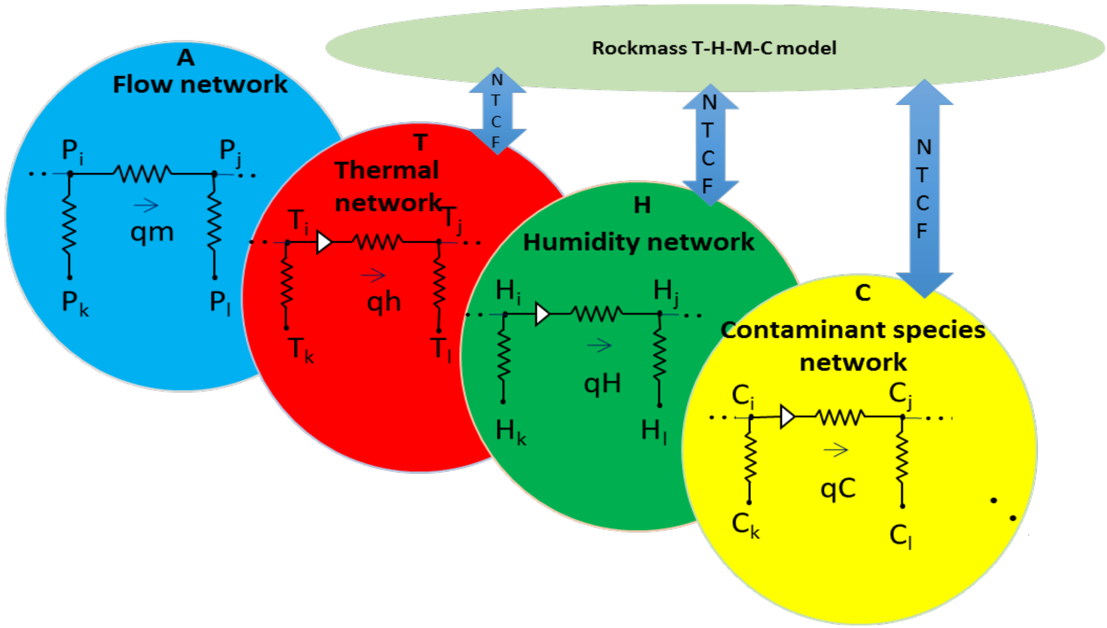
Concentration of
- Oxygen
- Carbon dioxide
- any contaminant to be purged

Coupled solution of the UTHA elements for an RA

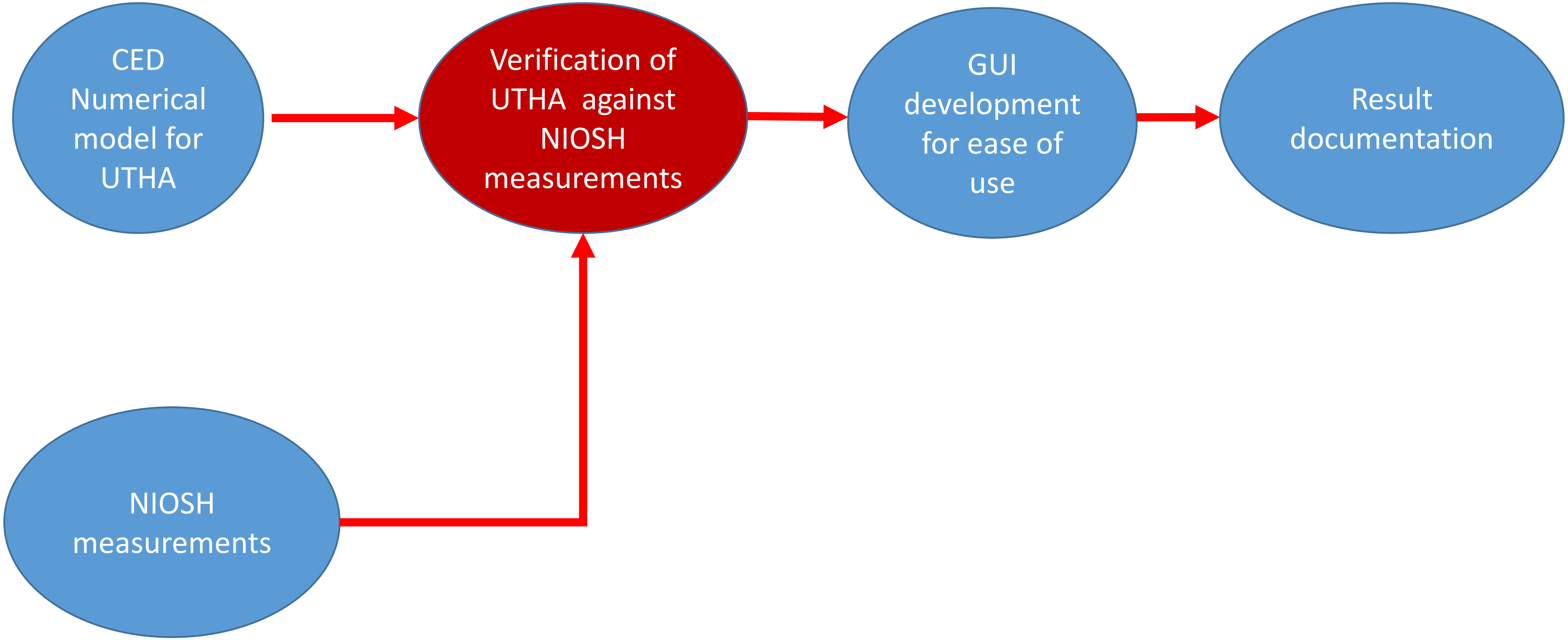
The 10-person RA example from NIOSH:



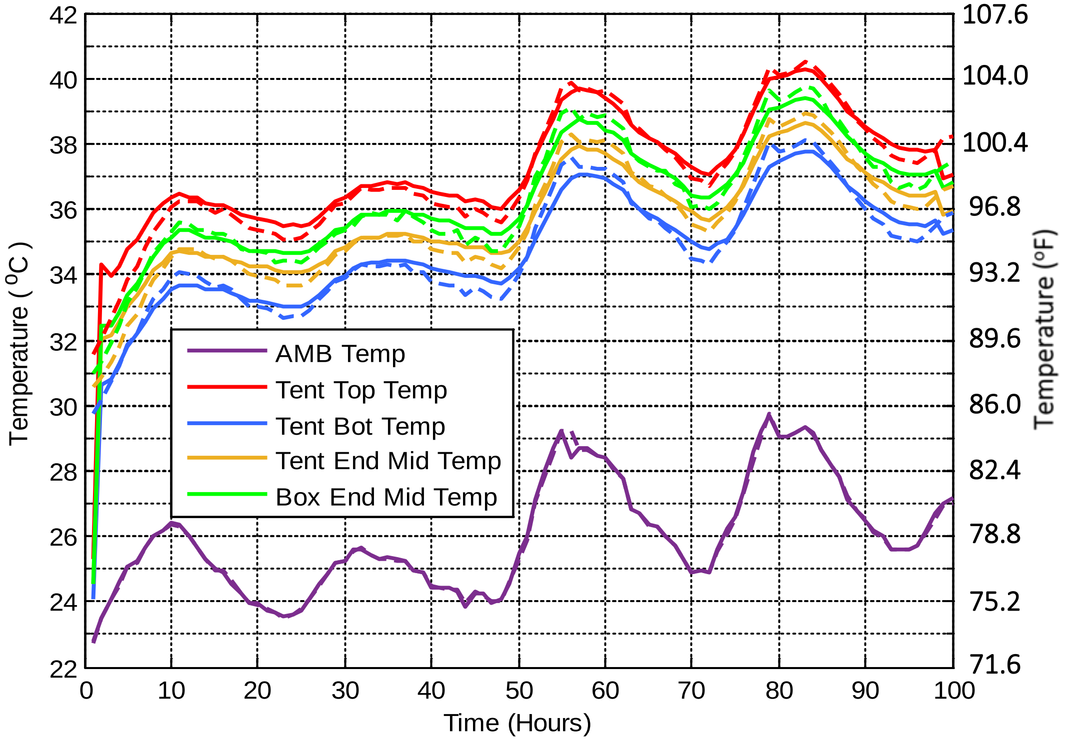
The coupled A-T-H-C and strata:



The UTHA Model Development



Model verification examples with the research model version of UTHA

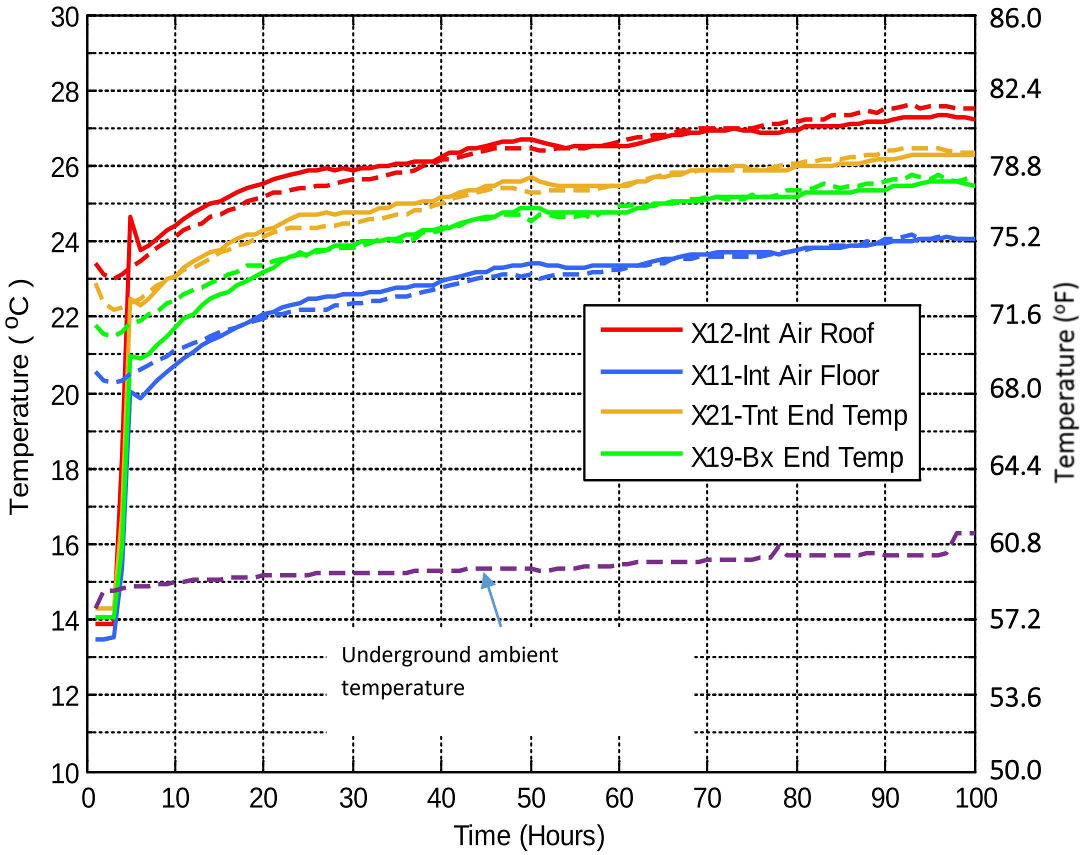


Averaged over 92-96 hours

Location	Measured		Simulated		Difference	
	[^{o}C]	[^{o}F]	[^{o}C]	[^{o}F]	[^{o}C]	[^{o}F]
Tent Top Temp	37.9	(100.3)	37.6	(99.7)	0.3	(0.6)
Tent Bot Temp	35.7	(96.2)	35.2	(95.3)	0.5	(0.8)
Tent End Mid Temp	36.6	(97.8)	36.2	(97.2)	0.4	(0.7)
Box End Mid Temp	37.2	(98.9)	36.8	(98.3)	0.3	(0.6)

NIOSH dry SRCM experiment. The overall RMS error of fit of those four locations is 0.4 ^{o}C (0.7 ^{o}F)

Model verification examples with the research model version of UTHA

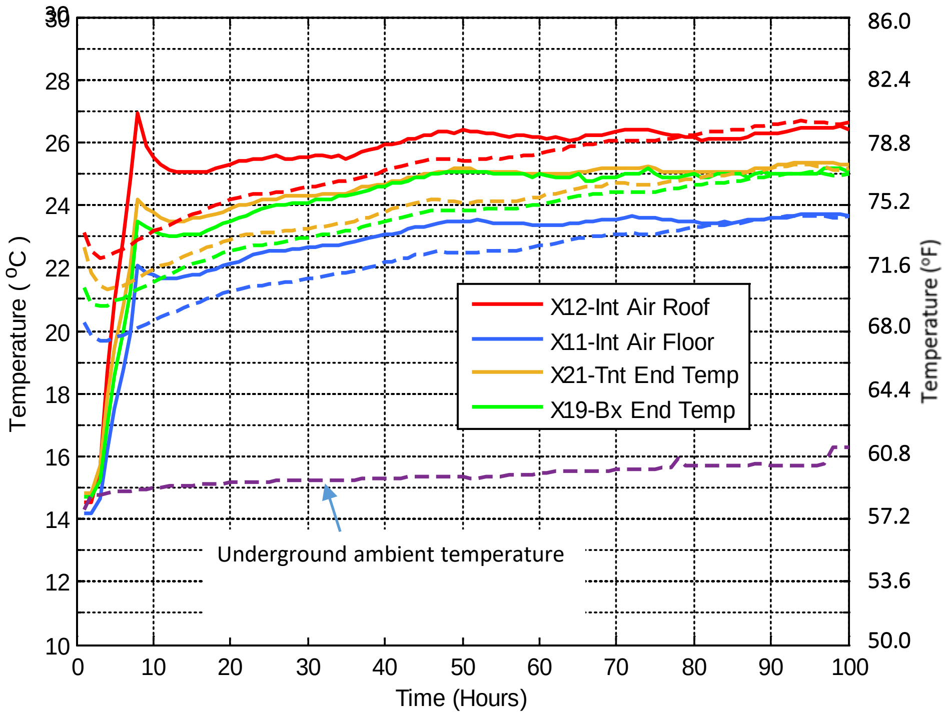


Averaged over 92-96 hours

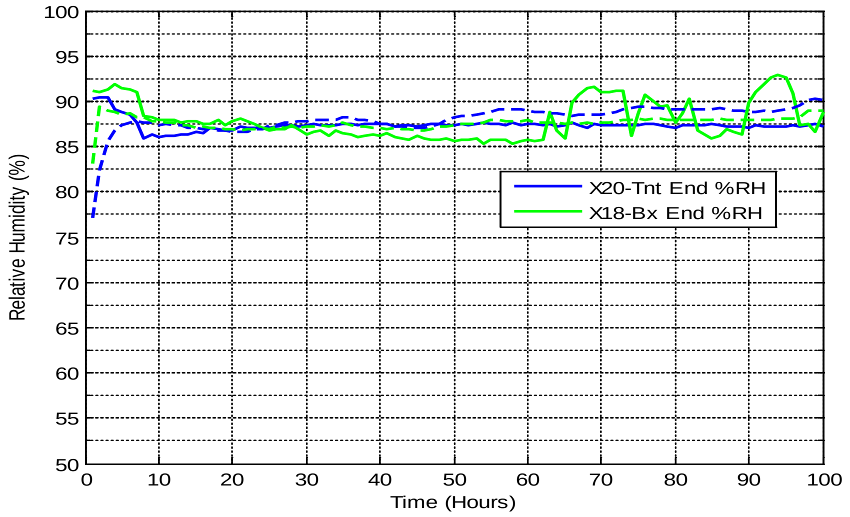
Location	Measured		Simulated		Difference	
	[^{o}C]	[^{o}F]	[^{o}C]	[^{o}F]	[^{o}C]	[^{o}F]
X12-Int Air Roof	27.3	(81.1)	27.6	(81.6)	-0.3	(-0.5)
X11-Int Air Floor	24.1	(75.3)	24.1	(75.4)	-0.1	(-0.1)
X21-Tnt End Temp	26.3	(79.3)	26.5	(79.6)	-0.2	(-0.3)
X19-Bx End Temp	25.5	(78)	25.7	(78.3)	-0.2	(-0.3)

NIOSH dry SRCM experiment. The overall RMS error of fit of those four locations is 0.2 ^{o}C (0.4 ^{o}F)

Model verification examples with the research model version of UTHA



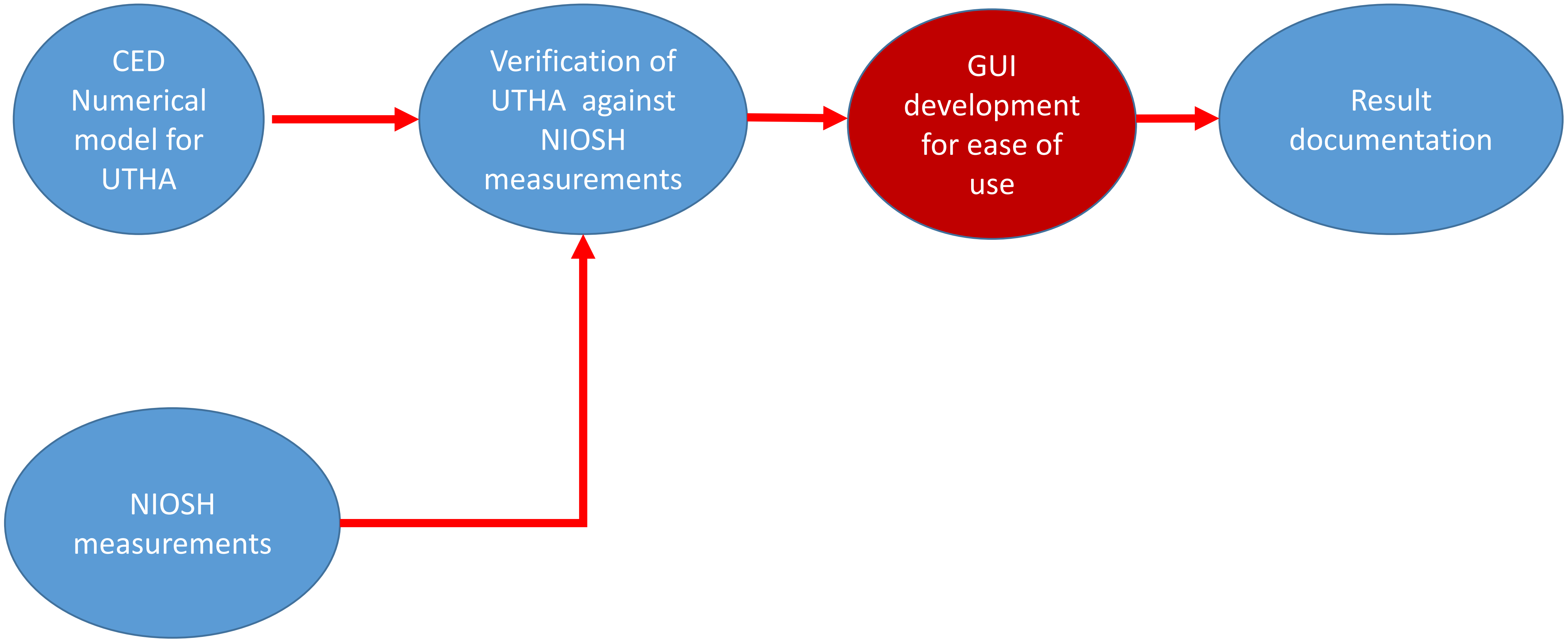
NIOSH wet SRCM experiment. The overall RMS error of fit of those four locations is 0.7 °C (1.4 °F)



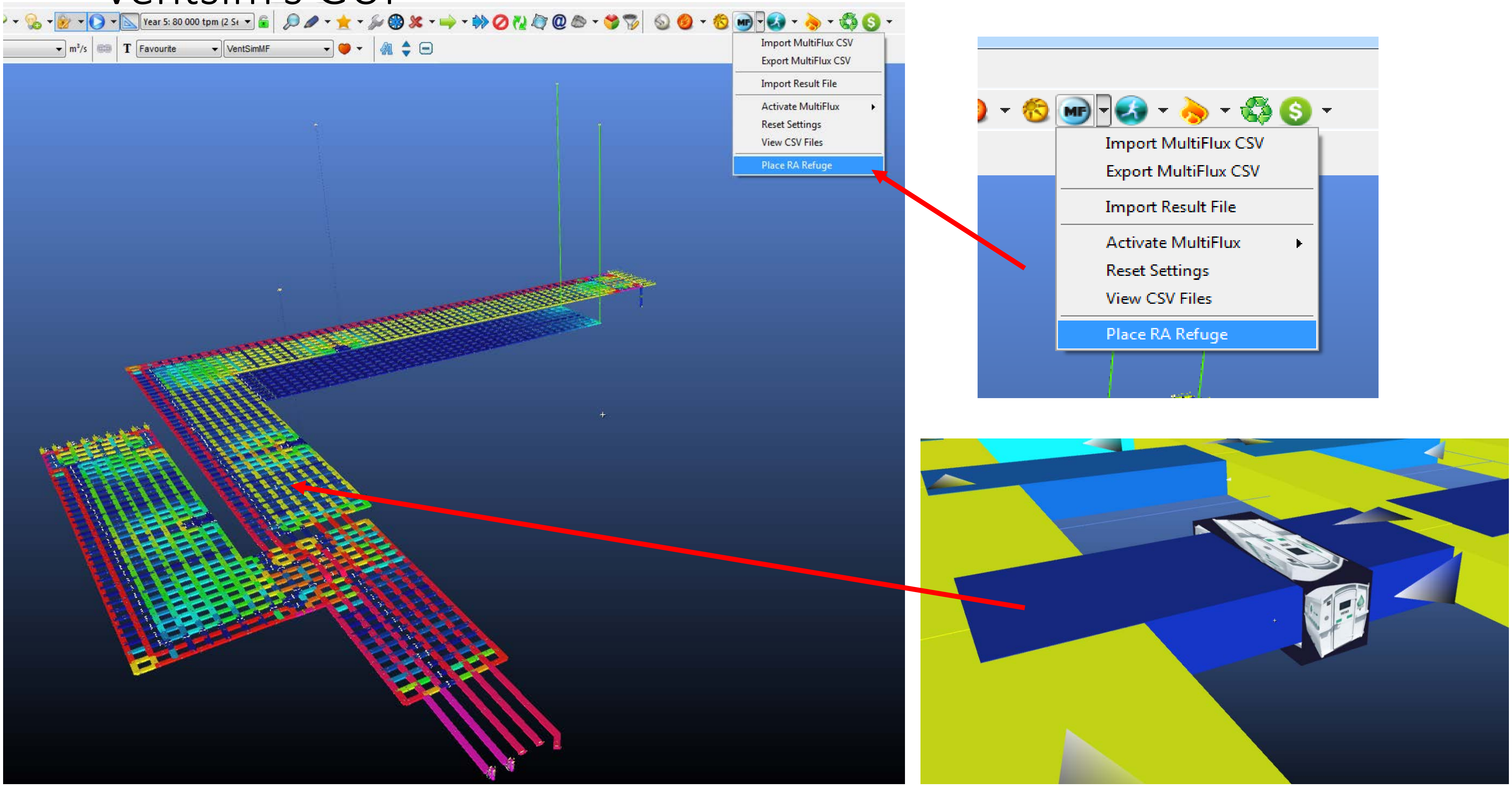
Averaged over 92-96 hours

Location	Measured		Simulated		Difference	
	[°C]	[°F]	[°C]	[°F]	[°C]	[°F]
X12-Int Air Roof	26.4	(79.5)	26.6	(79.9)	-0.2	(-0.4)
X11-Int Air Floor	25.3	(77.5)	25.4	(77.6)	-0.1	(-0.1)
X21-Tnt End Temp	25.0	(77)	25.0	(77)	0.0	(0)
X19-Bx End Temp	23.8	(74.8)	23.7	(74.7)	0.1	(0.2)

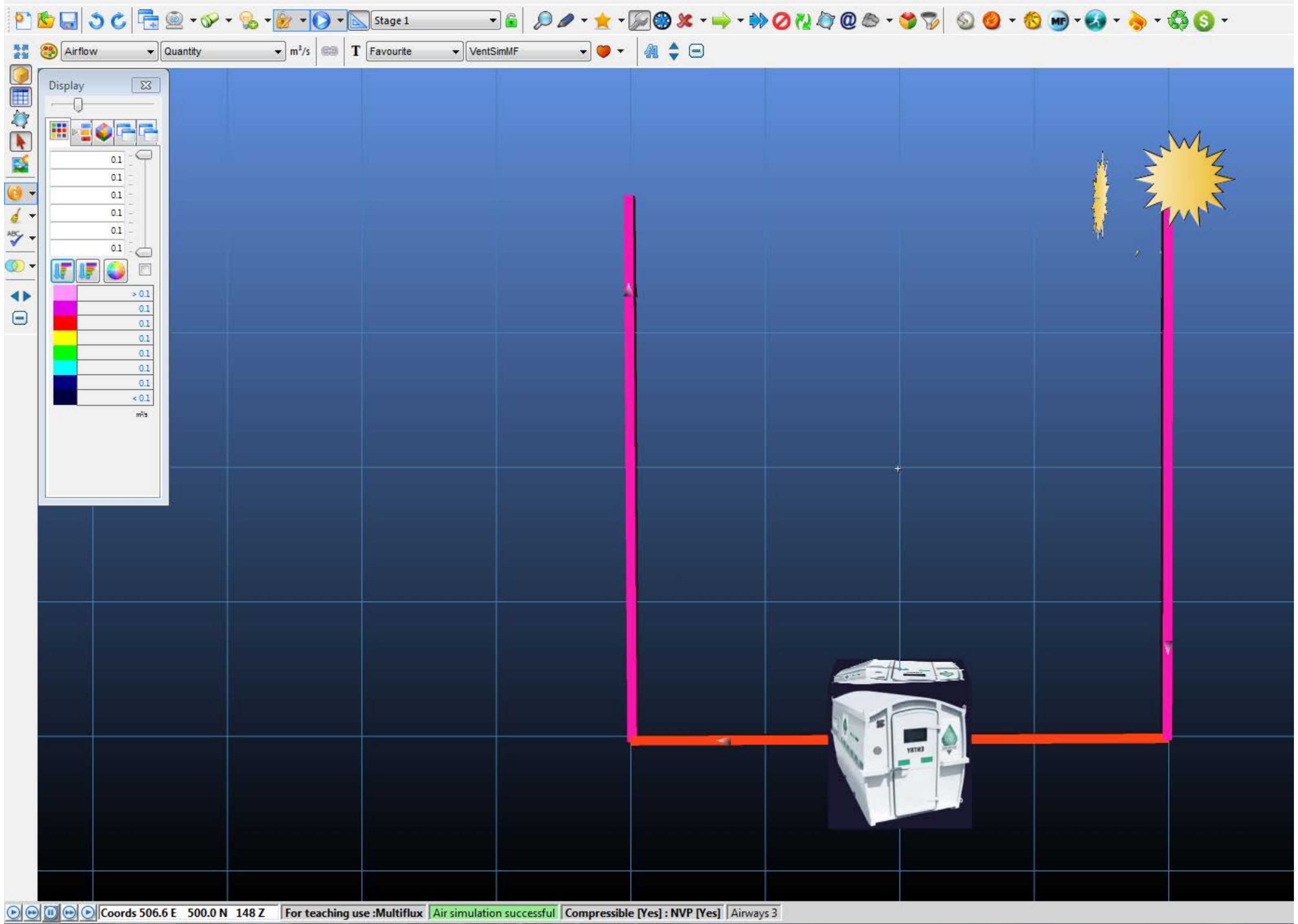
The UTHA Model Development



Model inputs: insertion of the location of the RA in the mine in Ventsim's GUI

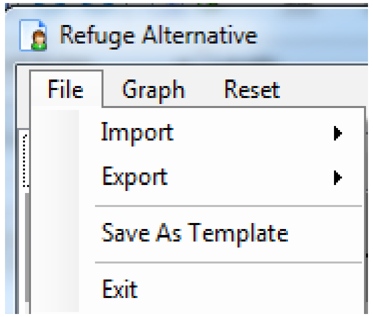


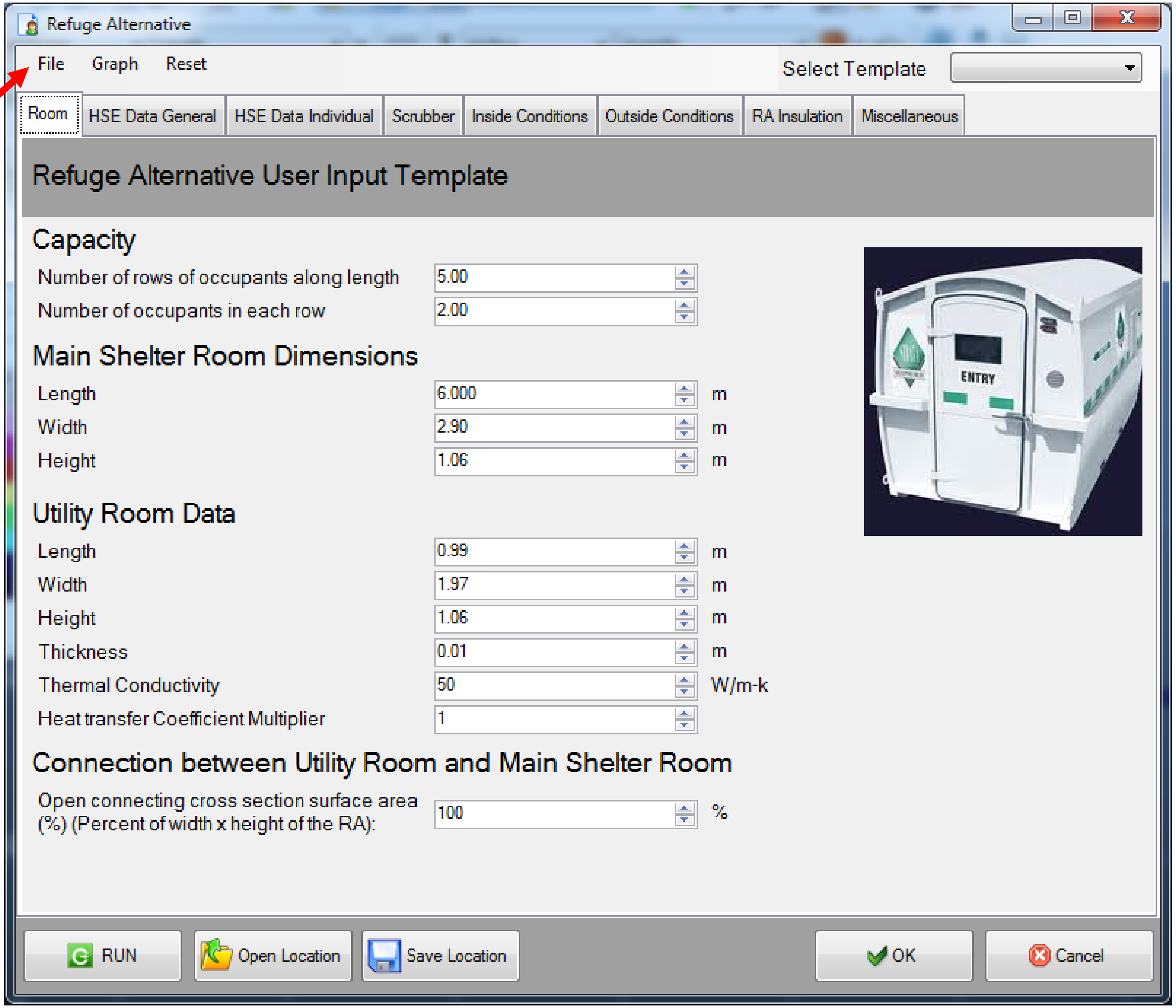
Usage from scratch with a simple mine layout: manual insertion of an RA



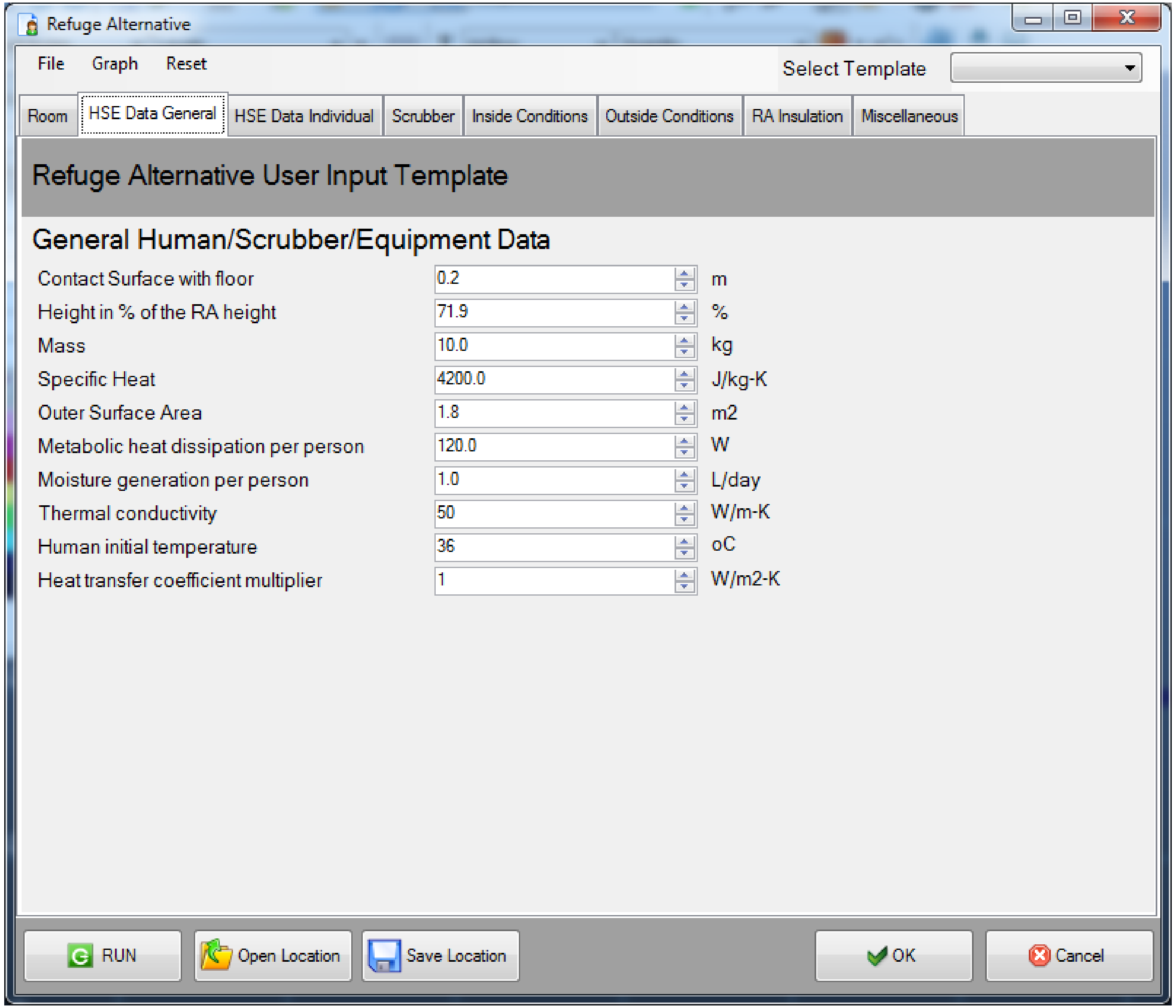
Data input tab for the RA in the GUI

File menu options

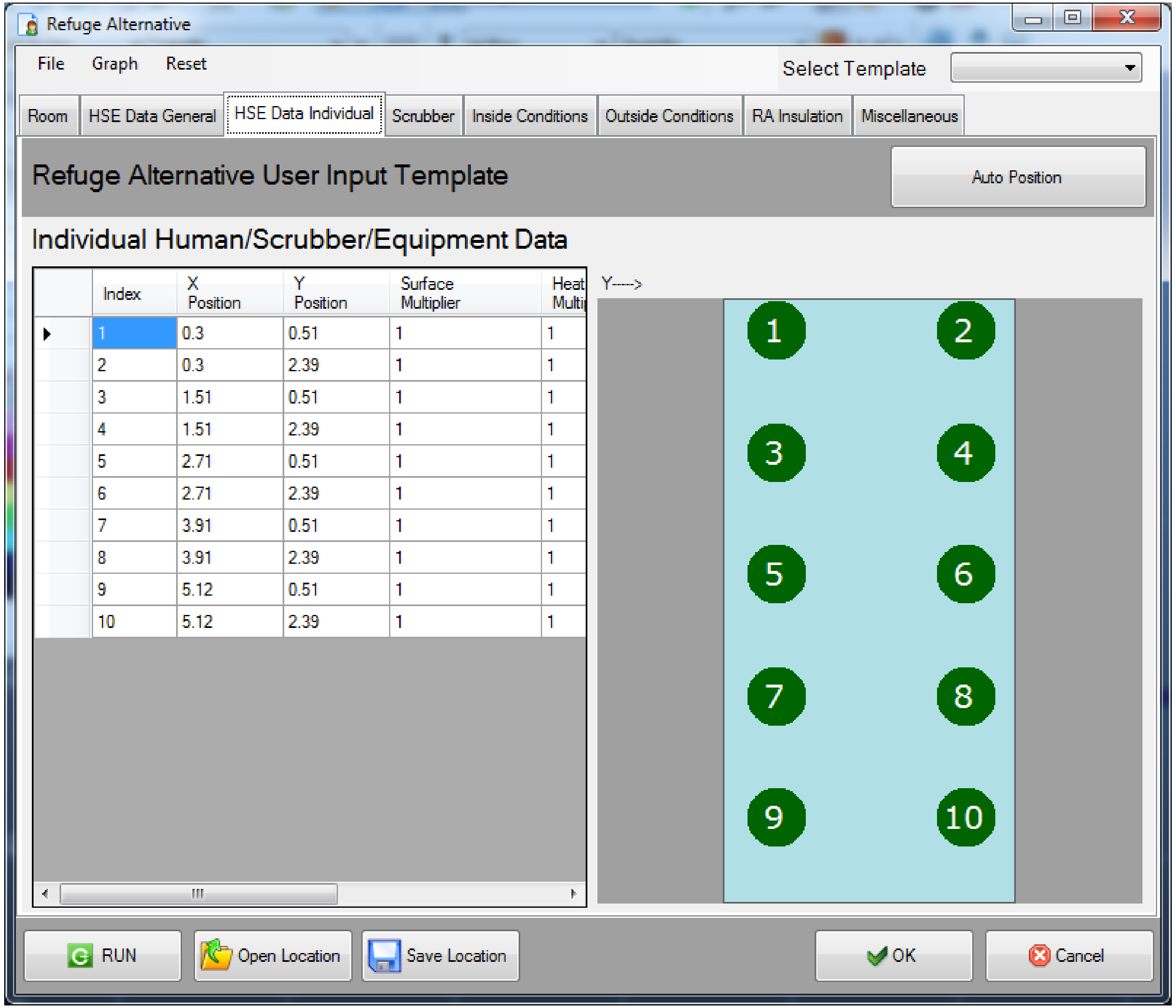




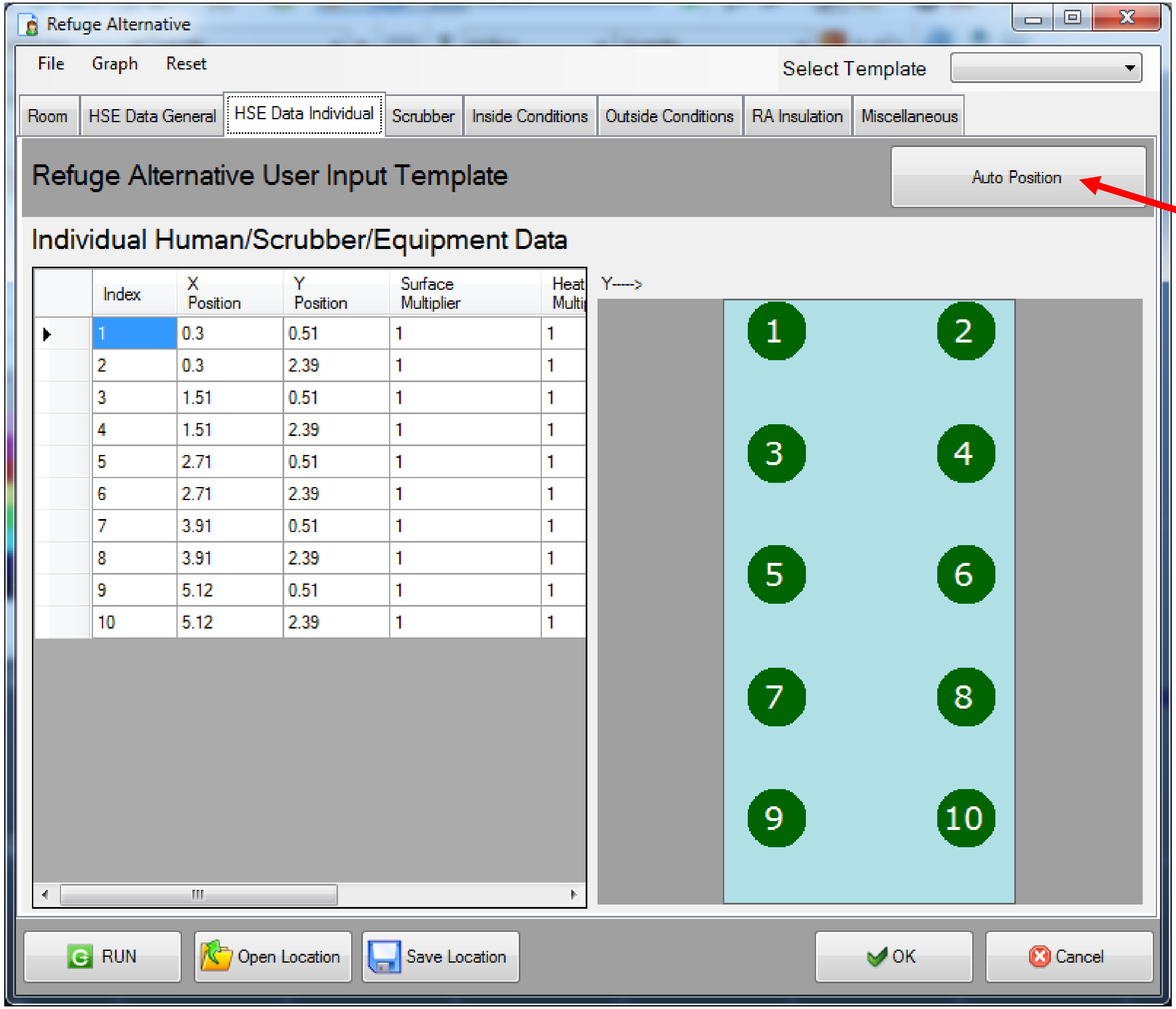
Data input tab for the RA in the GUI



Data input tab for the RA in the GUI



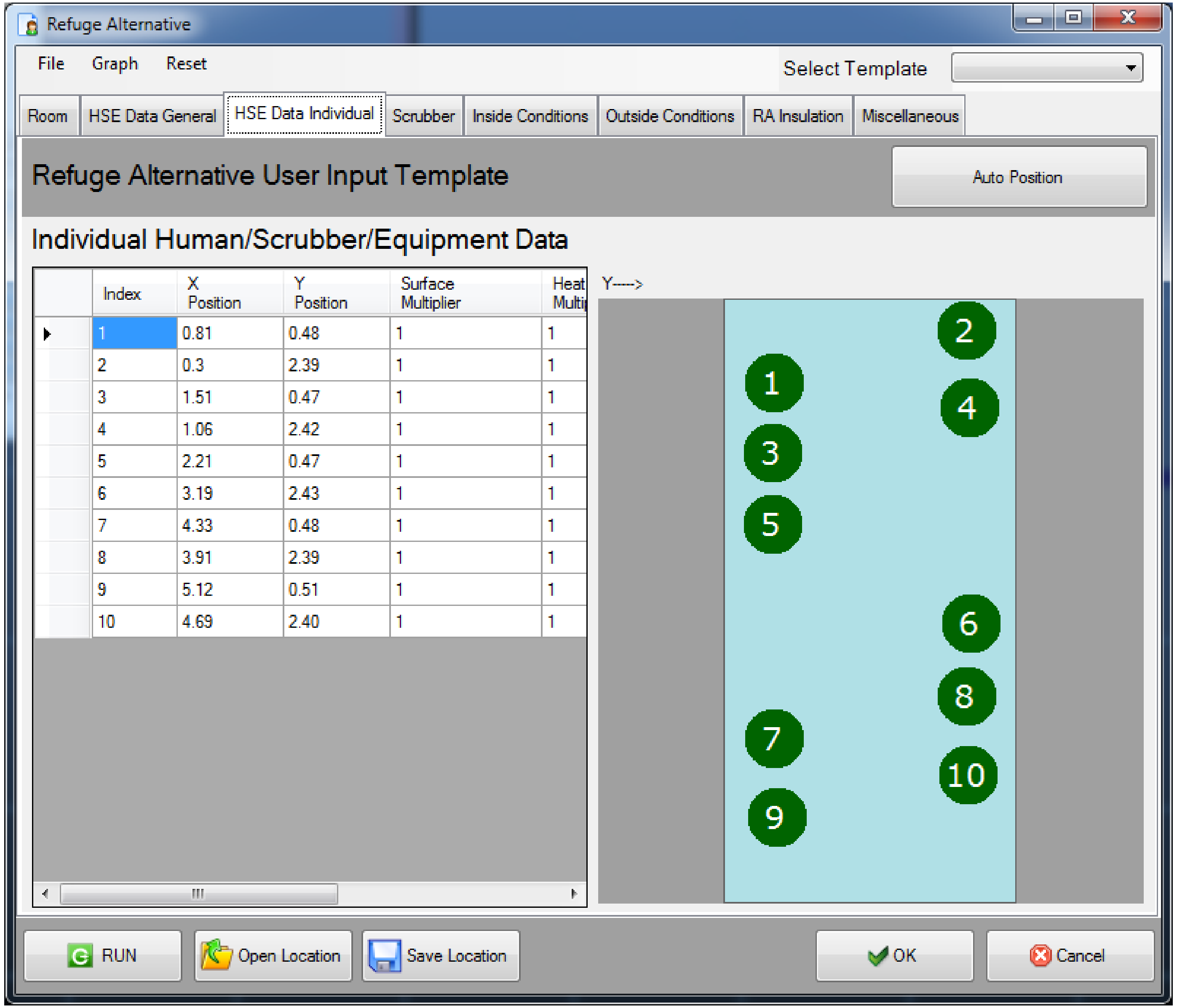
Data input tab for the RA in the GUI



Auto Position:
Default uniform arrangement of occupants

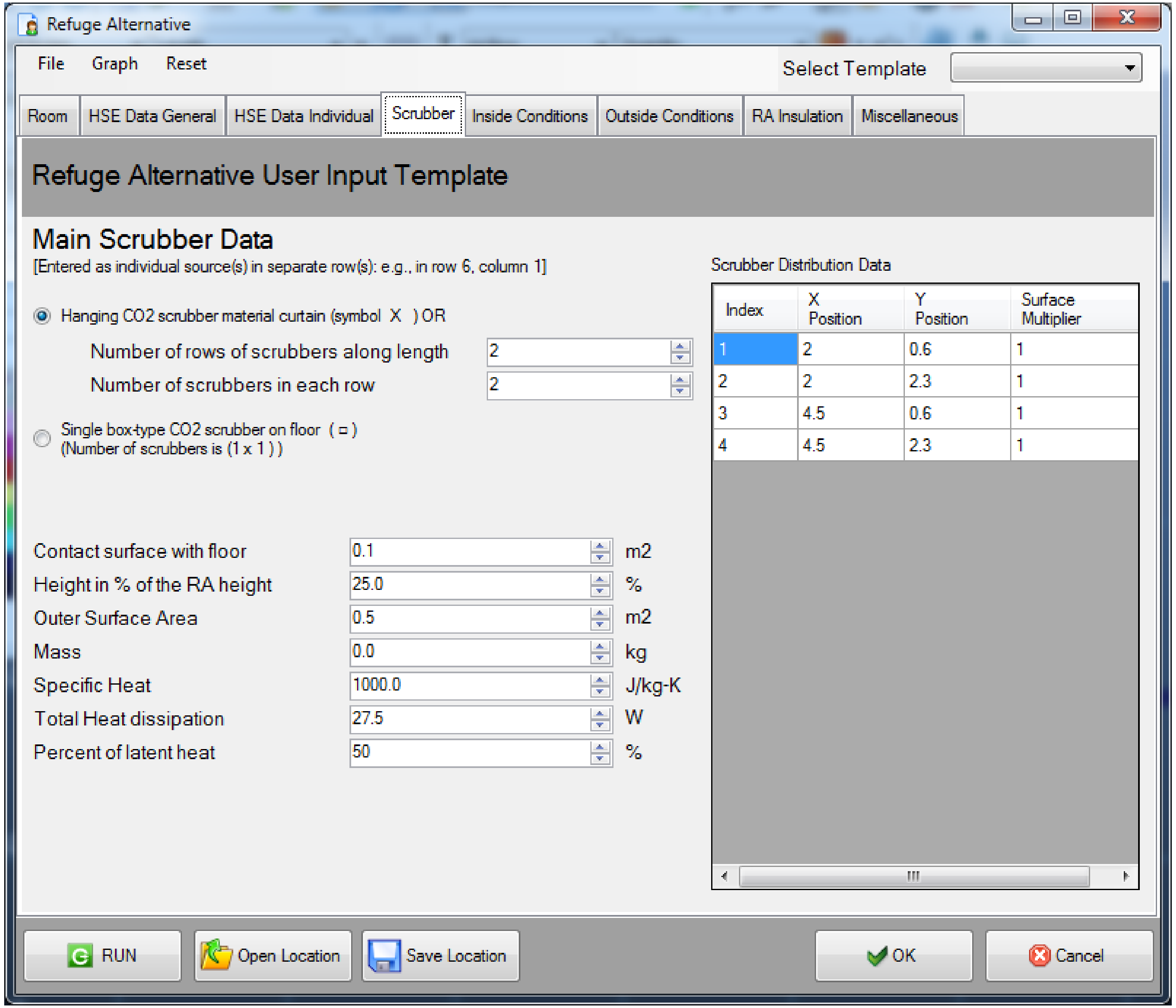
Data input tab for the RA in the GUI

Modified arrangement of occupants by manually moving the occupants or entering new data

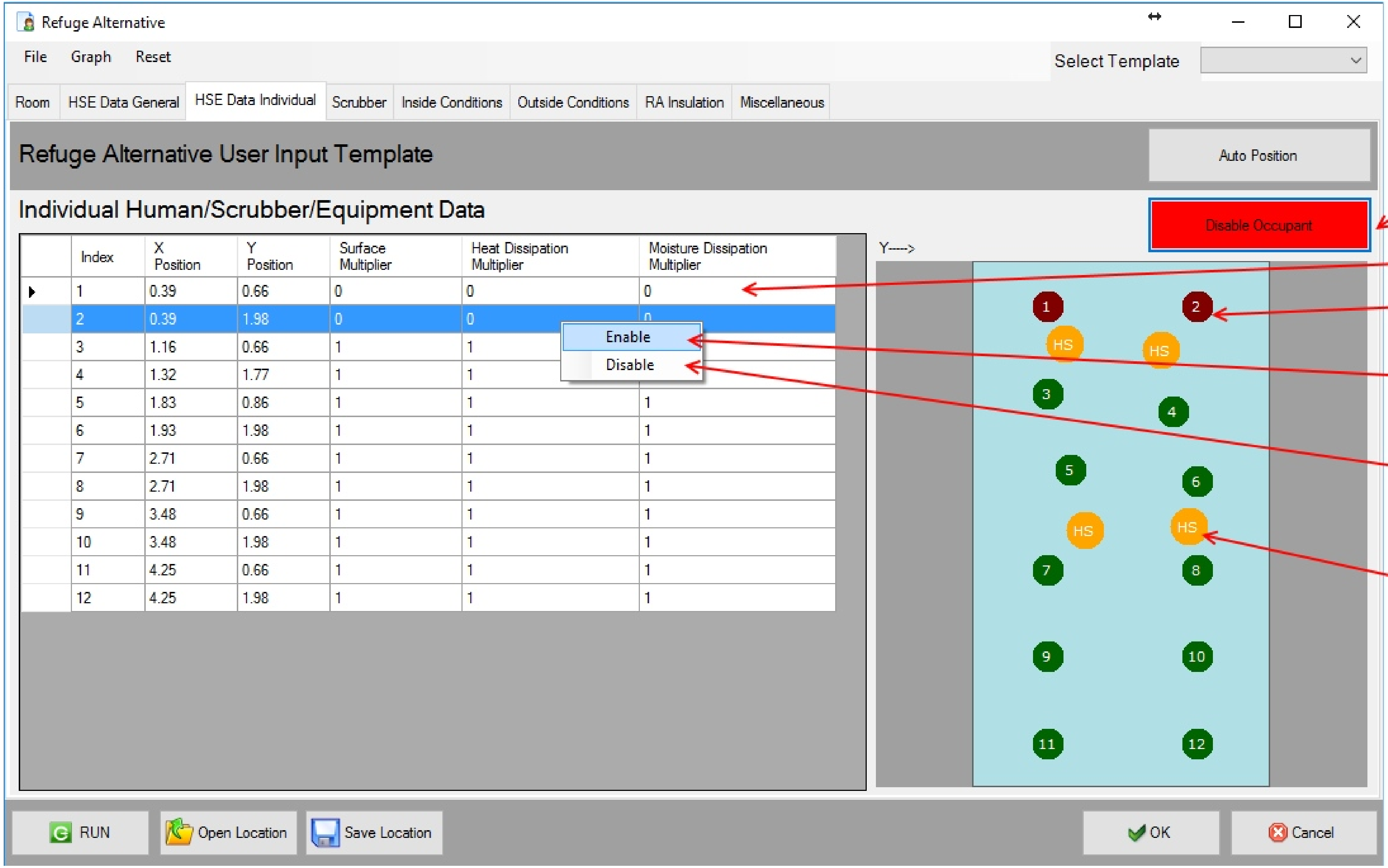


Index	X Position	Y Position	Surface Multiplier	Heat Multi
1	0.81	0.48	1	1
2	0.3	2.39	1	1
3	1.51	0.47	1	1
4	1.06	2.42	1	1
5	2.21	0.47	1	1
6	3.19	2.43	1	1
7	4.33	0.48	1	1
8	3.91	2.39	1	1
9	5.12	0.51	1	1
10	4.69	2.40	1	1

Data input tab for the RA in the GUI



RA Example: a 10-person RA with hanger-type CO_2 scrubber



Index	X Position	Y Position	Surface Multiplier	Heat Dissipation Multiplier	Moisture Dissipation Multiplier
1	0.39	0.66	0	0	0
2	0.39	1.98	0	0	0
3	1.16	0.66	1	1	
4	1.32	1.77	1	1	
5	1.83	0.86	1	1	1
6	1.93	1.98	1	1	1
7	2.71	0.66	1	1	1
8	2.71	1.98	1	1	1
9	3.48	0.66	1	1	1
10	3.48	1.98	1	1	1
11	4.25	0.66	1	1	1
12	4.25	1.98	1	1	1

Toggles disable/Move Mode

Disabled sets all 3 Multipliers to 0

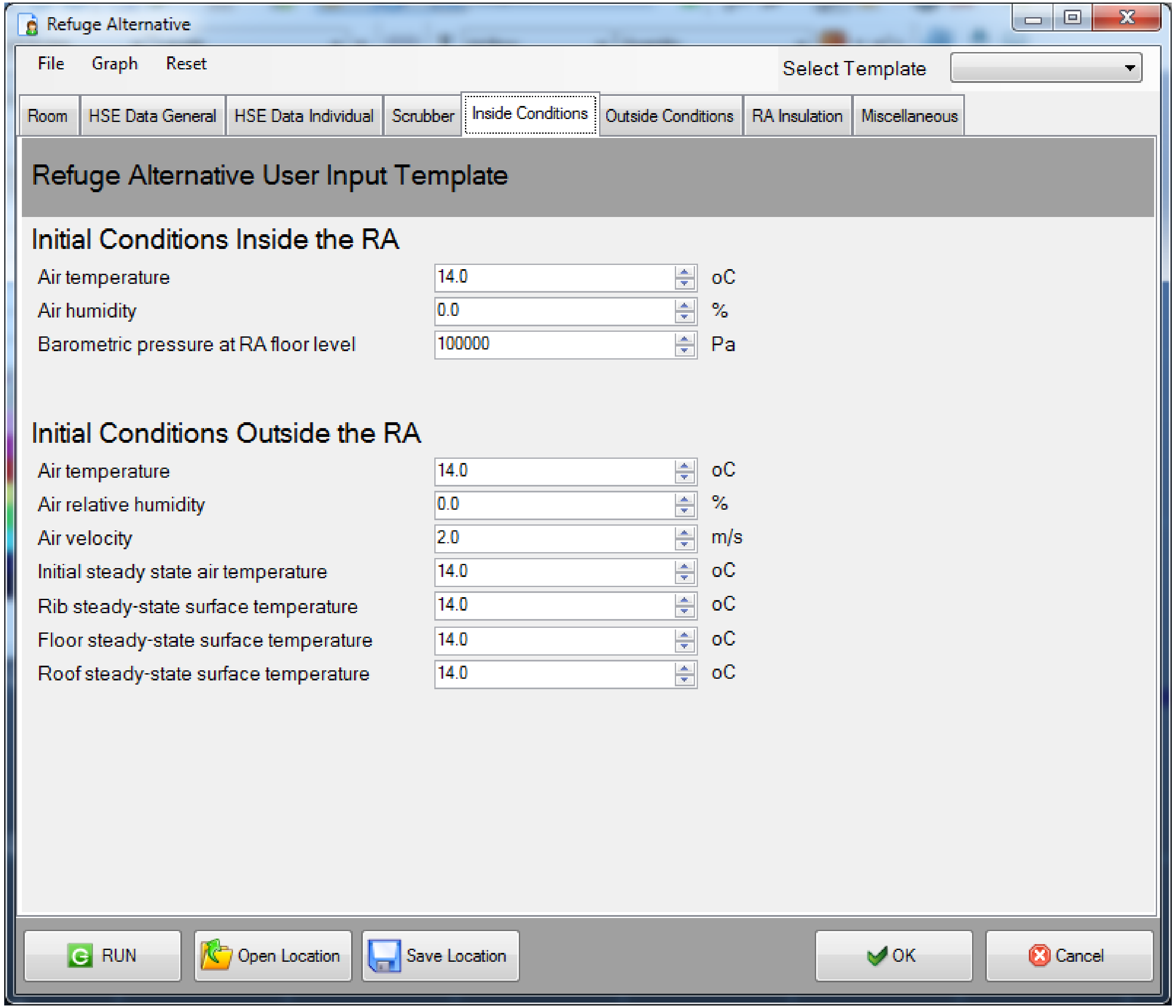
Disabled items are red

Pressing enabled here will flick all Multipliers to 1

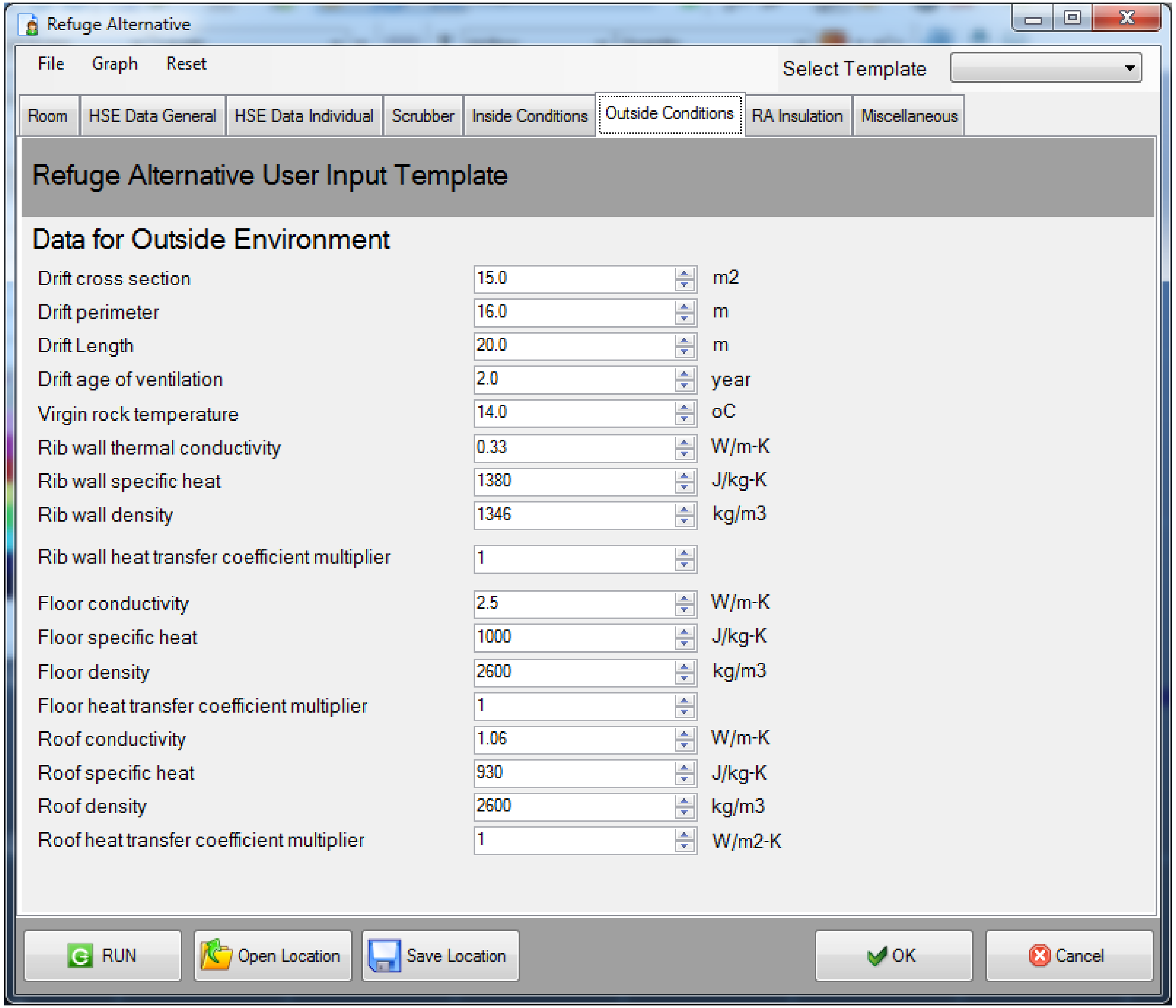
Pressing Disabled here will disable the occupant by setting all multipliers to 0

Hanger Scrubber Icon Movable by Dragging just like the Occupants

Data input tab for the RA in the GUI



Data input tab for RA in the GUI



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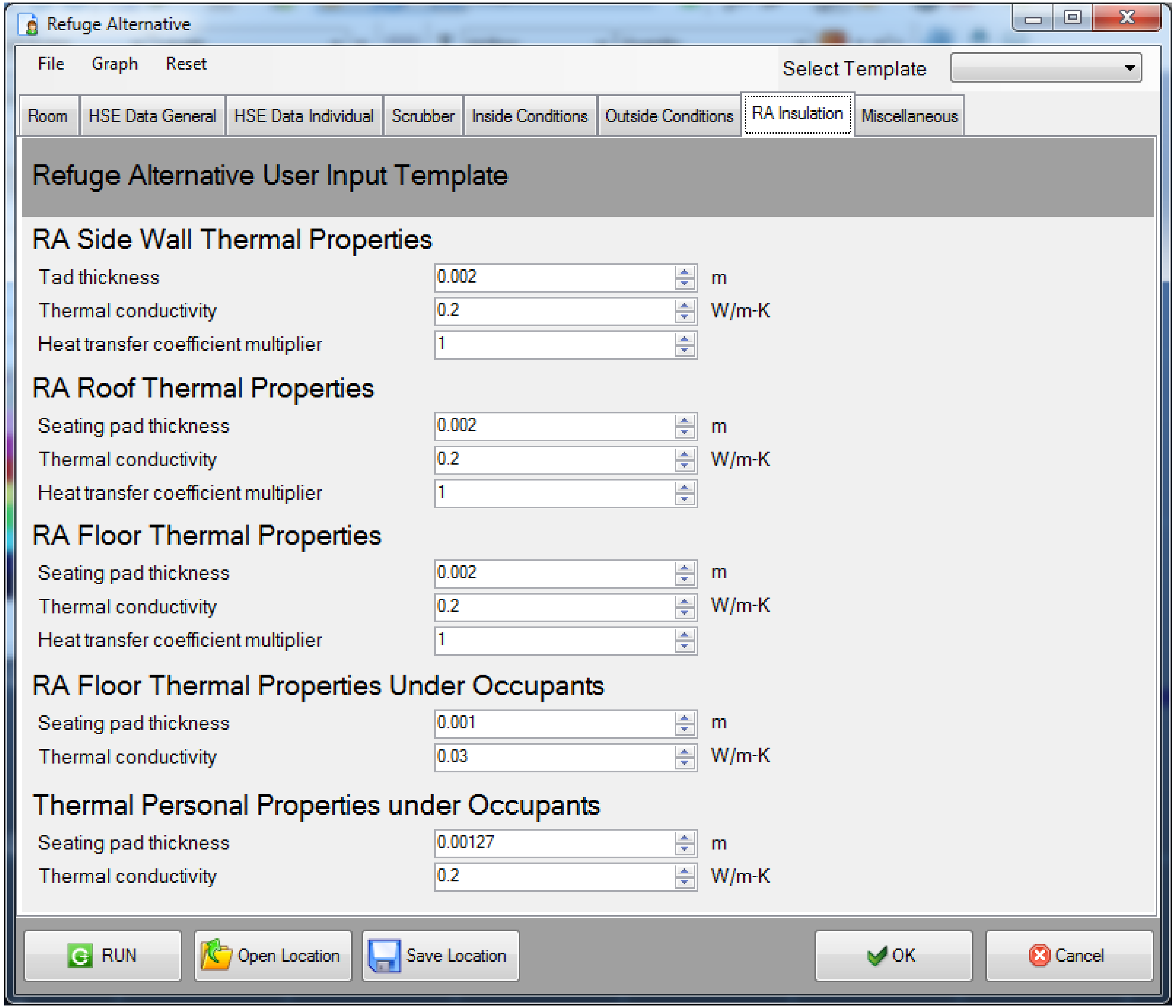

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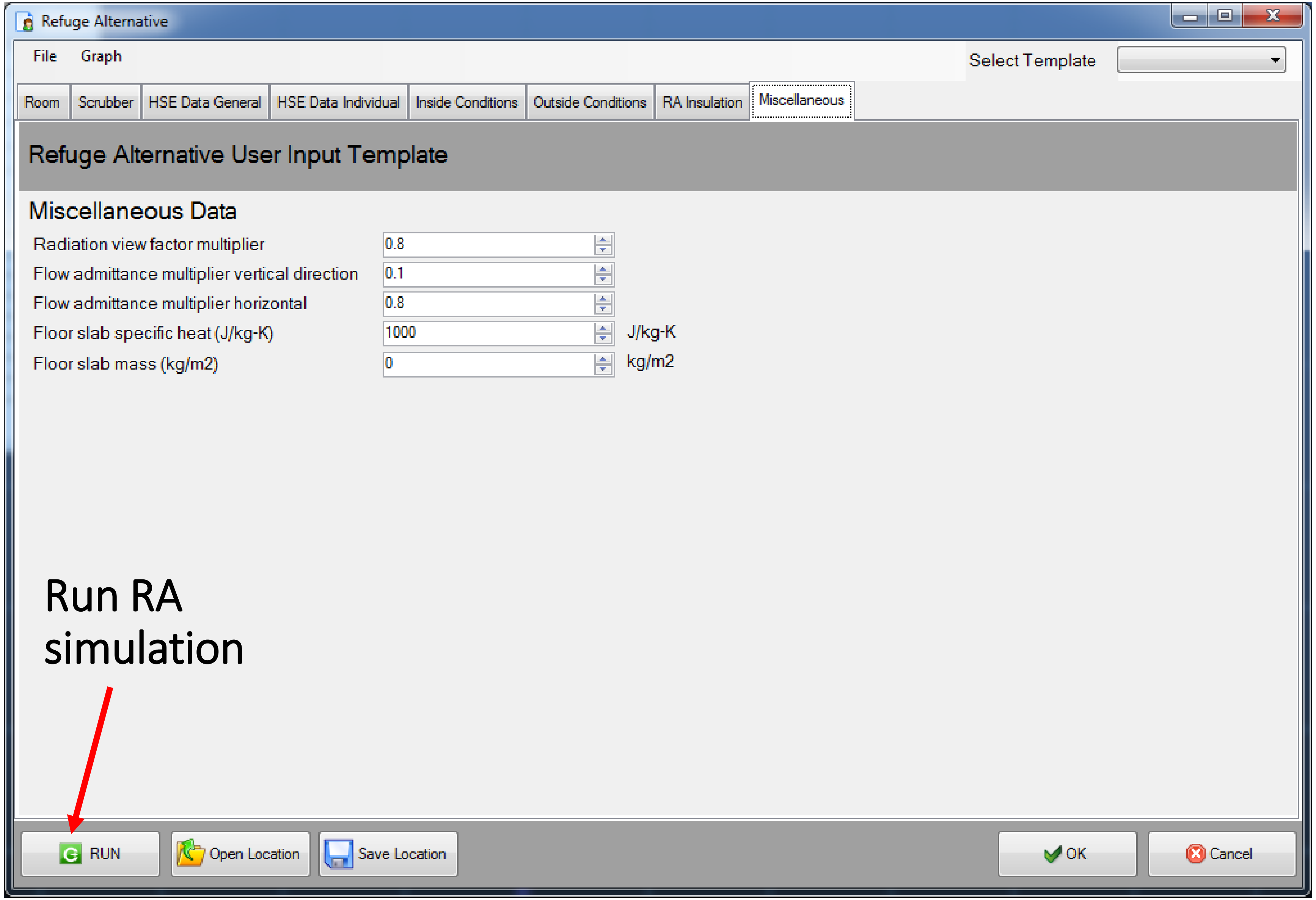
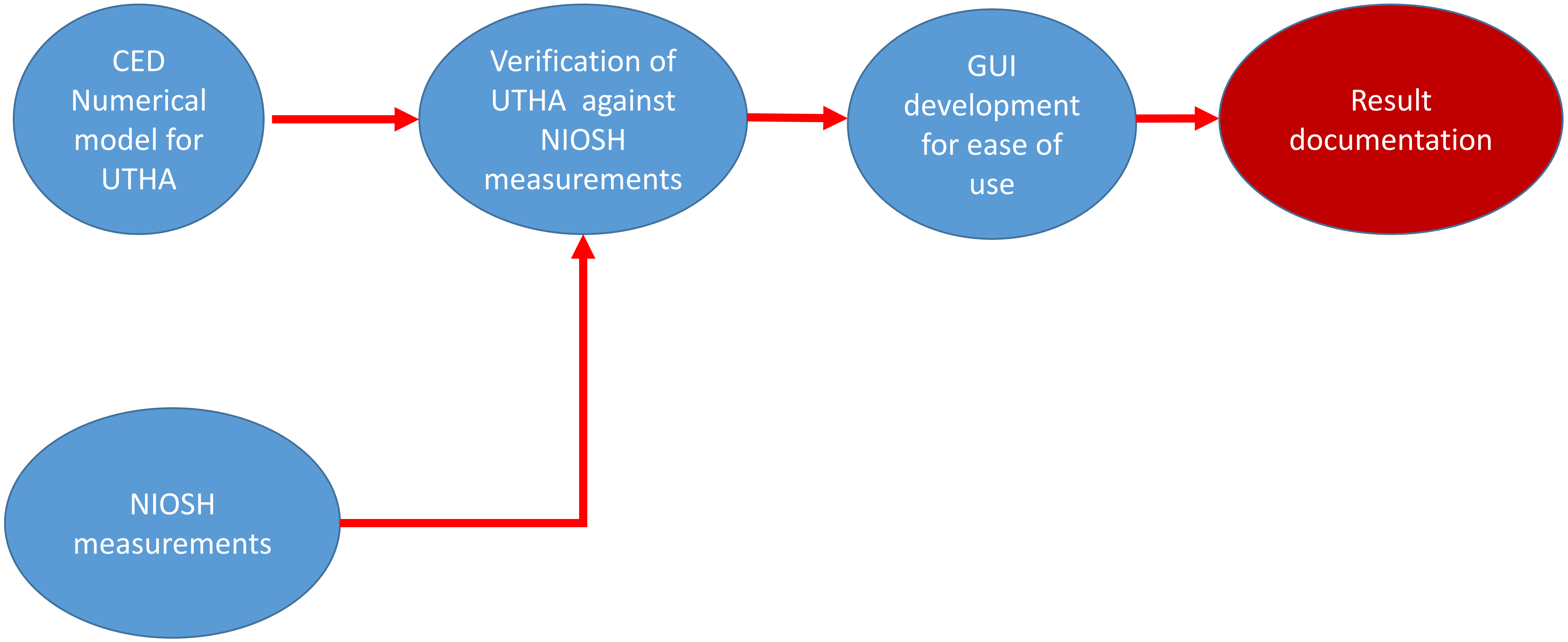
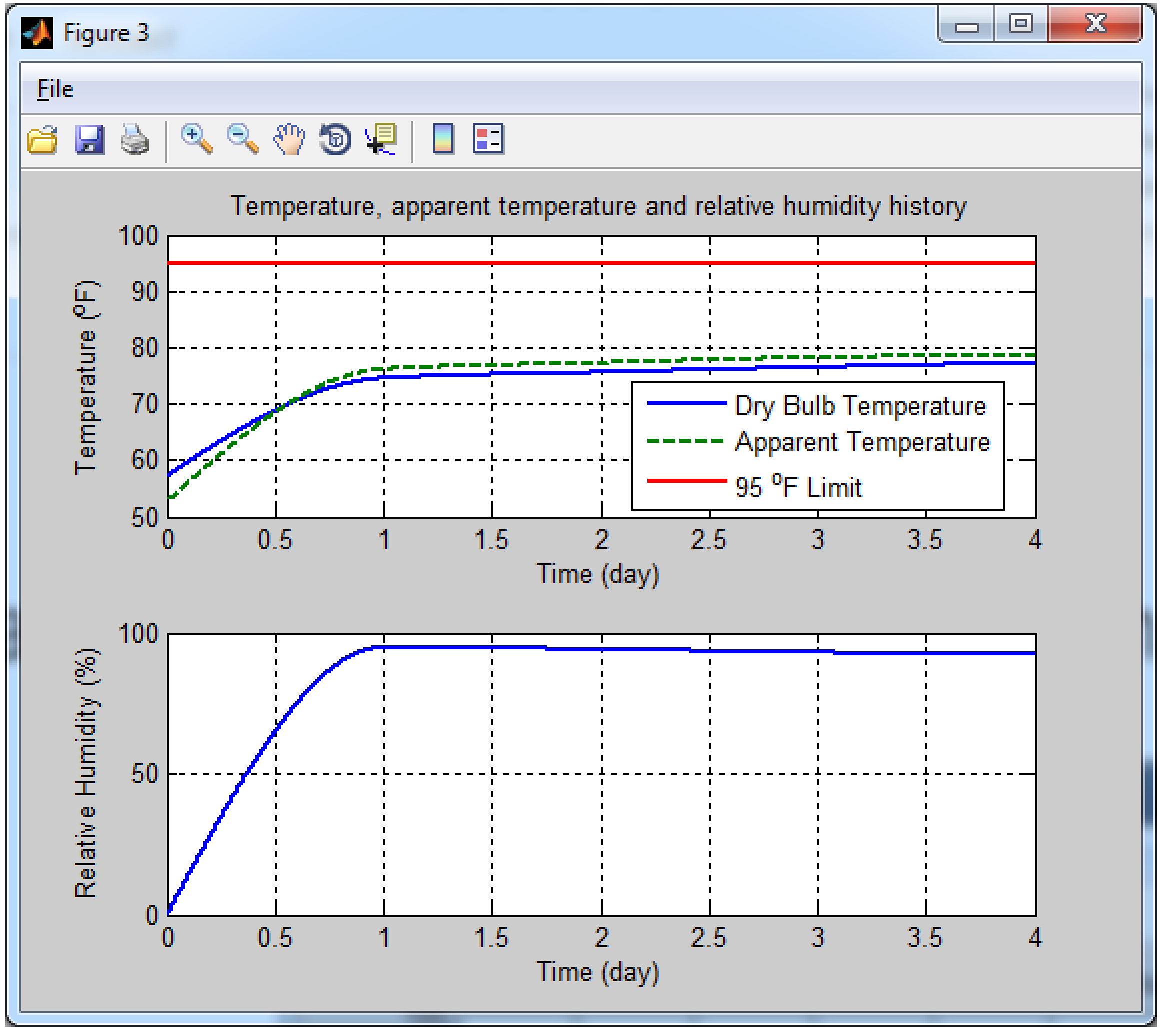


The UTHA Model Development

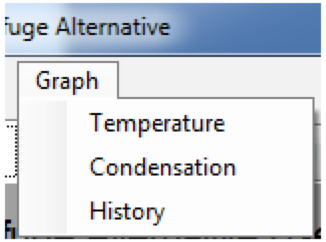


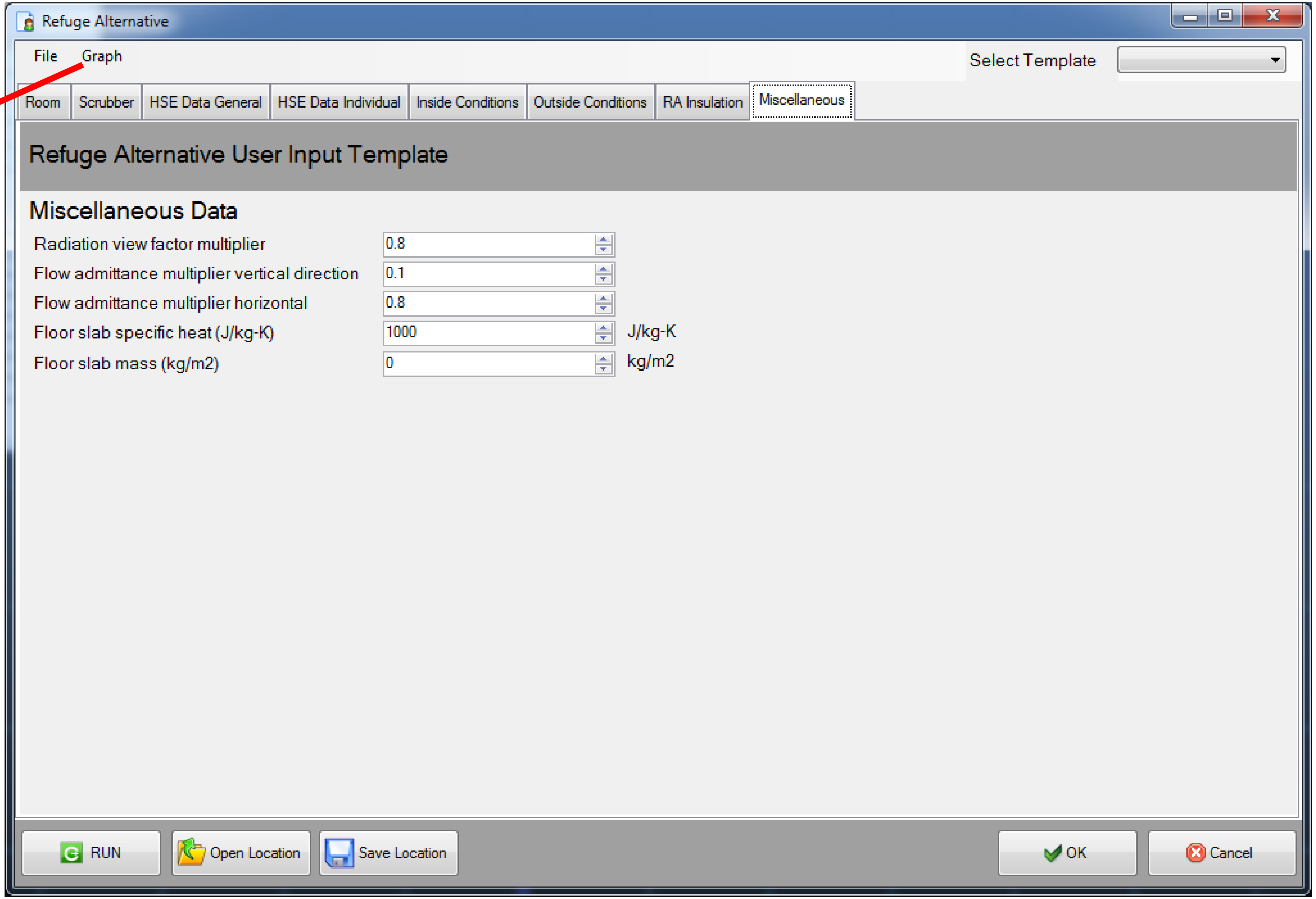
Temperature history plot upon successful completion of simulation



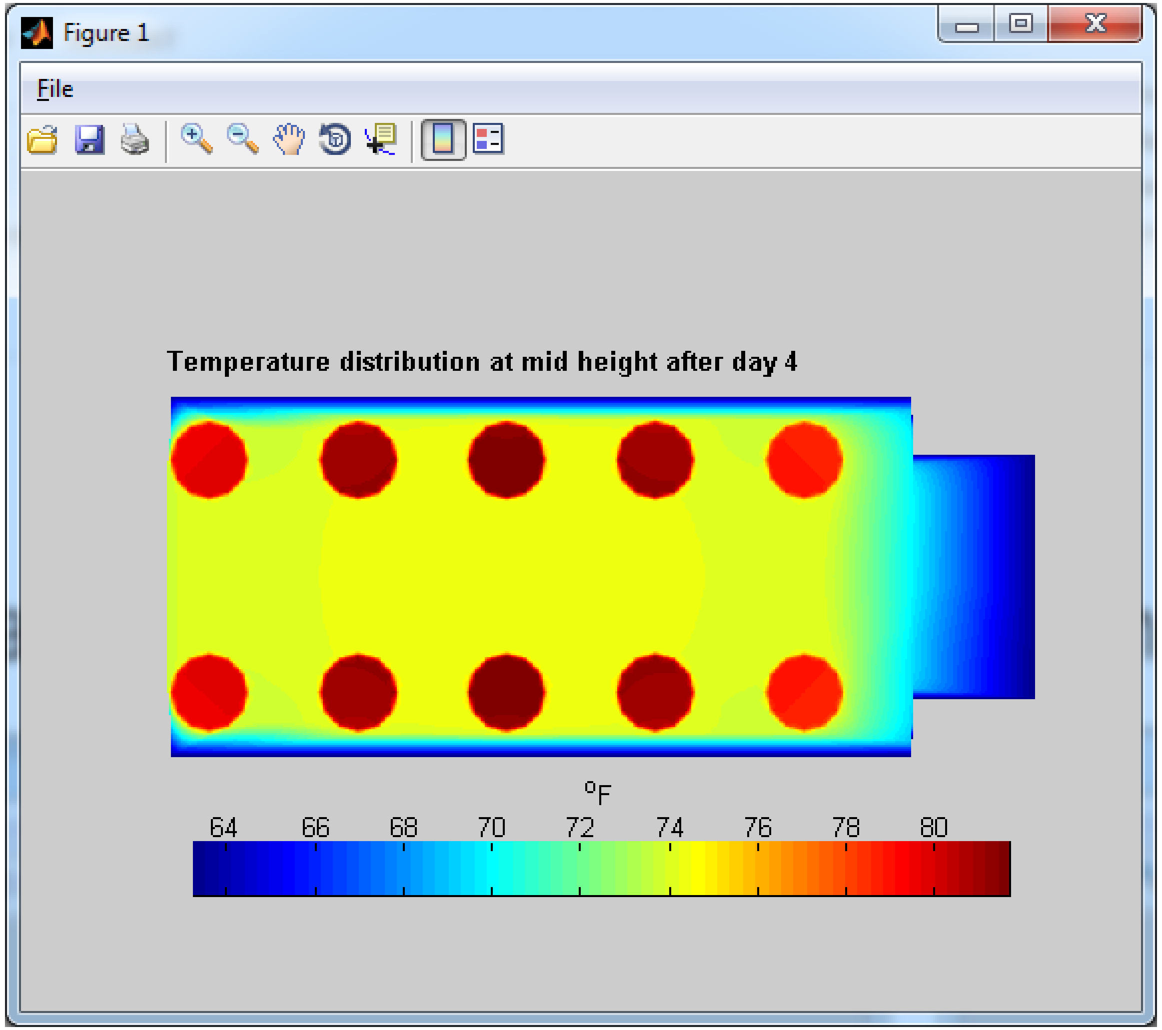
Results visualization control in the GUI

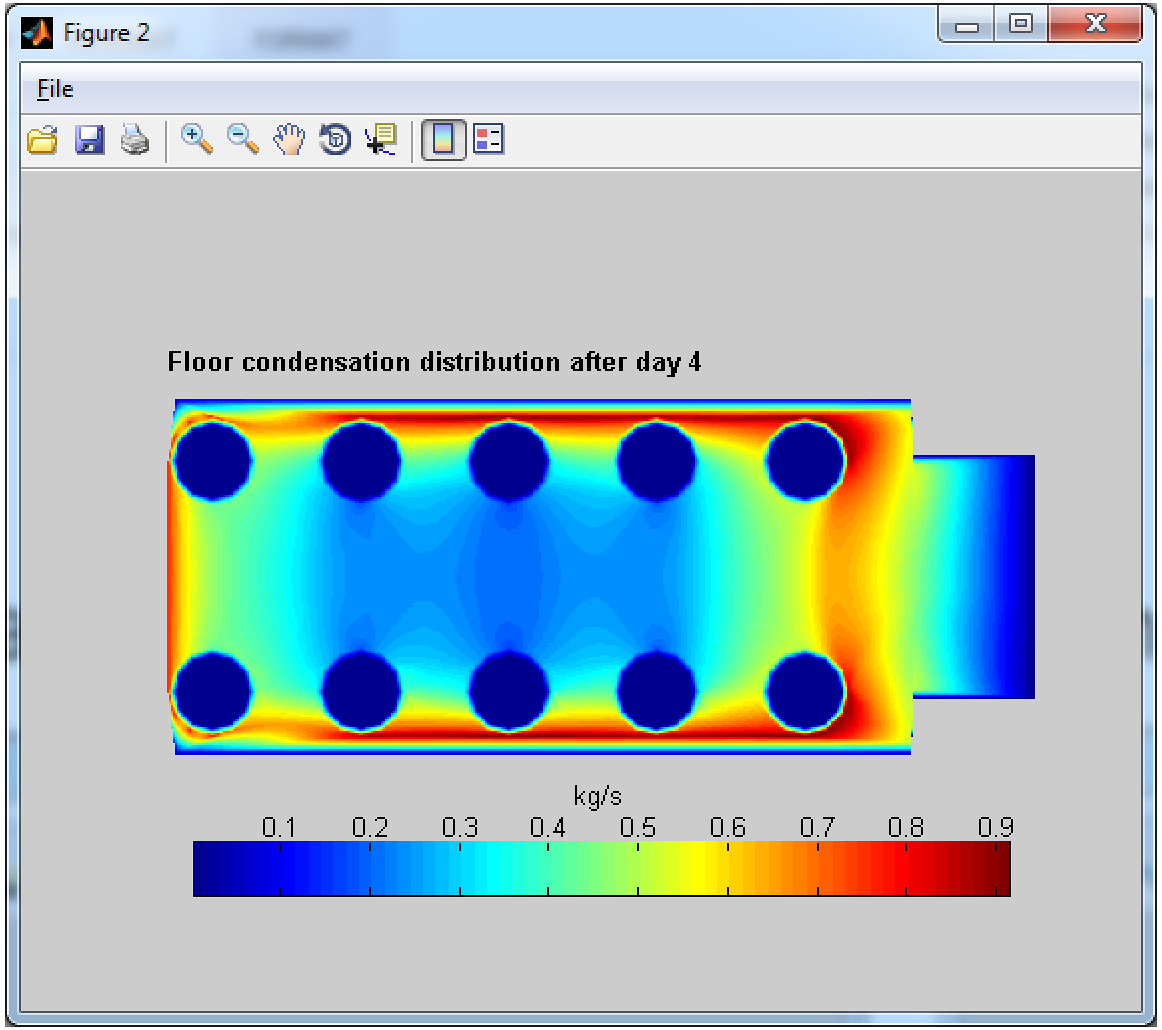
Graph menu options





More results for the 10-person RA, uniform distribution of occupants, hanger-type CO_2 scrubber

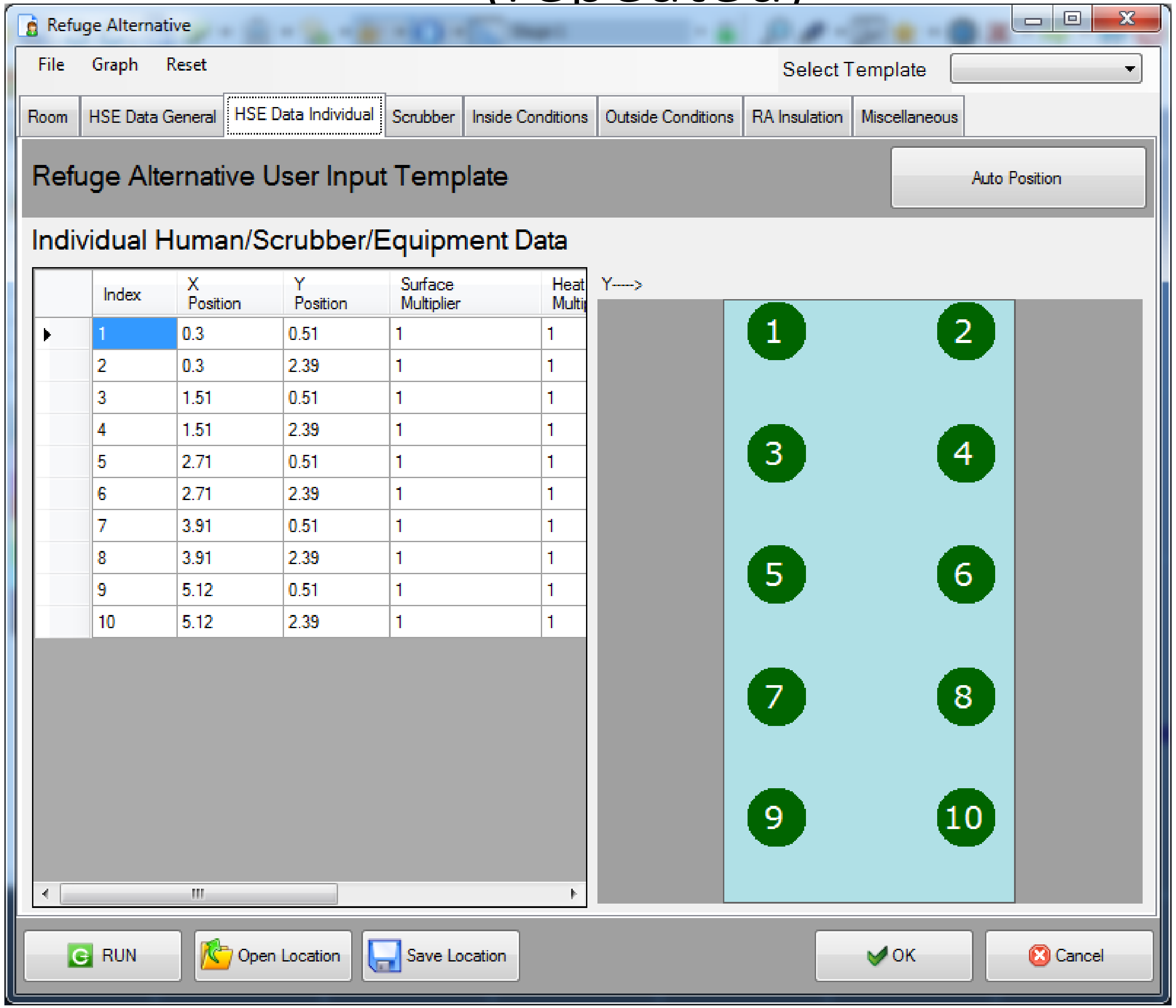




Temperature and condensation distribution maps

Results of RA application examples

Example 1: 10-person RA, uniform distribution of occupants, hanger-type CO_2 scrubber, 57.2 °F ambient temperature (repeated)



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5	2.71	0.51	1	1
6	2.71	2.39	1	1
7	3.91	0.51	1	1
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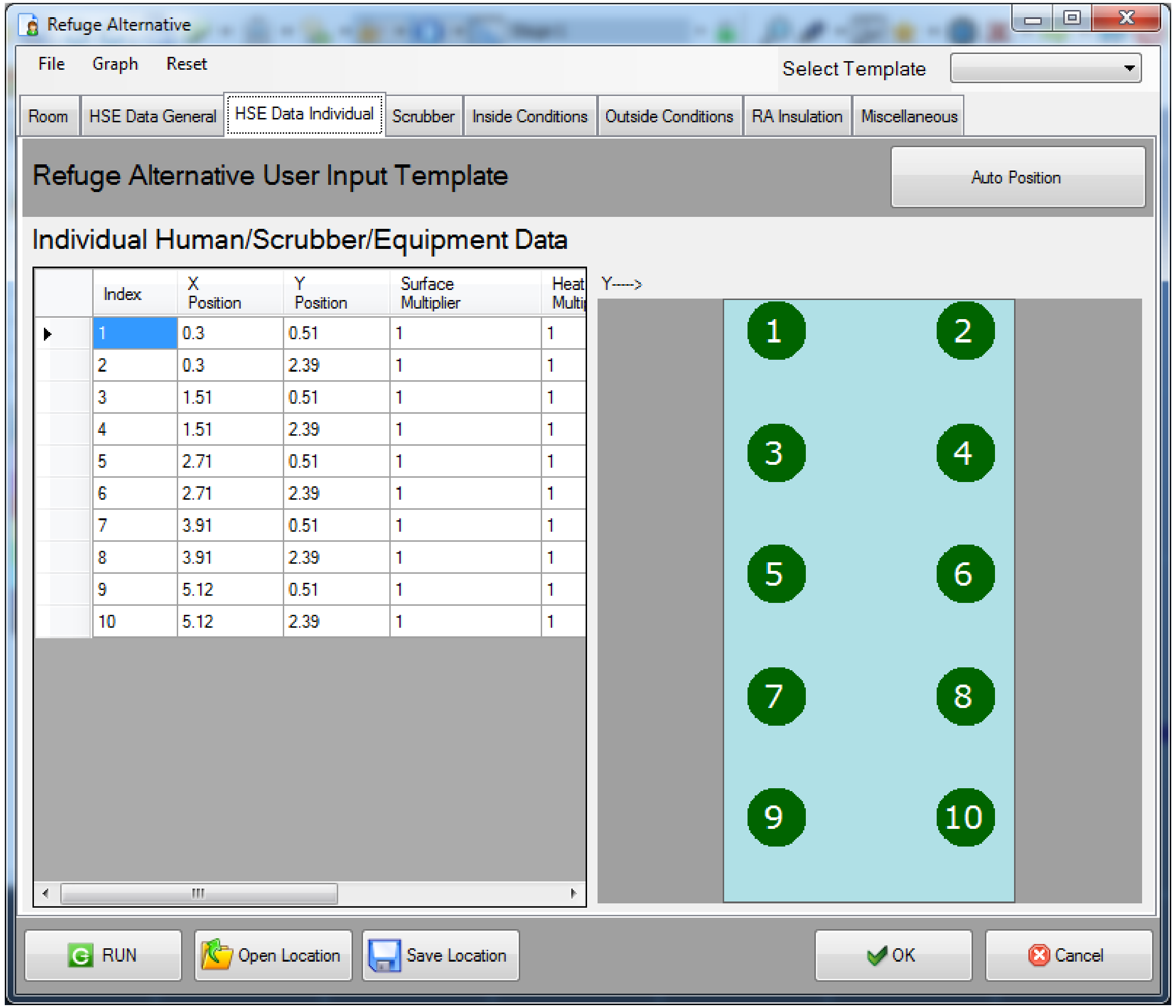
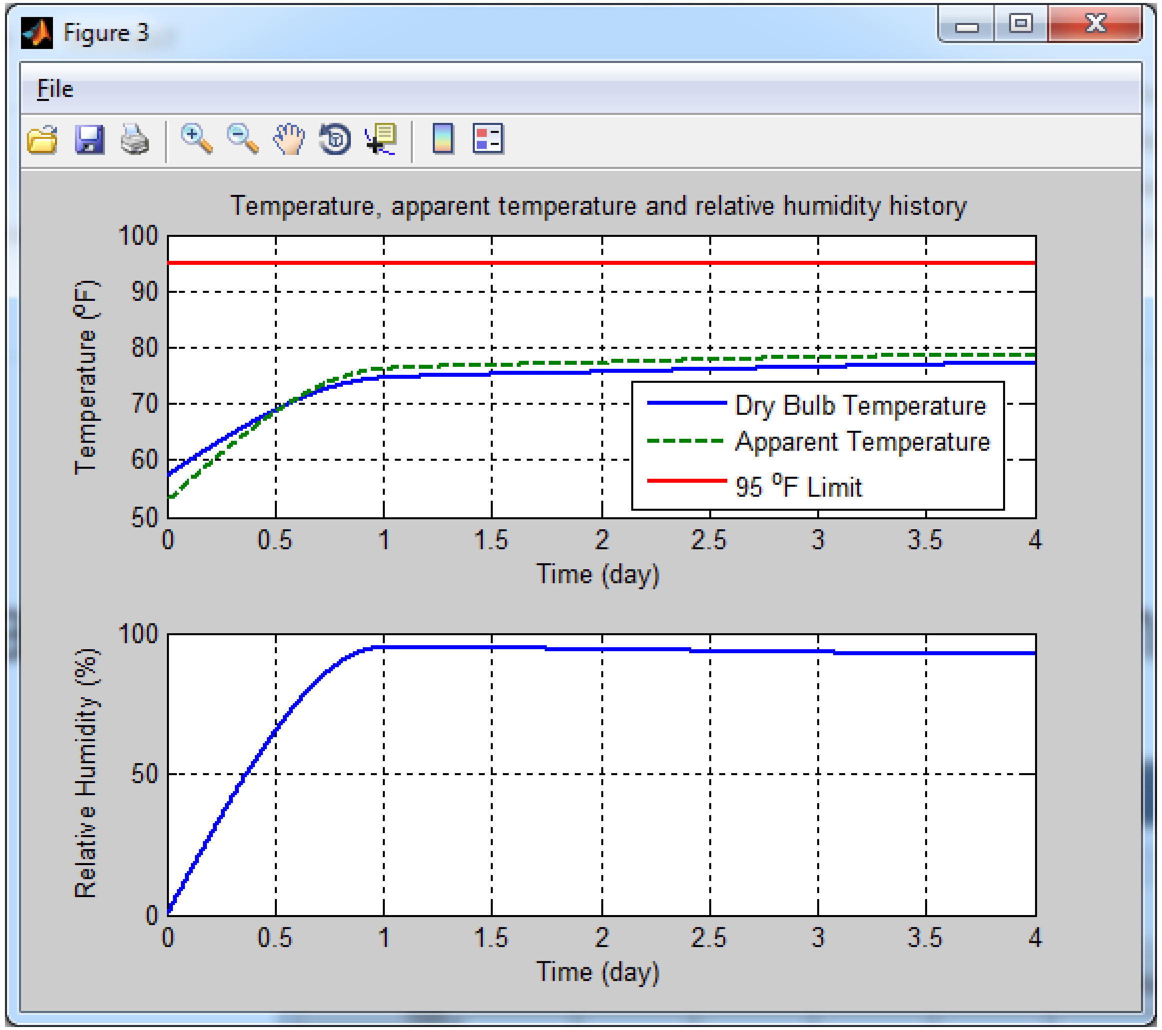
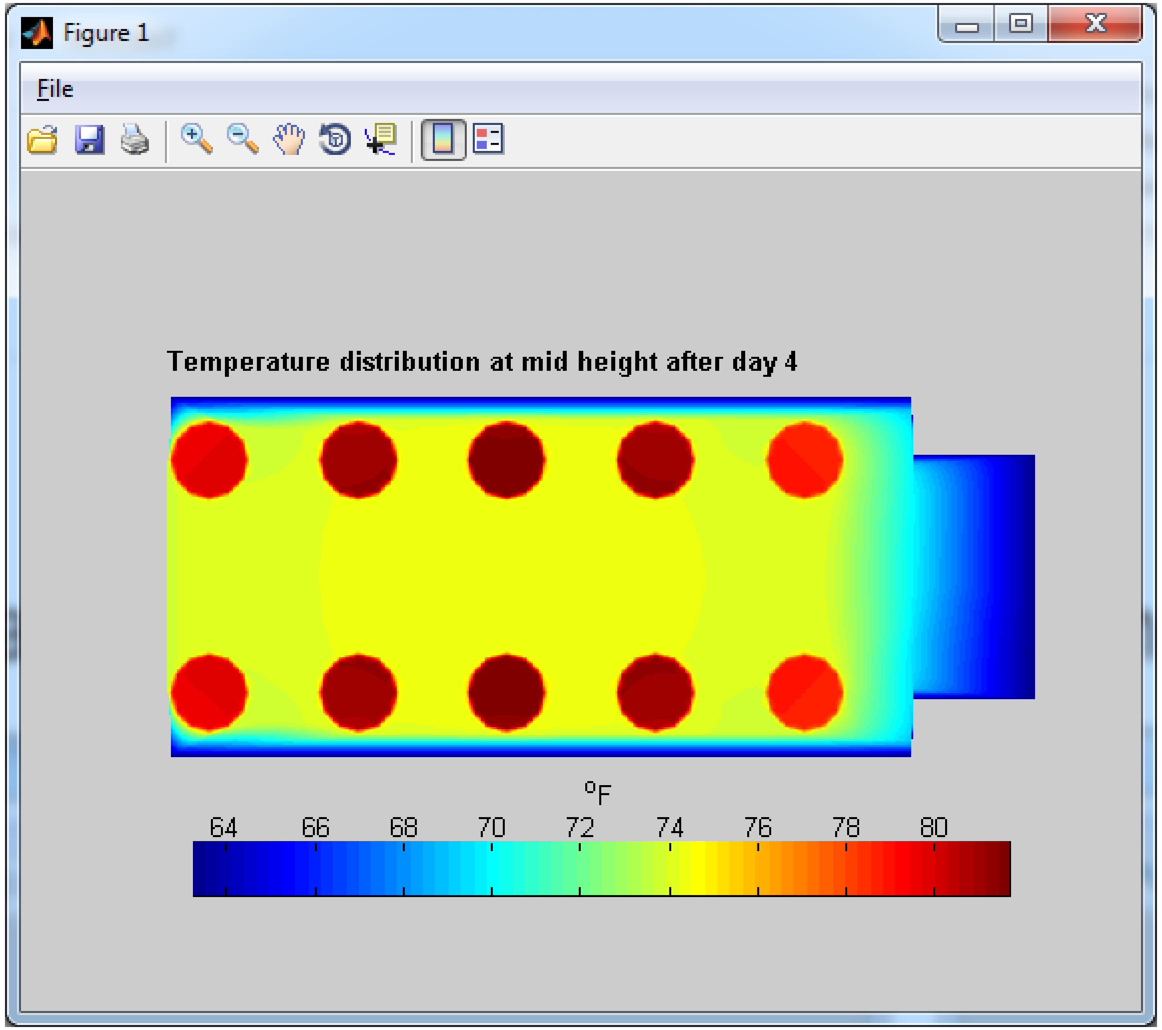
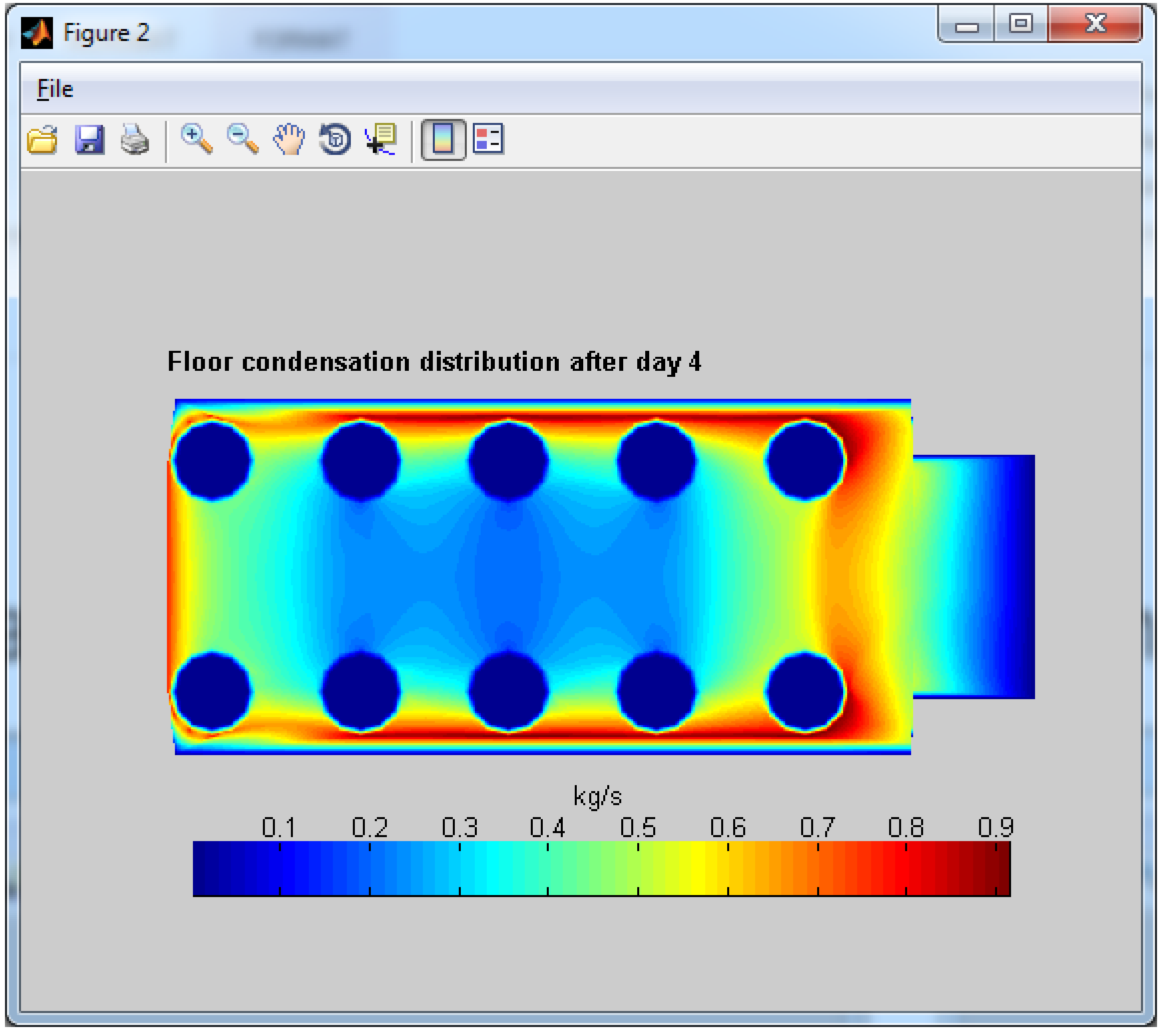




Temperature and humidity vs. time

Example 1: 10-person RA, uniform distribution of occupants, hanger-type CO_2 scrubber (repeated)

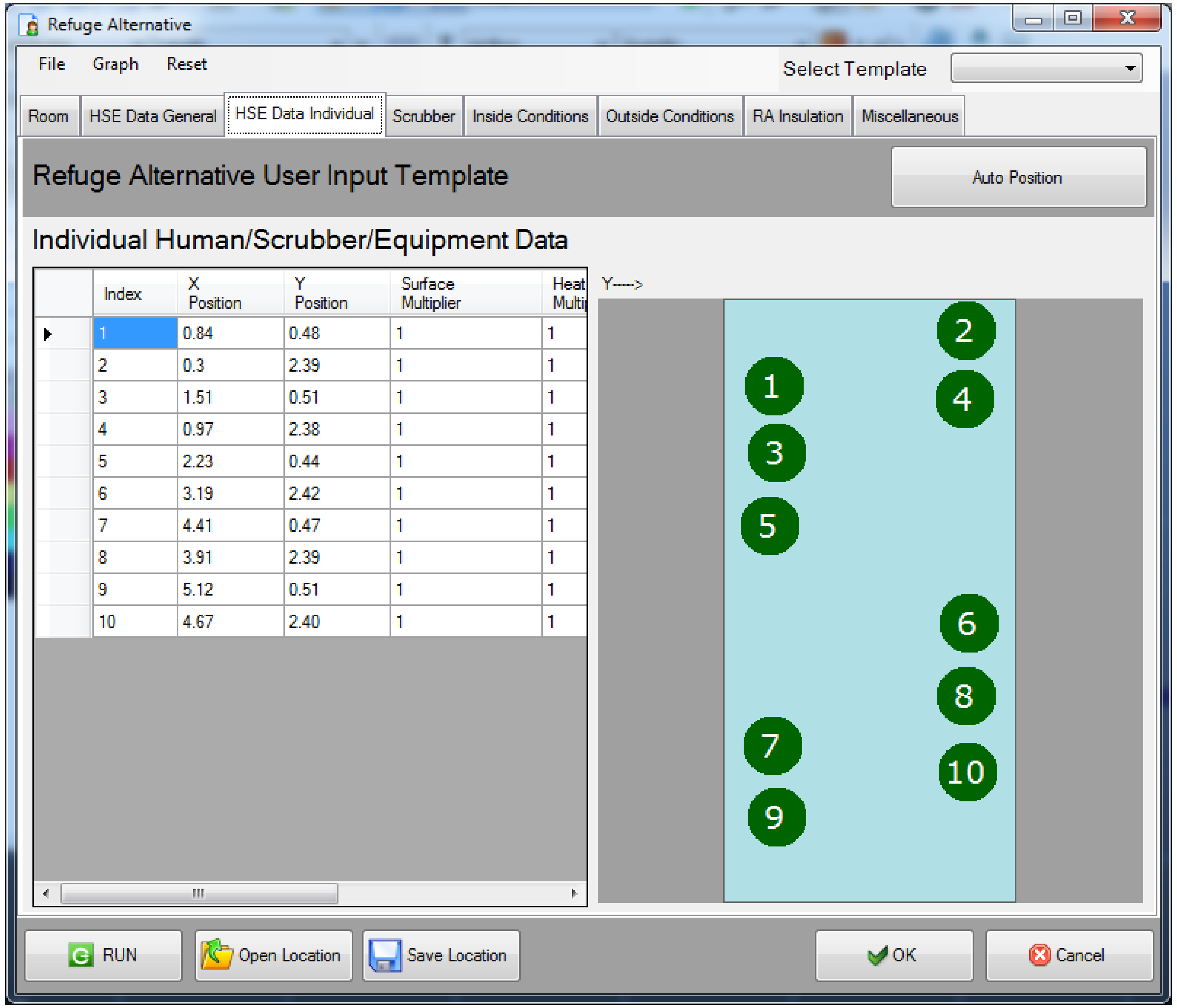


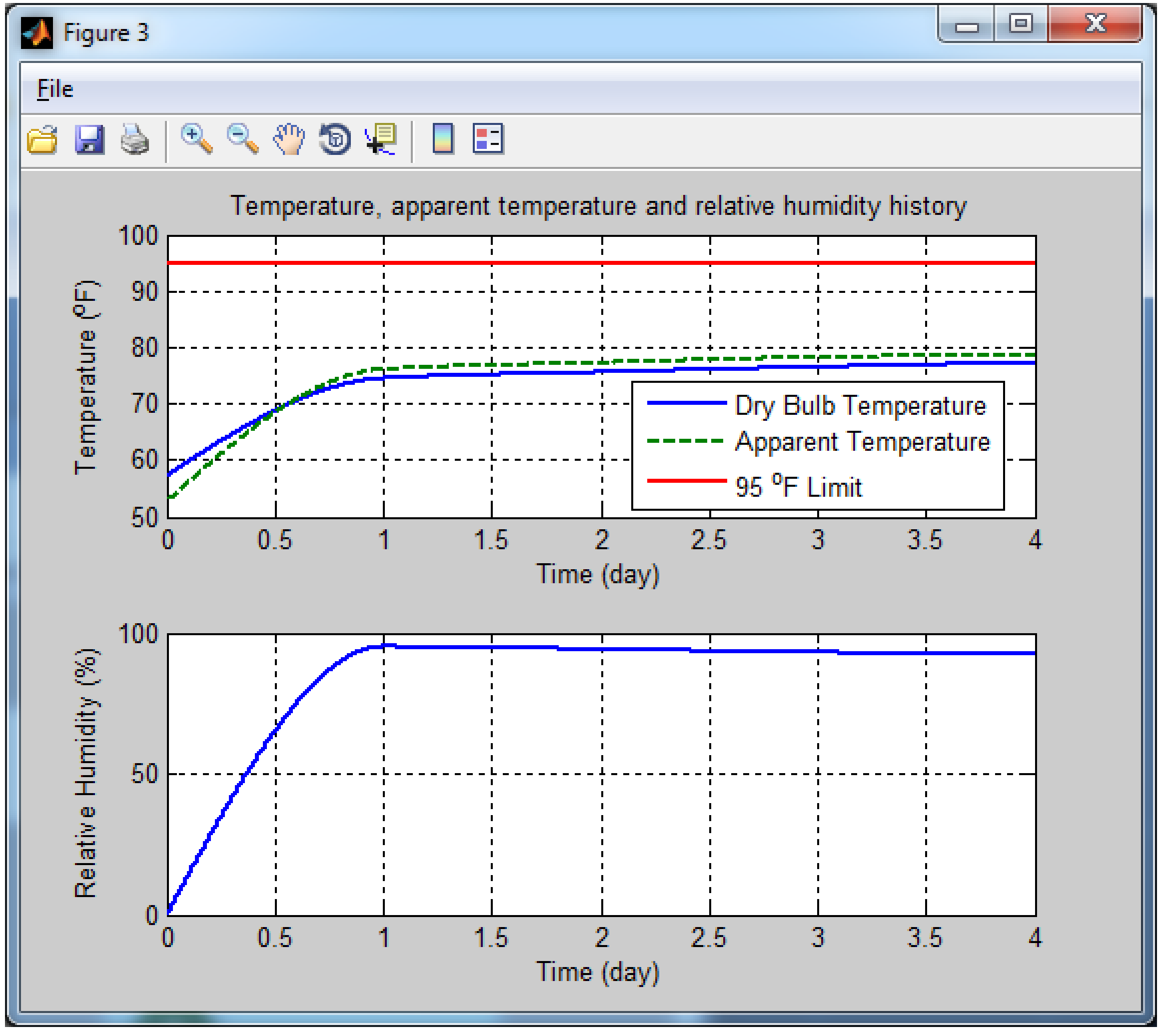


Temperature and condensation distribution maps

Example 2: 10-person RA, non-uniform distribution of occupants, hanger-type CO_2 scrubber, 57.2 °F ambient temperature

Manually moved occupants, other parameters unchanged

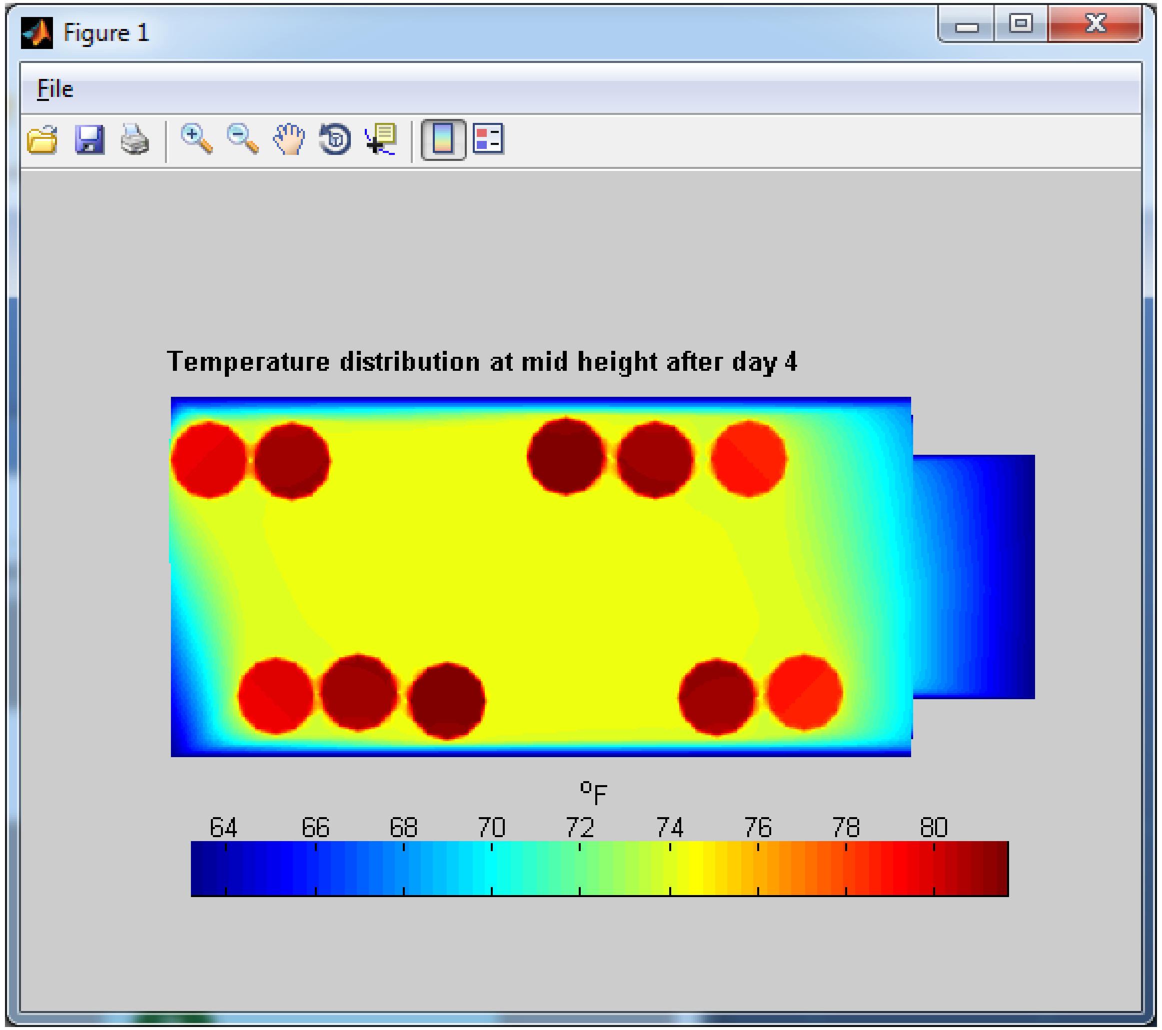


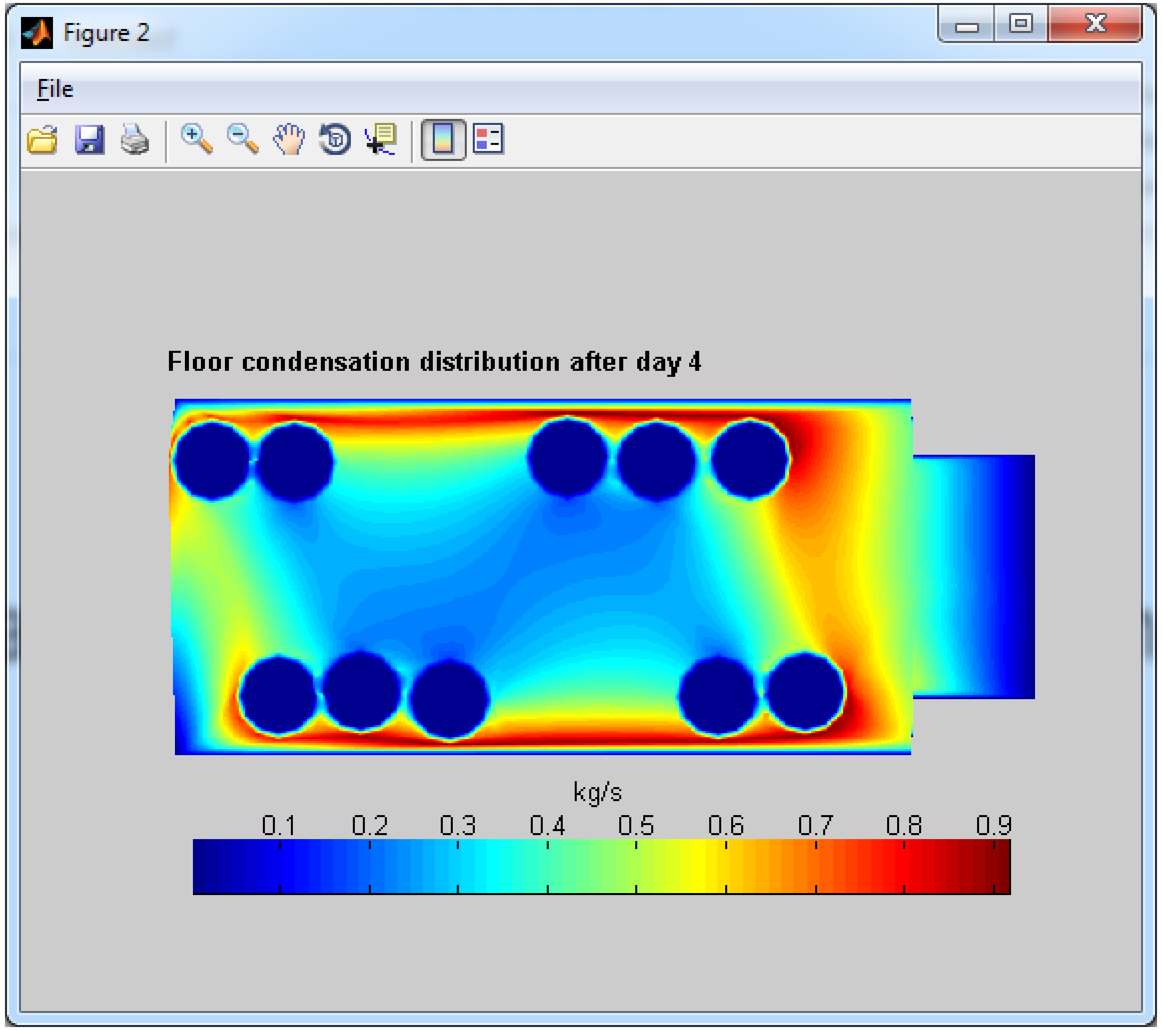


Temperature and humidity vs. time

Example 2: 10-person RA, non-uniform distribution of occupants, hanger-type CO_2 scrubber, 57.2 °F ambient temperature

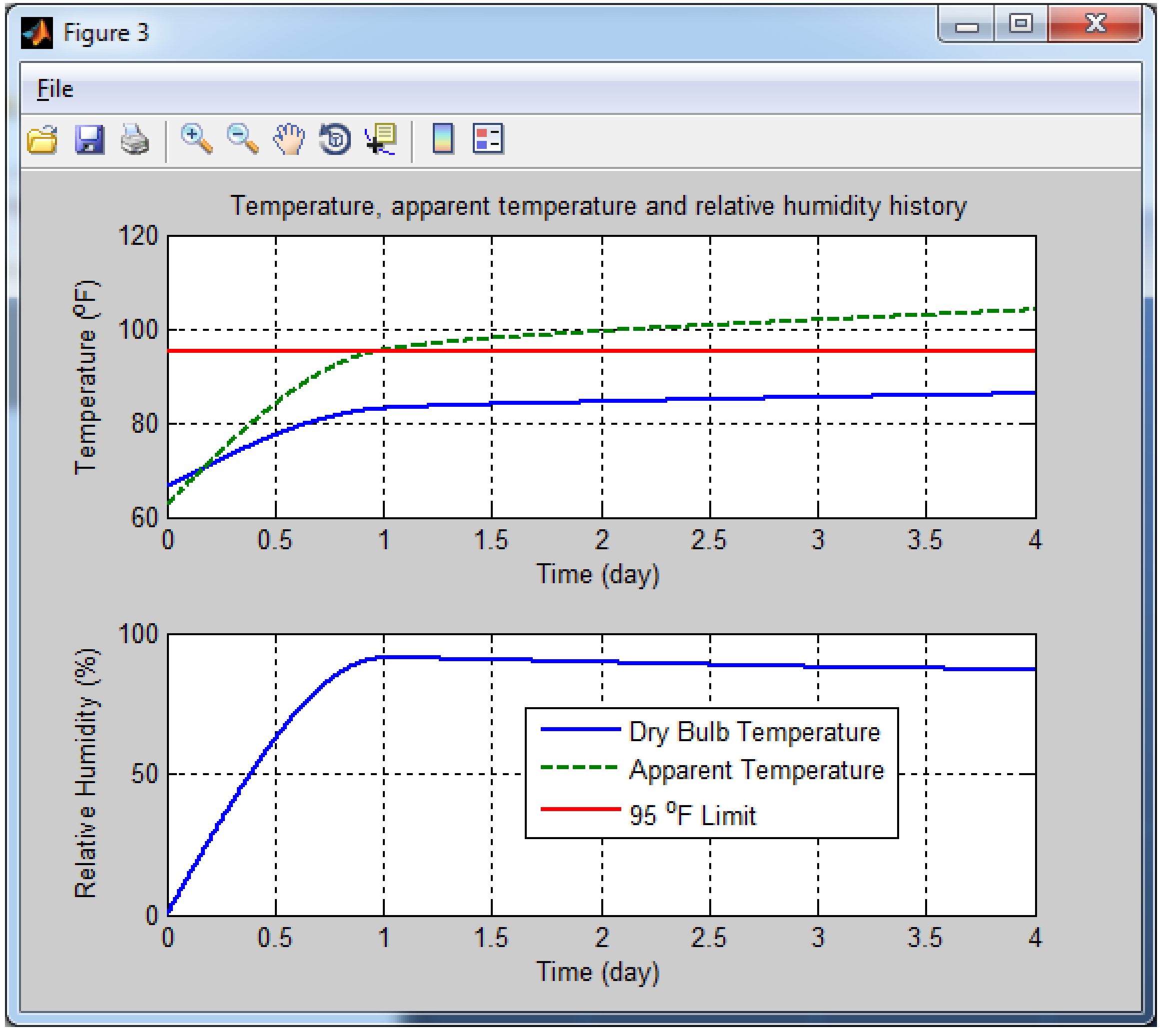
Manually moved occupants





Temperature and condensation distribution maps

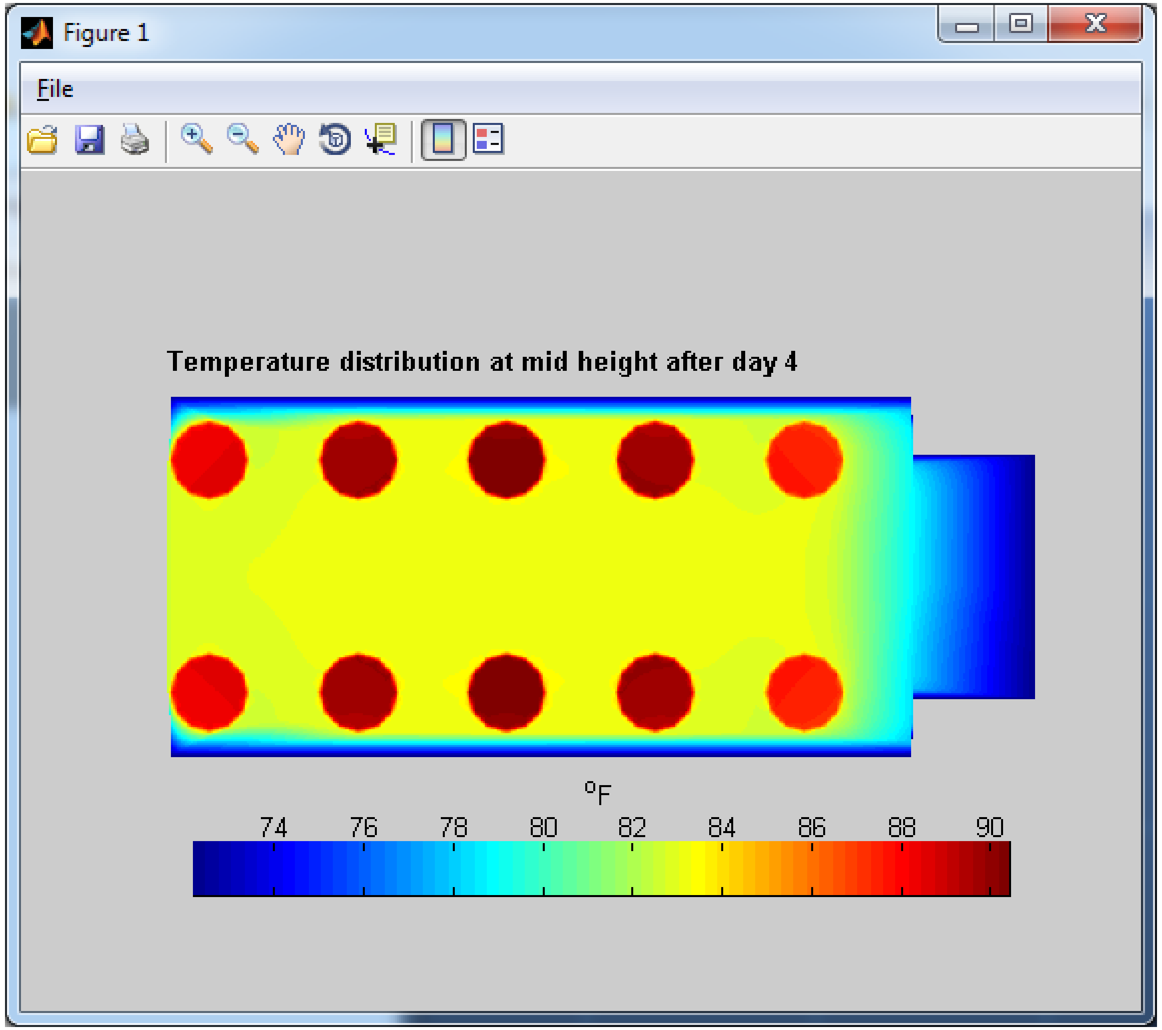
Example 3: 10-person RA, uniform distribution of occupants, hanger-type CO_2 scrubber, 66.2°F ambient temperature
The RA is not in compliance, Ta> 95°F

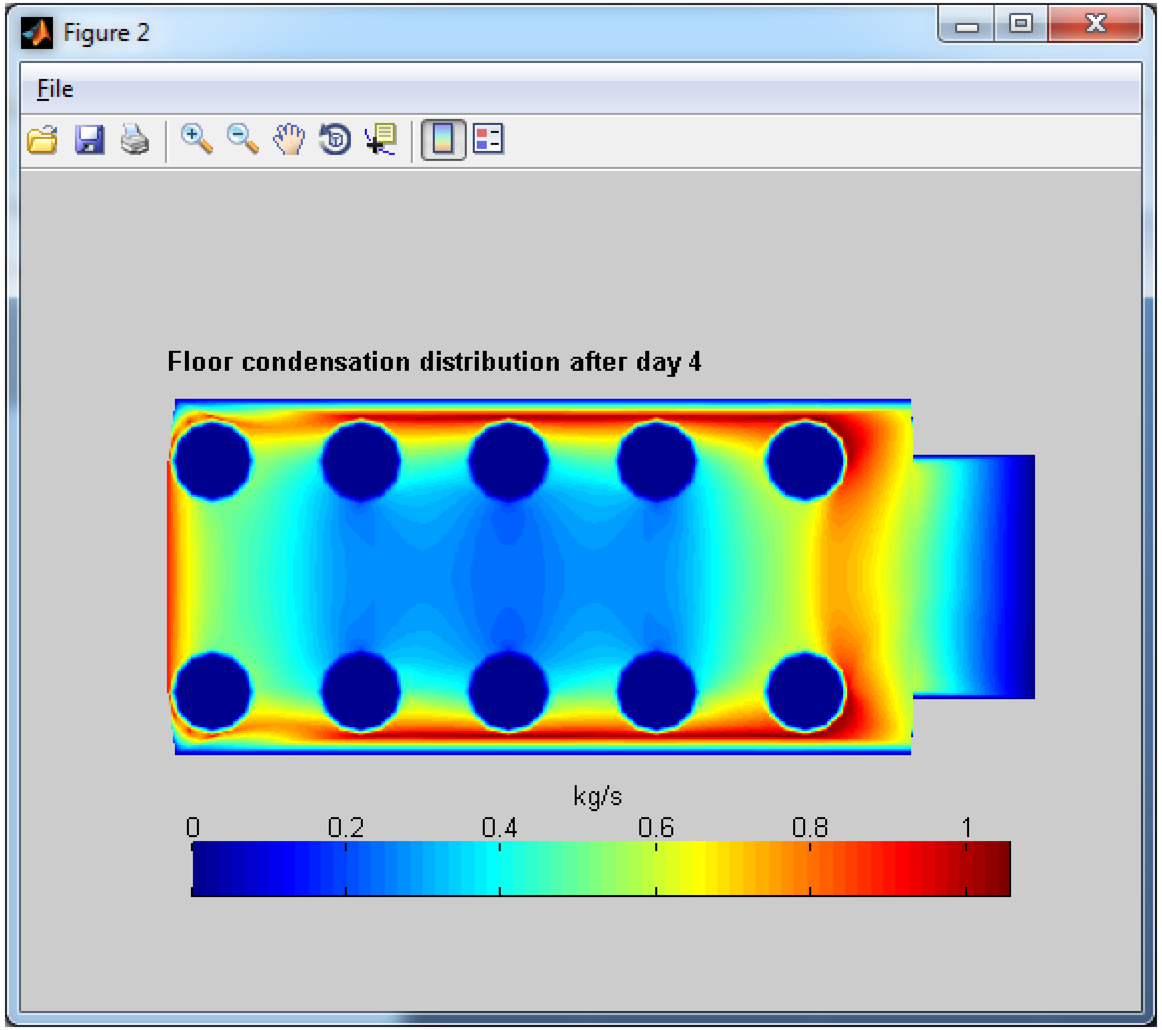


Temperature and humidity vs. time

Example 3: 10-person RA, uniform distribution of occupants, hanger-type CO_2 scrubber, 66.2ºF ambient temperature

The RA is not in compliance, Ta> 95ºF

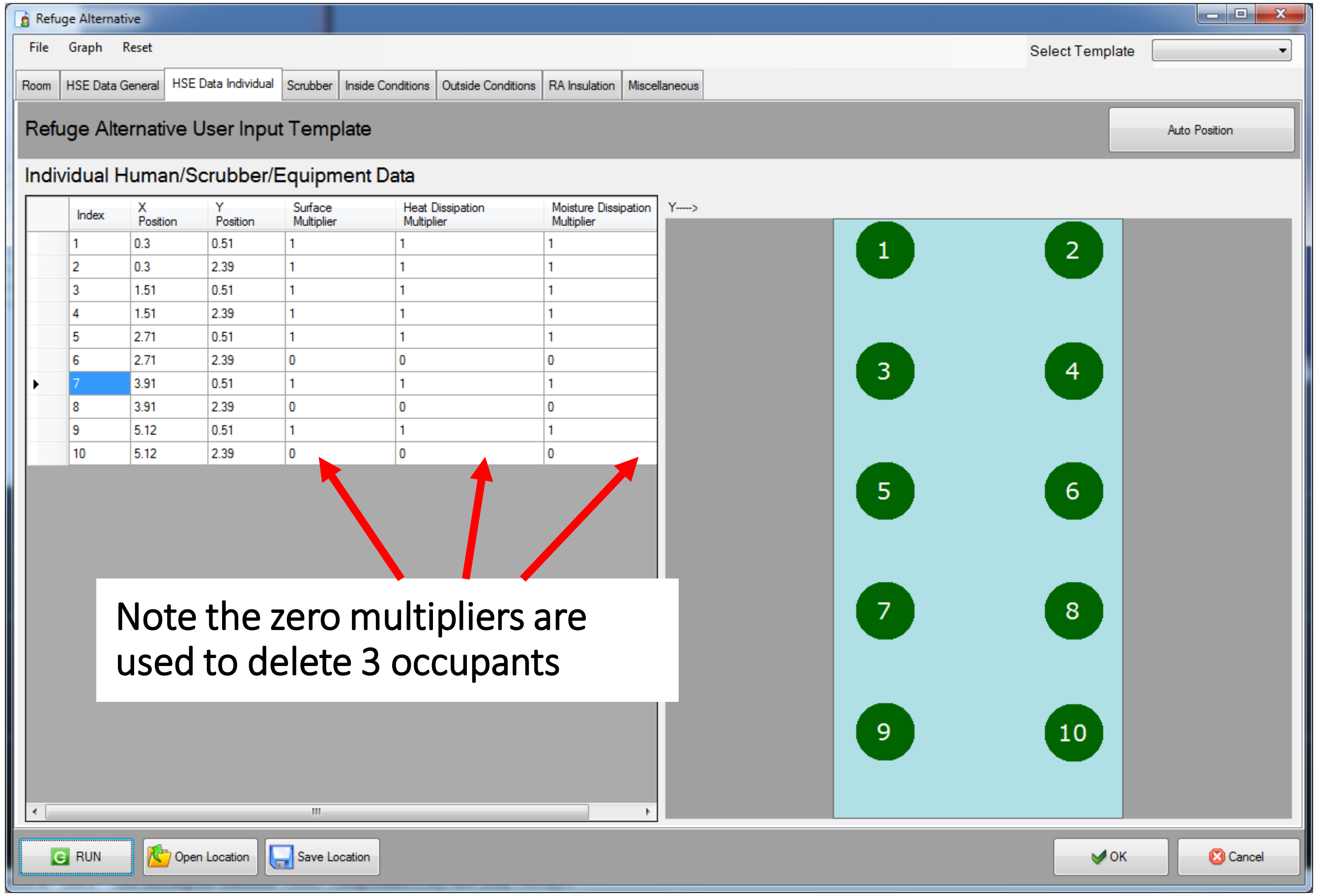


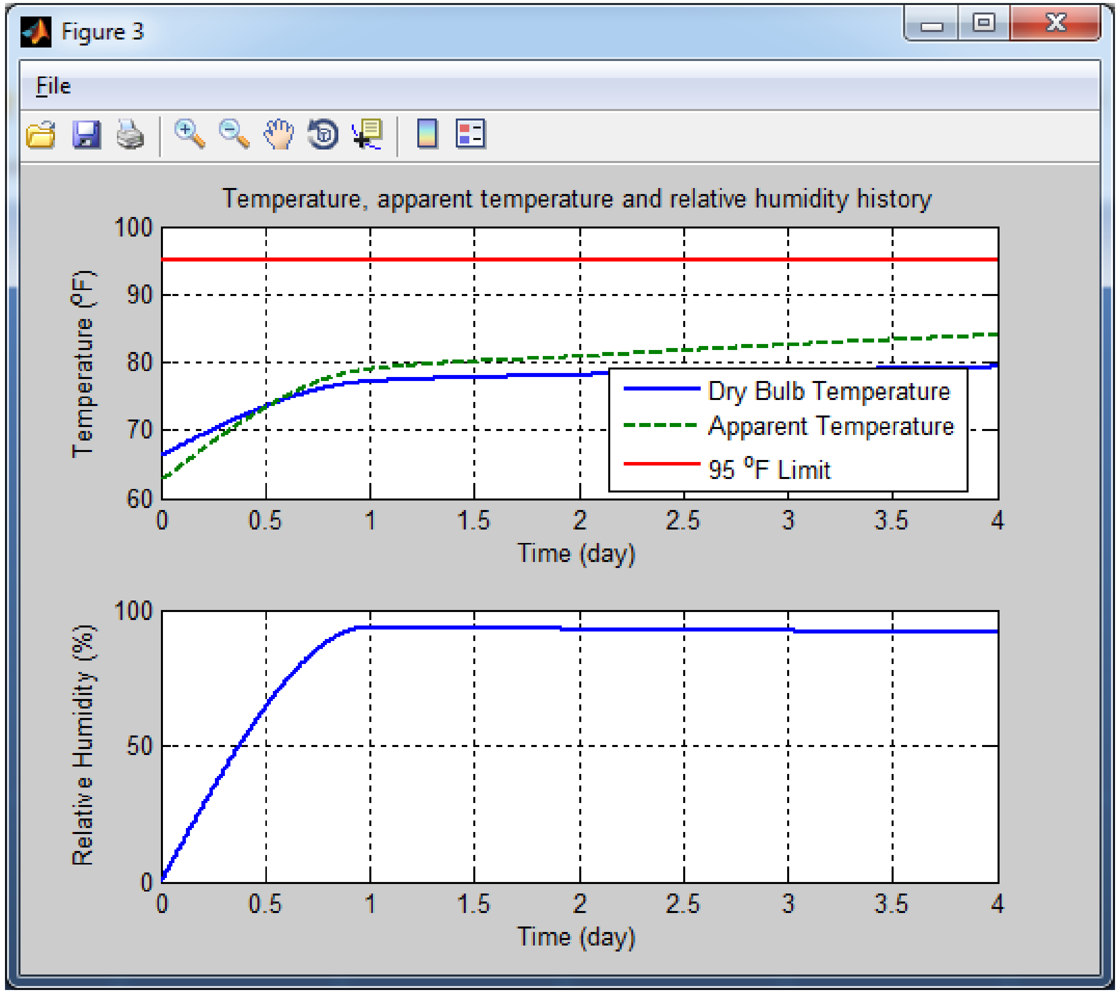


Temperature and condensation distribution maps

Example 4: 10-person RA, derated to 7-person occupancy, hanger-type CO_2 scrubber, 66.2°F ambient temperature

Reduced occupancy (10 to7) from one side of RA space

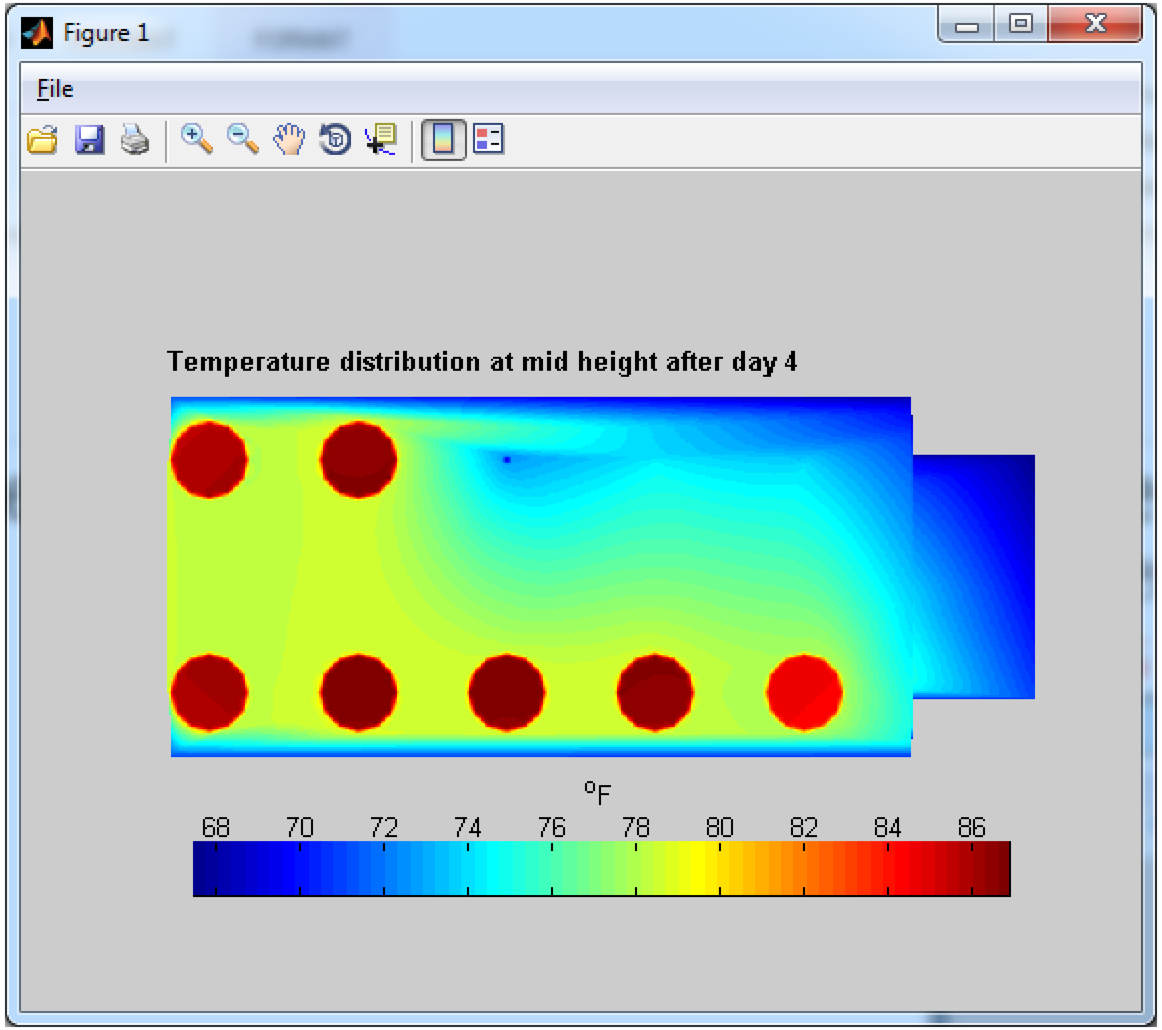


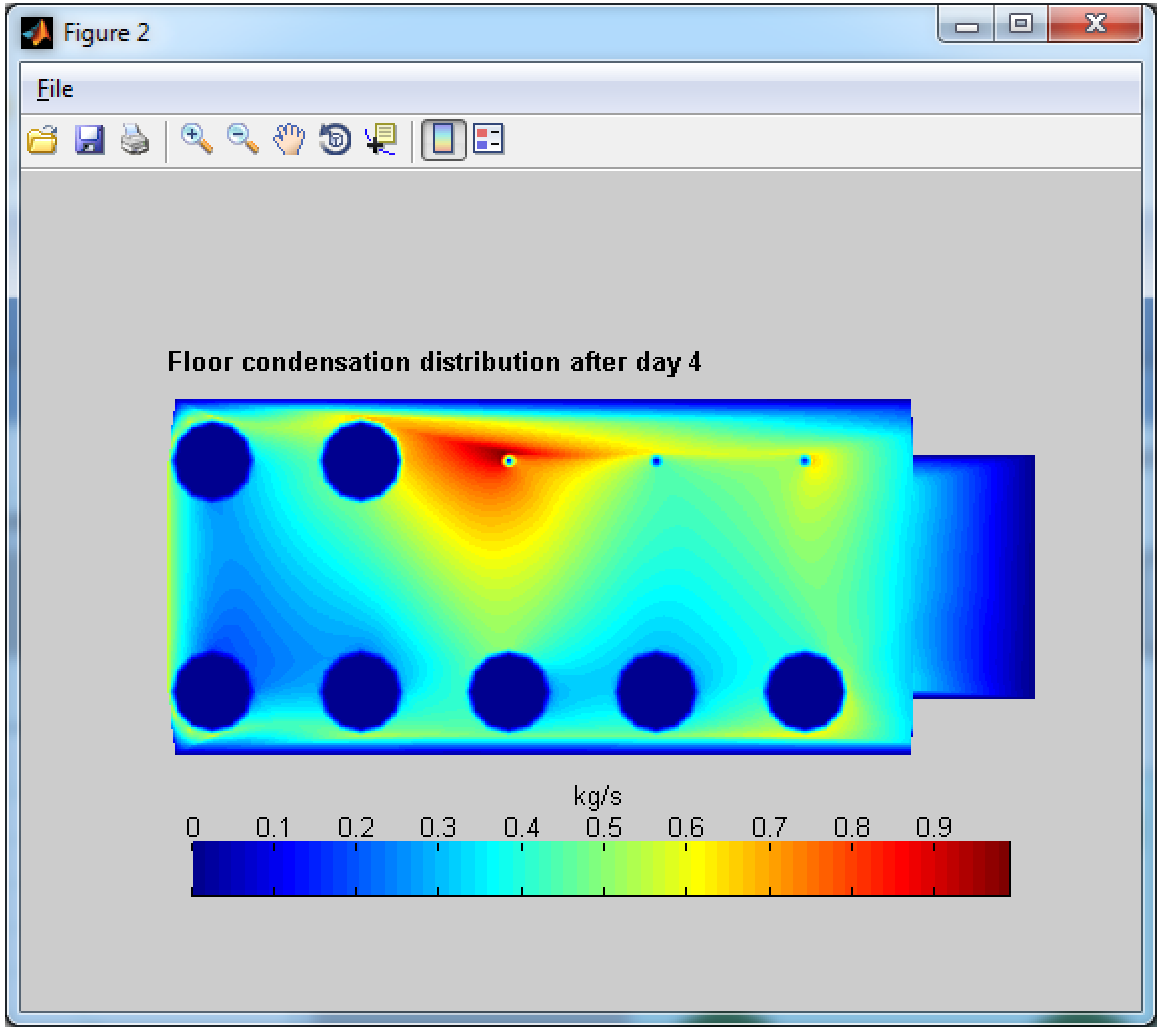


Temperature and humidity vs. time

Example 4: 10-person RA, derated to 7-person occupancy, hanger-type CO_2 scrubber, 66.2°F ambient temperature

Reduced occupancy from one side of RA space

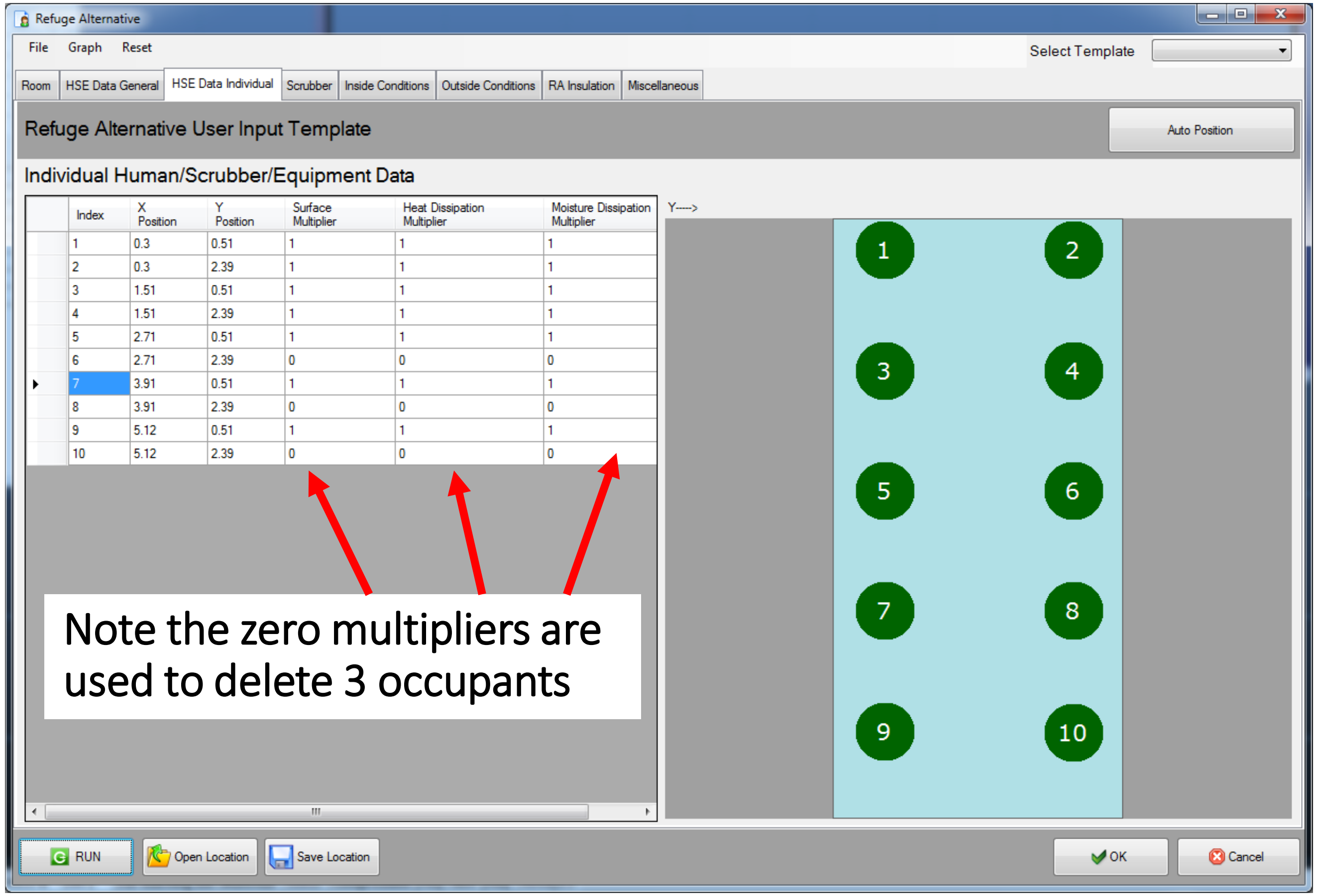




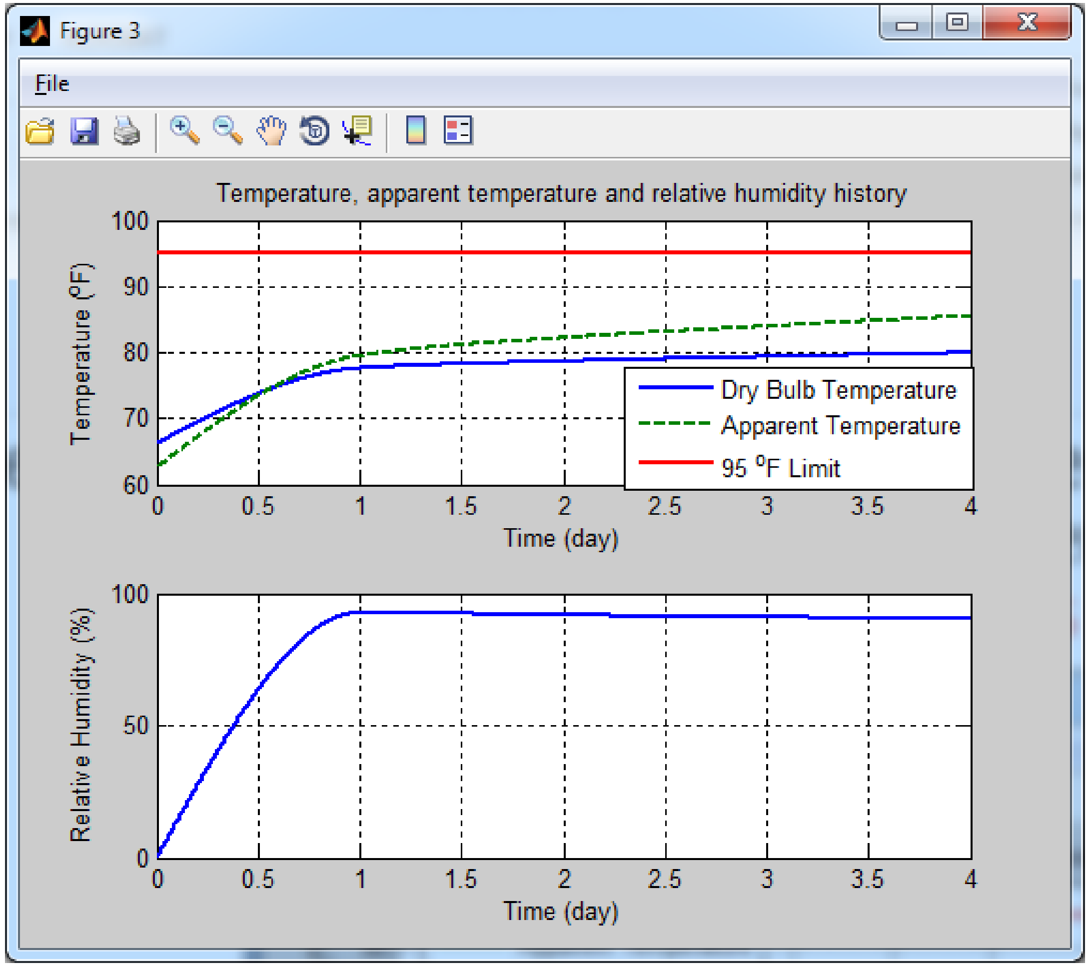
Temperature and condensation distribution maps

Example 5: 10-person RA, derated to 7-person occupancy, hanger-type CO_2 scrubber, 66.2°F ambient temperature

Reduced occupancy (10 to 7) from one end of RA space



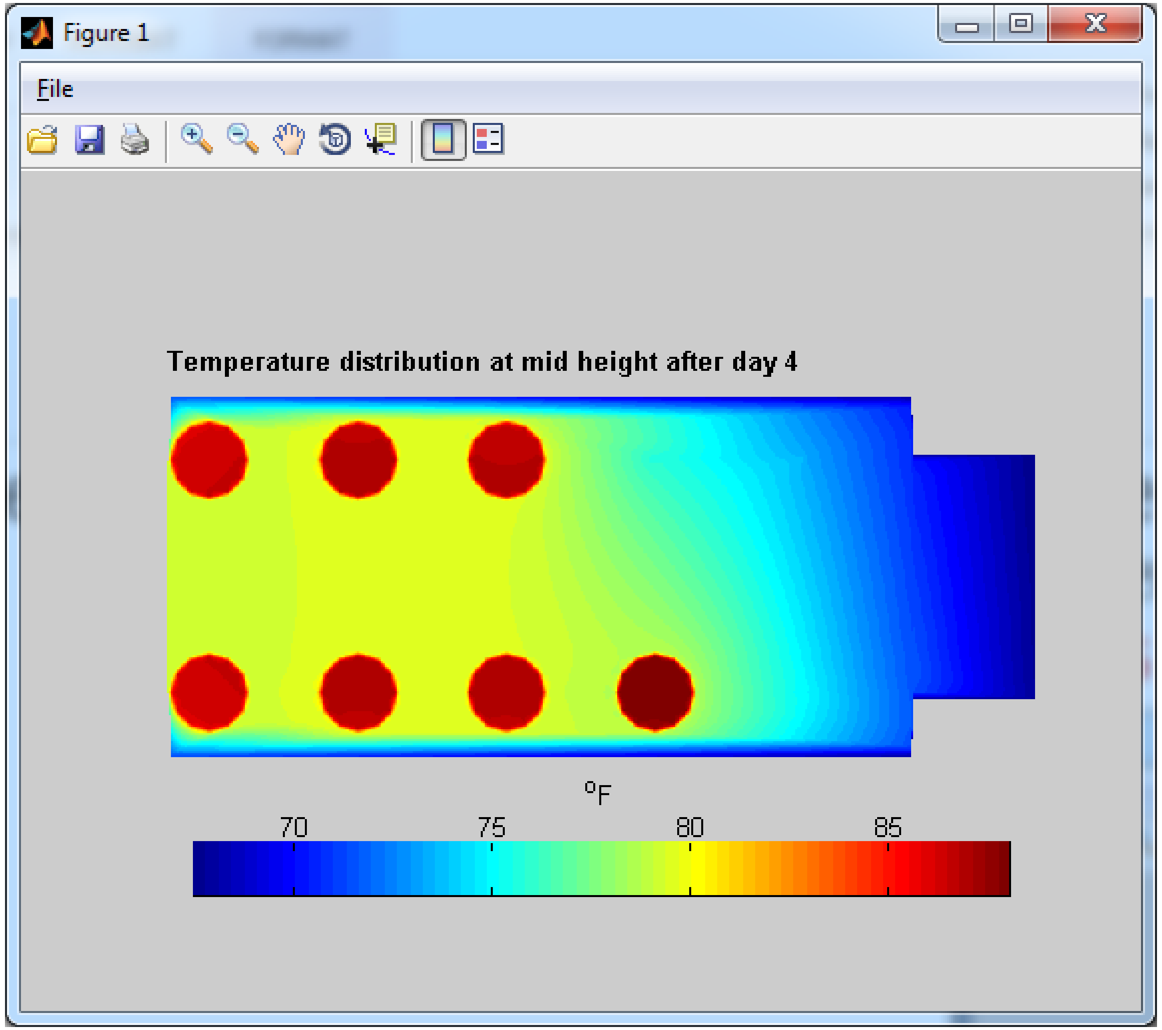
Index	X Position	Y Position	Surface Multiplier	Heat Dissipation Multiplier	Moisture Dissipation Multiplier
1	0.3	0.51	1	1	1
2	0.3	2.39	1	1	1
3	1.51	0.51	1	1	1
4	1.51	2.39	1	1	1
5	2.71	0.51	1	1	1
6	2.71	2.39	0	0	0
7	3.91	0.51	1	1	1
8	3.91	2.39	0	0	0
9	5.12	0.51	1	1	1
10	5.12	2.39	0	0	0

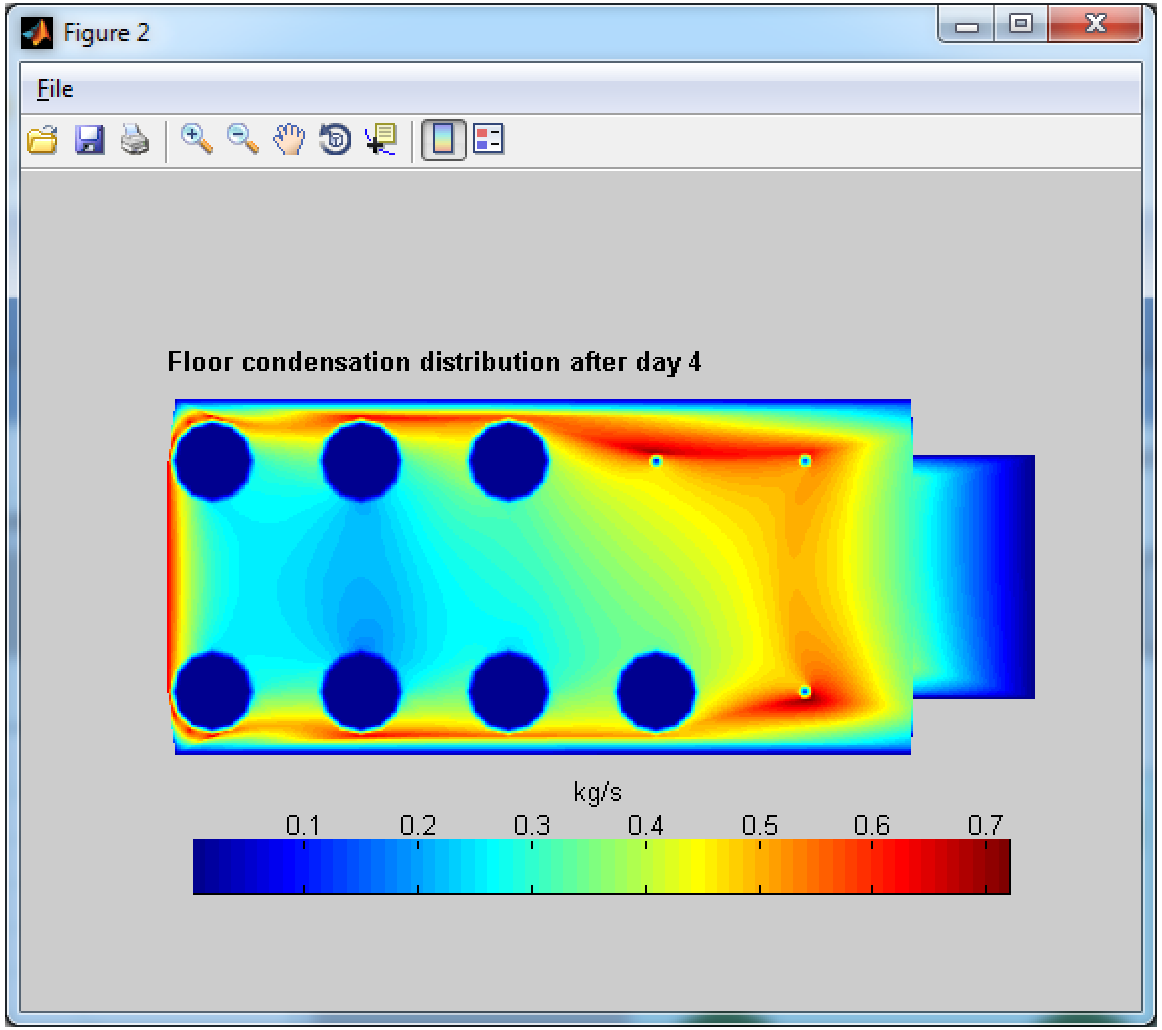


Temperature and humidity vs. time

Example 5: 10-person RA, derated to 7-person occupancy, hanger-type CO_2 scrubber, 66.2°F ambient temperature

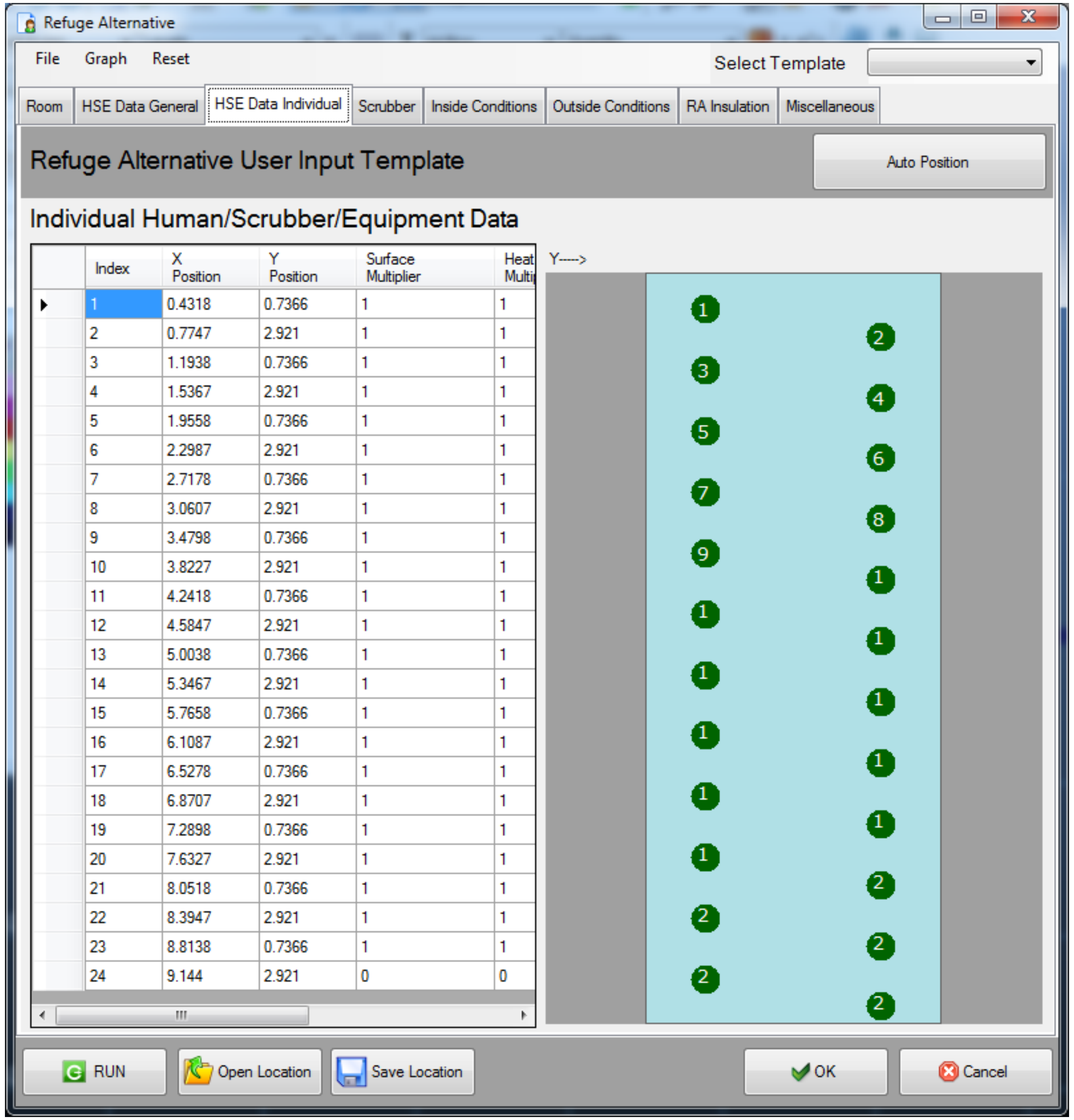
Reduced occupancy from one end of RA space



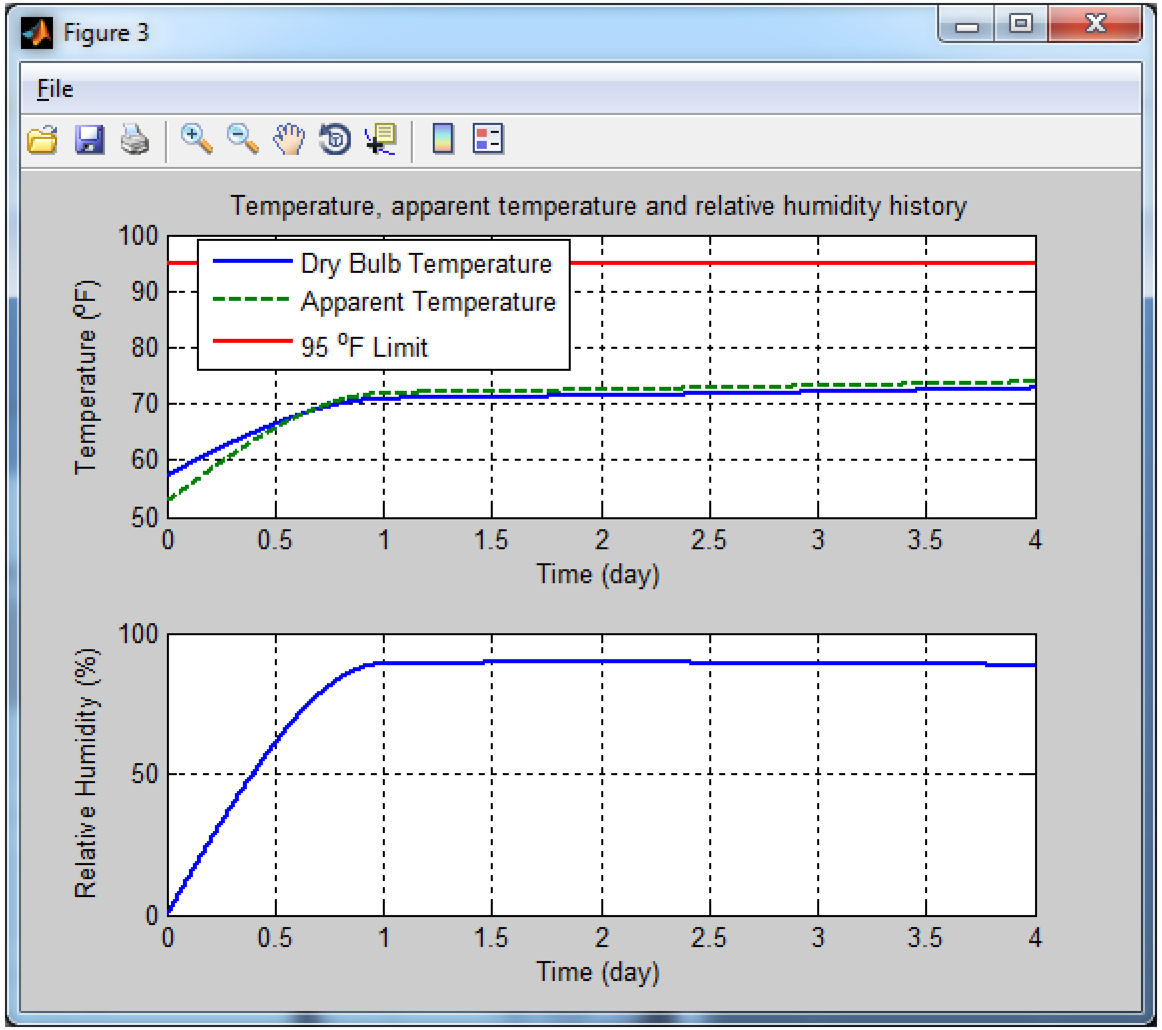


Temperature and condensation distribution maps

Example 6: 23-person RA, hanger-type CO_2 scrubber, 57.2 ^oF ambient temperature

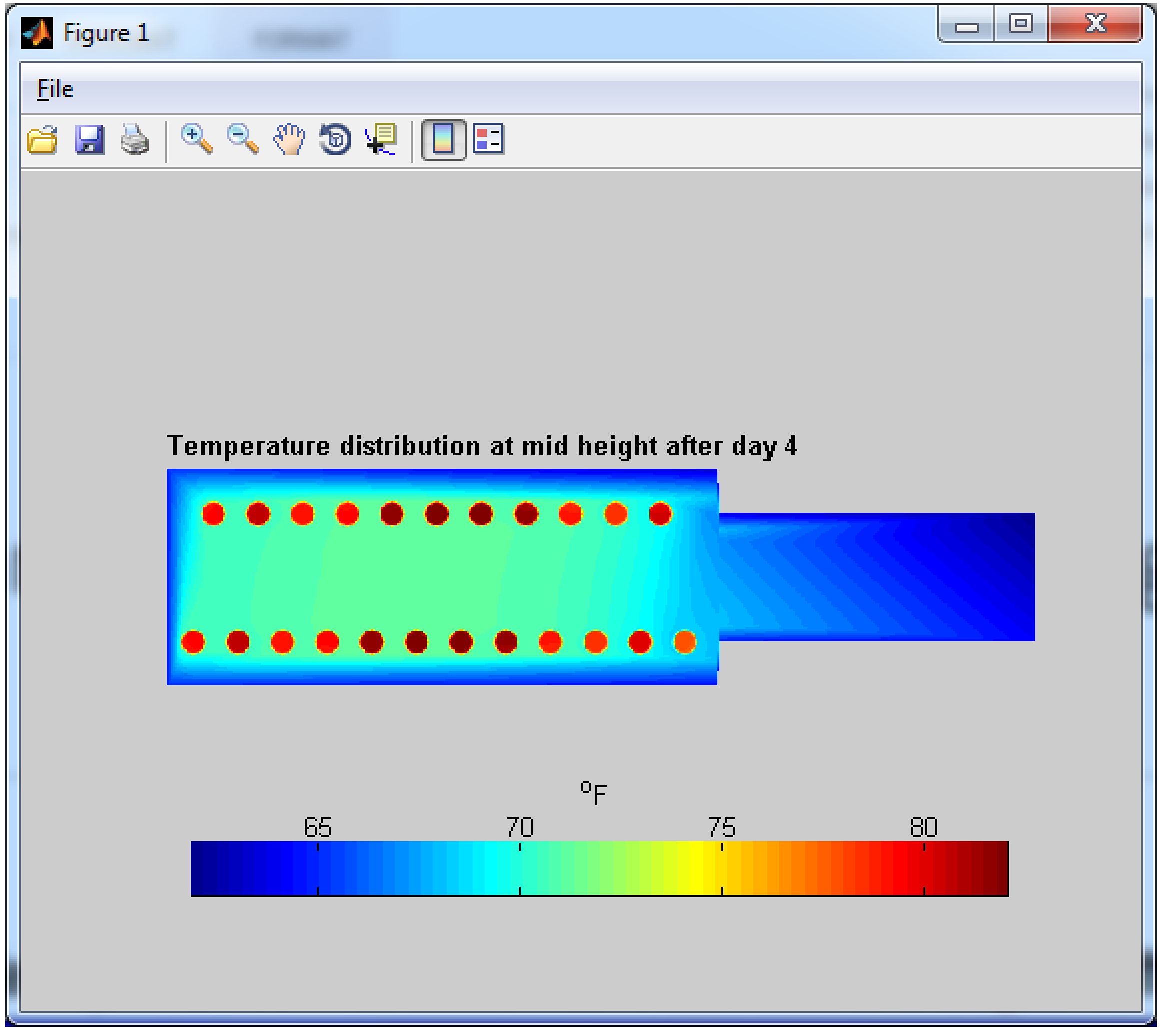


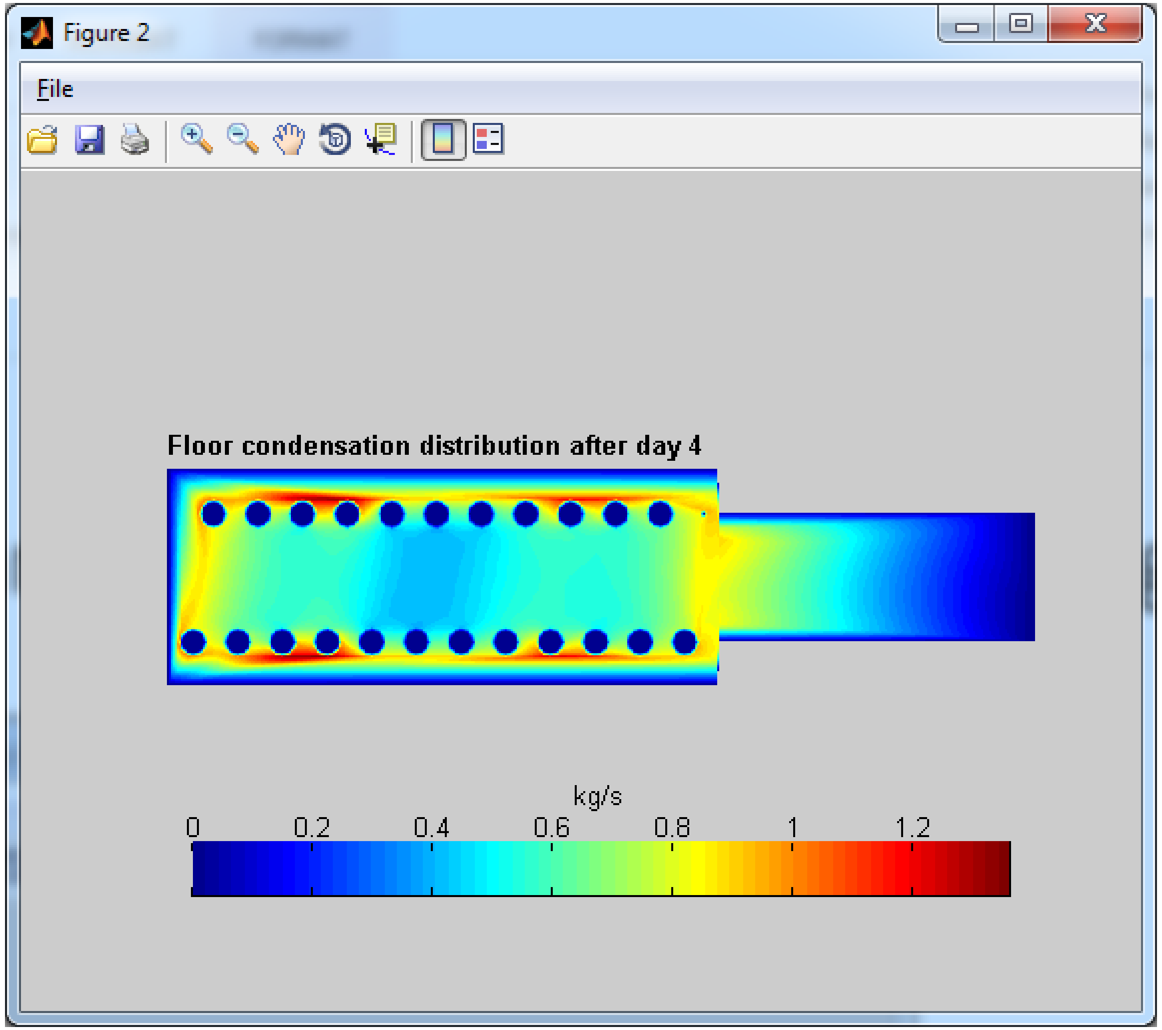
Index	X Position	Y Position	Surface Multiplier	Heat Multi
1	0.4318	0.7366	1	1
2	0.7747	2.921	1	1
3	1.1938	0.7366	1	1
4	1.5367	2.921	1	1
5	1.9558	0.7366	1	1
6	2.2987	2.921	1	1
7	2.7178	0.7366	1	1
8	3.0607	2.921	1	1
9	3.4798	0.7366	1	1
10	3.8227	2.921	1	1
11	4.2418	0.7366	1	1
12	4.5847	2.921	1	1
13	5.0038	0.7366	1	1
14	5.3467	2.921	1	1
15	5.7658	0.7366	1	1
16	6.1087	2.921	1	1
17	6.5278	0.7366	1	1
18	6.8707	2.921	1	1
19	7.2898	0.7366	1	1
20	7.6327	2.921	1	1
21	8.0518	0.7366	1	1
22	8.3947	2.921	1	1
23	8.8138	0.7366	1	1
24	9.144	2.921	0	0



Temperature and humidity vs. time

Example 6: 23-person RA, hanger-type CO_2 scrubber, 57.2 °F ambient temperature





Temperature and condensation distribution maps

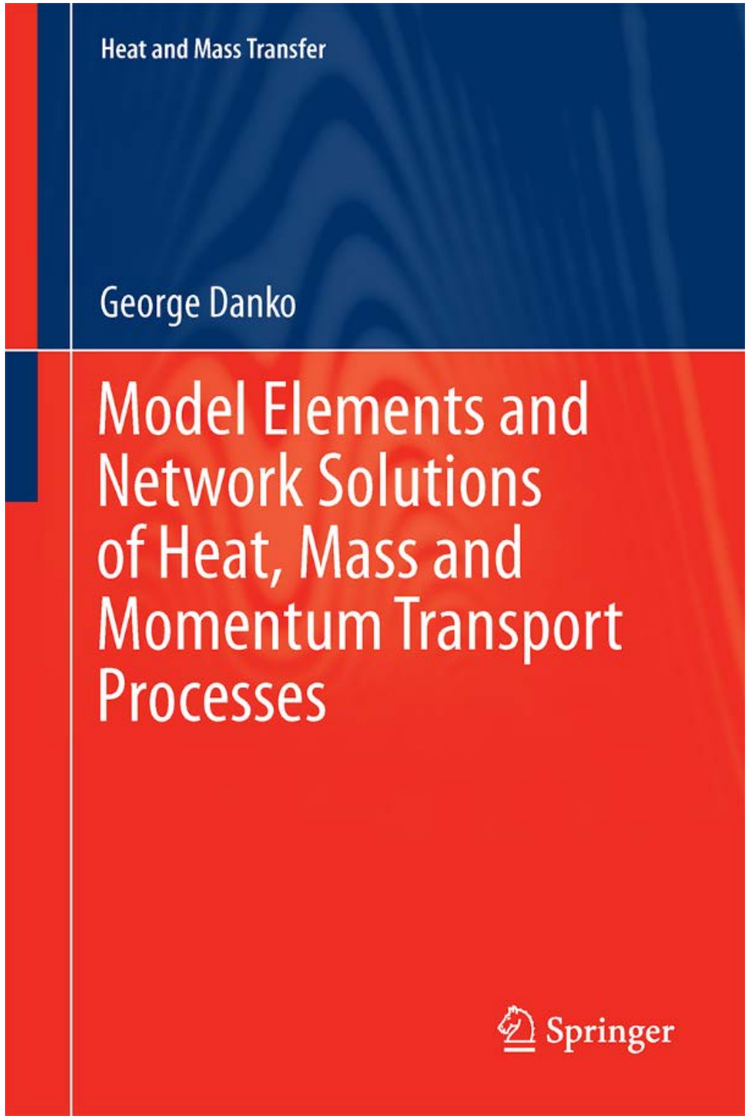
Conclusions and Recommendations

- UNR's universal RA model is easy to configure in a graphical environment
- Only the manufacturer's RA data, and some common data from the mine are needed to start the model simulation
- The model solves for temperature, humidity, condensation, and air movement within the RA space over 96 hours of occupation in a few minutes run time
- The universal model can rate the acceptability of any RA at any in situ mine condition without the need of further experiments with the RA at the mines
- The model has matched the 10-person RA measurement results for three different NIOSH experiments within a few percent
- More sets of NIOSH's experimental results for different RA types should be used for further verifications of the universal thermal model before commercialization to mines
- The Ventsim ventilation model can predict the Tair ambient temperature around all RA locations with the known location of a fire. The UTHA simulation tool can then predict RA temperatures increased due to the fire. This information can be used to guide rescue operations
- For distribution, the universal thermal model is integrated into the Ventsim Visual mine ventilation and climate software which has customer support and thousands of licensed users
- Chasm Consulting, the vendor of the Ventsim software, is committed to market the UTHA software once the universal RA model is sufficiently verified against additional measurement results.

Thank You

Question?

The Computational Energy Dynamics (CED) Model



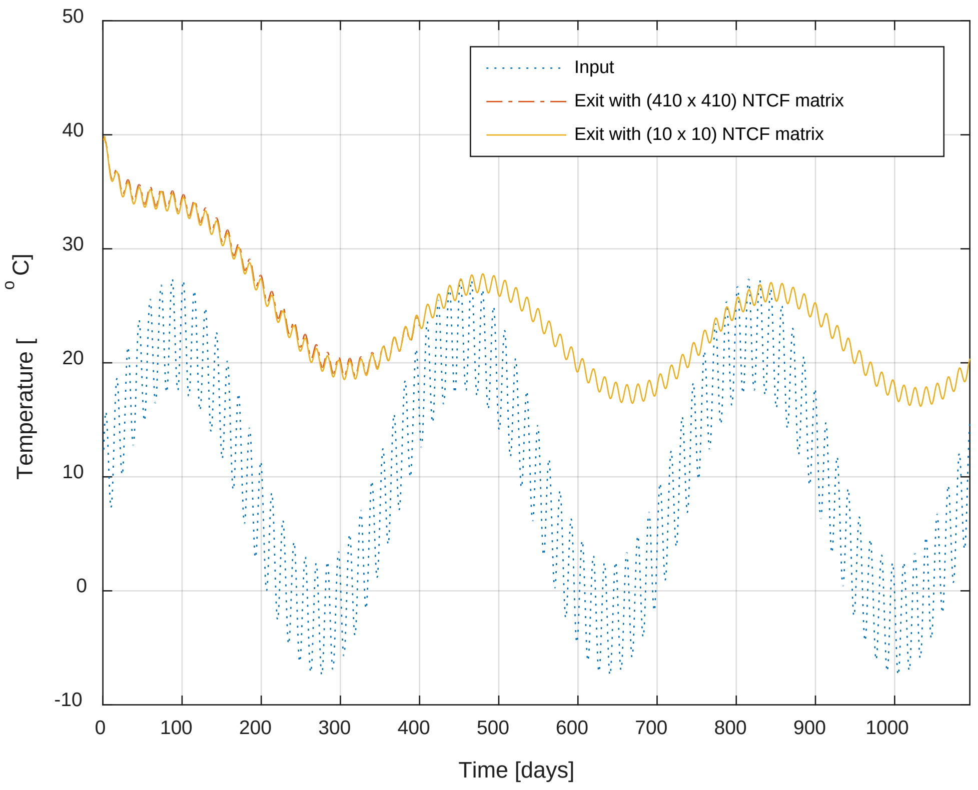
A new modeling tool is developed for the solution of large-scale, coupled, flow, heat, moisture, and contaminant transport problems. **CED is used to solve tasks in mine ventilation**; geothermal energy recovery; nuclear spent fuel repository or ventilated, interim storage facility design; and **refuge shelter studies** for trapped miners.

A book deals with the CED transport model elements:

http://www.springer.com/gp/book/9783662529294

Thermal Transients Simulation Underground

Input and simulated output air temperature result at 3,000 m downstream from input from modeling the thermal flywheel effect in the strata heat with MULTIFLUX



A long thermal history time may be necessary to include in the thermal model of the strata to adequately incorporate the thermal flywheel effect in the temperature evaluation in long drifts from the intake which varies with time