Lessons From an Advanced Building Simulation Course

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Course on Tool Use

- User Interface
- Executable Calculation

Use of accepted tool, e.g. EnergyPlus, eQuest, et al.

Focus on application of the tool
Course on Tool Use

User Interface | Executable Calculation

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Focus on application of the tool

Advanced Simulation Course

User Interface | Programming Language
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Advanced Simulation Course

User Interface  Programming Language

Focus is on modeling skill through tool creation and application

\[ T_i \rightarrow T_j \rightarrow T_k \rightarrow T_l \]
Use of accepted tool, e.g. EnergyPlus, eQuest, et al.

Focus on application of the tool

\[
\frac{1}{2} \left[ (\rho c)_{ep} + (\rho c)_{eq} \right] \frac{\partial T_j}{\partial t} = -k_{ep} \frac{\partial T}{\partial x} \bigg|_{ep} - k_{eq} \frac{\partial T}{\partial x} \bigg|_{eq}
\]
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Focus on application of the tool

**Conduction Elements**

Spatial discretization (equal elements):

\[
\rho C \frac{dT_i}{dt} = \frac{k}{\Delta x} T_i - 2 \frac{k}{\Delta x} T_j + \frac{k}{\Delta x} T_k
\]
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Conduction and Convection Elements

\[
\frac{1}{2} \left[ (\rho c)_{eq} \right] \frac{\partial T_i}{\partial t} = -k_{eq} \frac{\partial T}{\partial x} \bigg|_{eq} - h(T_k - T_i)
\]
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Conduction and Convection Elements

\[
\frac{1}{2} \left[ (\rho c)_{eq} \right] \frac{dT_i}{dt} = -k_{eq} \frac{\partial T_i}{\partial x} \bigg|_{eq} - h (T_k - T_i)
\]

Spatial discretization:

\[
\frac{1}{2} \left[ (\rho c)_{eq} \right] \frac{dT_i}{dt} = \frac{k}{\Delta x} T_j - \frac{k}{\Delta x} T_k - h T_k + h T_i
\]
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Spatially discretized node/element network assembled into a system of differential algebraic equations

\[
\begin{align*}
&M(t) \frac{d\bar{T}}{dt} + \left[ S(\bar{T}, t) \right] \bar{T} = \bar{f}(t) 
\end{align*}
\]
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User Interface

Programming Language

Spatially discretized node/element network assembled into a system of differential algegraic equations

\[
M(t) \frac{dT}{dt} + S(T, t) \overrightarrow{T} \overrightarrow{T} = \overrightarrow{f}(t)
\]

Implementation is checked against problems with analytical solutions
Common Base Case
Common Base Case
Common Base Case

\[ M(t) \rightarrow T \] \[ + \] \[ S(\rightarrow T, t) \rightarrow T = \rightarrow f(t) \]

Conduction Elements
Common Base Case

\[ M(t) \xrightarrow{d} T + S(\vec{T}, t) \xrightarrow{d} T = -f(t) \]

Conduction Elements
Interior Convection Elements
Common Base Case

\[ M(t) \rightarrow T \quad \text{d} - \rightarrow T \quad \text{d}t + \left[ S(\rightarrow T, t) \rightarrow T \right] = -\rightarrow f(t) \]

Conduction Elements
Interior Convection Elements
Exterior Convection Elements
Common Base Case

\[ M(t) \xrightarrow{d} T + S(\rightarrow T, t) \xrightarrow{\rightarrow} T = \rightarrow f(t) \]

Conduction Elements
Interior Convection Elements
Exterior Convection Elements
Solar (direct & diffuse)
Common Base Case

\[ M(t) \stackrel{d}{\rightarrow} T + S(\rightarrow T, t) \stackrel{\rightarrow}{=} f(t) \]

Conduction Elements
Interior Convection Elements
Exterior Convection Elements
Solar (direct & diffuse)
Longwave Radiation Elements
Common Base Case

\[
\frac{d}{dt} T + S \rightarrow T = f(t)
\]

Conduction Elements
Interior Convection Elements
Exterior Convection Elements
Solar (direct & diffuse)
Longwave Radiation Elements
Common Base Case

\[ M(t) \rightarrow T \quad dT/dt + S(T, t) \rightarrow T = -f(t) \]

Conduction Elements
Interior Convection Elements
Exterior Convection Elements
Solar (direct & diffuse)
Conv. + Rad. \( \Rightarrow \) Room Element
Common Base Case

Conduction Elements
Interior Convection Elements
Exterior Convection Elements
Solar (direct & diffuse)
Conv. + Rad. ⇒ Room Element
Ventilation Elements
Common Base Case

\[ M(t) \rightarrow T \, dt + S(\rightarrow T, t) \rightarrow T = f(t) \]

Conduction Elements
Interior Convection Elements
Exterior Convection Elements
Solar (direct & diffuse)
Conv. + Rad. \( \Rightarrow \) Room Element
Ventilation Elements
Internal Mass (e.g. Furniture)
Common Base Case

Conduction Elements
Interior Convection Elements
Exterior Convection Elements
Solar (direct & diffuse)
Conv. + Rad. ⇒ Room Element
Ventilation Elements
Internal Mass (e.g. Furniture)

All rolled into:

\[
\left[ M(t) \right] \frac{dT}{dt} + \left[ S(\vec{T}, t) \right] \vec{T} = \vec{f}(t)
\]
1. Predictive optimal controller for external shading

\[ M(t) \rightarrow T dt + S(T, t) \rightarrow T = f(t) \]

\[ \text{cost} = \int_{24}^{12} (|\ddot{Q}_{htg}| + \epsilon |\dddot{Q}_{cool}|) dt \]

\[ f_{min} \text{cost}, ... \]
1. Predictive optimal controller for external shading

\[
[M(t)] \frac{d\overrightarrow{T}}{dt} + [S(\overrightarrow{T}, t)] \overrightarrow{T} = \overrightarrow{f}(t)
\]

\[
cost = \int_{12}^{24} \left( |\dot{Q}_{htg}| + \epsilon |\dot{Q}_{cool}| \right) dt
\]

\[
fmincon(cost, ...)
\]
1. Predictive optimal controller for external shading

15 March, Atlanta GA

\( T_{roomair} = 24^\circ C \)
2. Uncertainty analysis of monthly cooling loads

\[ M(t) \text{d}t \rightarrow T + S(\rightarrow T, t) \rightarrow T = \rightarrow f(t) \]
2. Uncertainty analysis of monthly cooling loads

Stochastic Variables:

Ventilation volume flow rate
\[ \dot{V} = \dot{V}_{\text{base}} + \dot{V}_{\text{scale}} \cdot \text{windspeed} \]
\[ \dot{V}_{\text{base}} \in [10 \frac{m^3}{h}, 20 \frac{m^3}{h}] \]
\[ \dot{V}_{\text{scale}} \in [5 \frac{m^2}{s} h, 7 \frac{m^2}{s} h] \]

Solar gain thru 2-pane window
\[ Gain_{\text{solar}} = 1 - \rho_{\text{outer}} - \alpha_{\text{outer}} - \alpha_{\text{inner}} \]
\[ \rho_{\text{outer}} \in [0.1, 0.2] \]
\[ \alpha_{\text{outer}} \in [0.1, 0.3] \]

Internal Mass
\[ c_{\text{room}} = M_f \cdot V_{\text{room}} \cdot c_{\text{air}} \]
\[ M_f \in [2 \frac{kg}{m^3}, 5 \frac{kg}{m^3}] \]

Monte Carlo, sampling stochastic variables from uniform distributions
2. Uncertainty analysis of monthly cooling loads

July Cooling Load, Atlanta GA
\[ T_{roomair} \leq 24^\circ C \]
3. Inverse problem: infiltration rate estimation

“Measured” data created by simulating with infiltration rate given by
\[ \dot{V} = a + b(windspeed) \] with \( a = 30 \), \( b = 20 \)

Estimates of \( a \) and \( b \) calculated by minimizing
\[ \int_0^{\text{end}} (T_{\text{measured}} - T(a, b))^2 \, dt \]

Result: \( a = 32.3, b = 23.9 \)
4. Optimal design of radiator valve settings

Blue: interior temperature; green: exterior temperature
5. Thermal comfort as a function of location

PMV for 8am, 22 December in Atlanta
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Development of a 'laboratory' tool
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- **User Interface**
- **Executable Calculation**

Use of accepted and validated tool

Focus on use of a real-world tool and analyzing results

Advanced Simulation Course

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- **Programming Language**

Development of a 'laboratory' tool

Focus on development of modeling skill via learning where results come from
**Course on Tool Use**

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- **Executable Calculation**

  - Use of accepted and validated tool
  - Focus on use of a real-world tool and analyzing results
  - Simulation core off-limits

**Advanced Simulation Course**

- **User Interface**
- **Programming Language**

  - Development of a 'laboratory' tool
  - Focus on development of modeling skill via learning where results come from
  - Nothing is off-limits
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Use of accepted and validated tool

Focus on use of a real-world tool and analyzing results

Complimentary approaches ⇒ better modelers

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Development of a 'laboratory' tool

Focus on development of modeling skill via learning where results come from

Nothing is off-limits