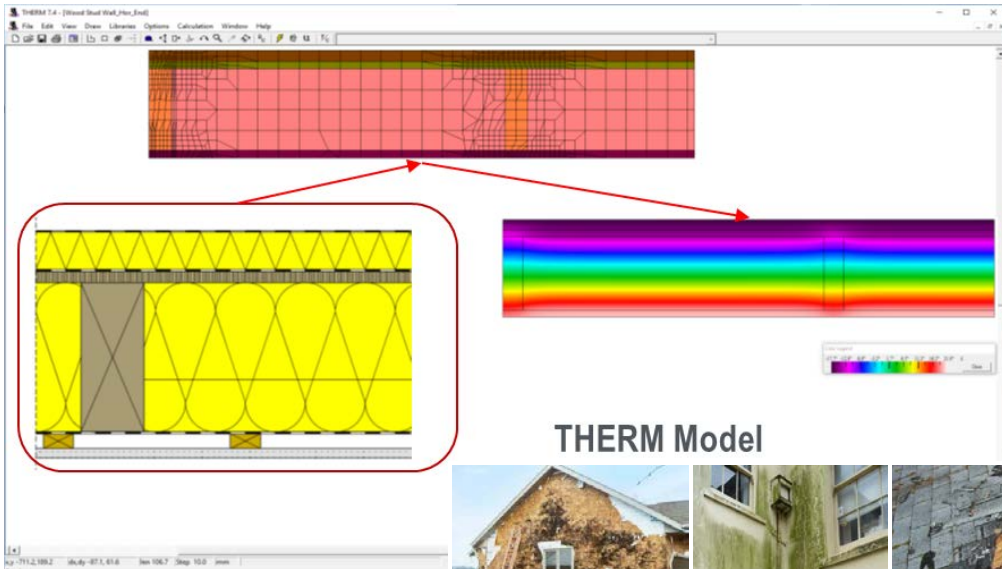
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

THERMM: Heat & Moisture Modeling Tool



Charlie Curcija, dccurcija@lbl.gov / LBNL
Simon Pallin, pallinsb@ornl.gov /ORNL

Project Summary

Timeline:

Start date: 10/1/2016 (actual start Jan, 2017)

Planned end date: 12/31/2019

Key Milestones:

1. Mathematical and numerical model – 3/31/2018
2. GUI design – 6/30/2018
3. Beta software tool release – 12/31/2018
4. Final software tool release and full technical documentation – 1/31/2020

Key Partners:

NFRC	PassivHaus Institute US
AERC – Fenestration Attachment Rating	Forest Products Lab
ASHRAE	WESTLab
British Columbia Institute of Technology	Owens Corning

Budget:

Total Project $ to Date:

- DOE: $718K (Last 12 months: $450K)
- Cost Share: $0K (Last 12 months: $0K)

Total Project $:

- DOE: $1,250K
- Cost Share: $250K

Project Outcome:

Software tool capable of modeling 2-D dynamic heat and moisture transfer in building envelopes, incorporating automated meshing and error estimation for rapid model development. Open source code base for third party contributions. API that can be utilized by other tools, such as E+, web-based custom tools.

Team

Charlie Curcija

Simon Vidanovic

Robert Hart

Howdy Goudey

Simon Pallin

Andre Desjarlais

Florian Antretter

LBNL Team

LBNL team is led by Dr. Charlie Curcija, co-leader of the LBNL's Windows group. Charlie is heat transfer expert, with extensive experience in windows and building envelop heat transfer and energy performance.

Simon Vidanovic is an engineer and programmer, with expertise in numerical methods. He is bringing the right balance to programming task.

Robert Hart is a scientist with the expertise in both modeling and measurements of heat transfer

Howdy Goudey is the manager of Windows group Thermal Lab, with extensive experience in the measurement of heat transfer

ORNL Team

ORNL team is led by Dr. Simon Pallinwho brings extensive experience in modeling, measurements and analysis of moisture transport in building envelopes

Andre Desjarlais is Program Manager for the Building Envelope Systems Research Program at the Oak Ridge National Laboratory. He has been involved in building envelope and materials research for over 40 years, bringing unprecedented expertise in both heat and moisture transfer.

Florian Antretter brings his experience as a member of WUFI team at Fraunhofer institute for Building Physics in Germany.

Purpose and Objectives

Problem Statement: Moisture transfer and heat transfer are two critical and inter-related problems in building envelope characterization, design and optimization. The presence of moisture can degrade both the durability and thermal performance of the building envelope as well as introduce mold problems that endanger the health and safety of building occupants. Successful design of modern energy efficient envelopes is highly dependent on proper moisture management.

Target Market and Audience: Building envelope designers, manufacturers, rating organizations, certified simulators, other related professionals

Impact of Project: Technical potential for energy savings by 2030 from building envelopes (commercial and residential) is 7.1 quads/year, or over $70 Billions/year. Better moisture modeling capability would allow for better energy efficient design, helping save some of this energy.

World class modeling tools form the basis for good building design, as well as helping building envelope component manufacturers innovate and sell their products globally.

Approach

Approach: Enhance LBNL's state-of-the-art building envelope 2-D heat transfer modeling tool THERM with moisture transfer modeling capabilities. In the process, also bring dynamic modeling capabilities to THERM.

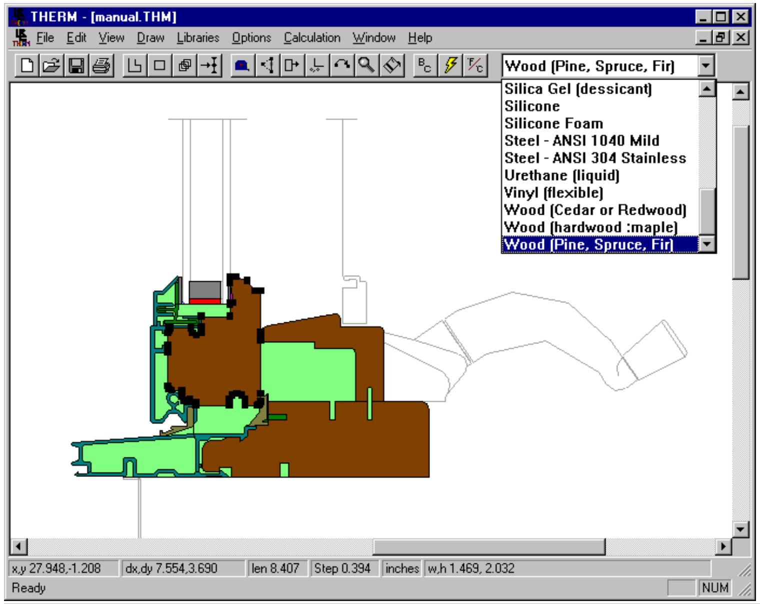
Key Issues:

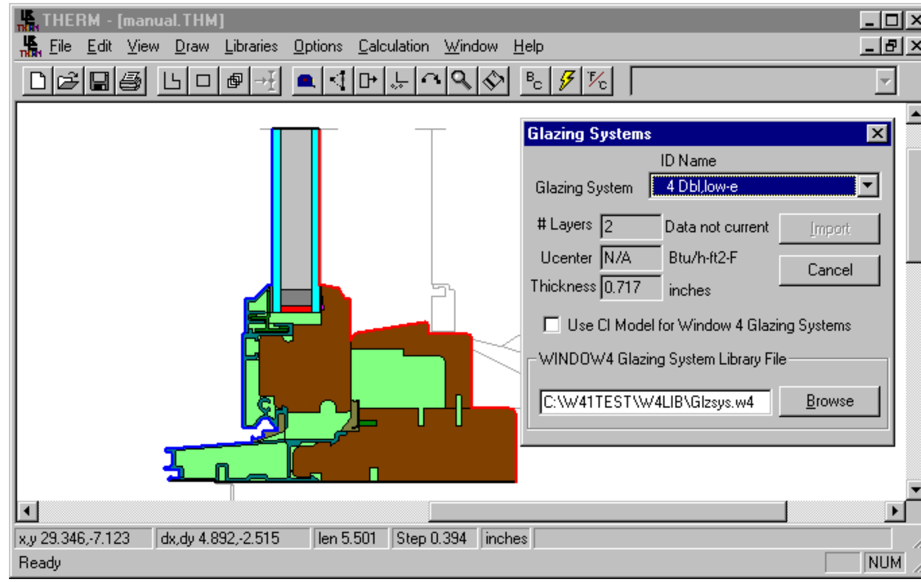
- Extend Finite Element Method (FEM) in THERM to time domain (currently steady-state)
- Add moisture modeling numerical model to THERM.
- Extend current GUI to enable additional data required to model dynamic performance and moisture transfer (e.g., add initial conditions and extend boundary conditions, add new outputs).
- Provide as much of the software tool as open source code, as feasible while complying with export restrictions and third party components.

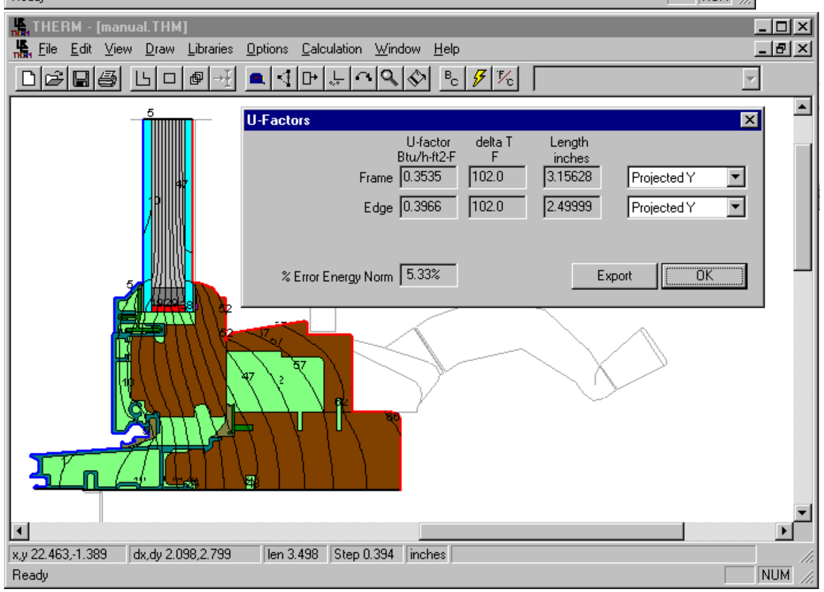
Distinctive Characteristics:

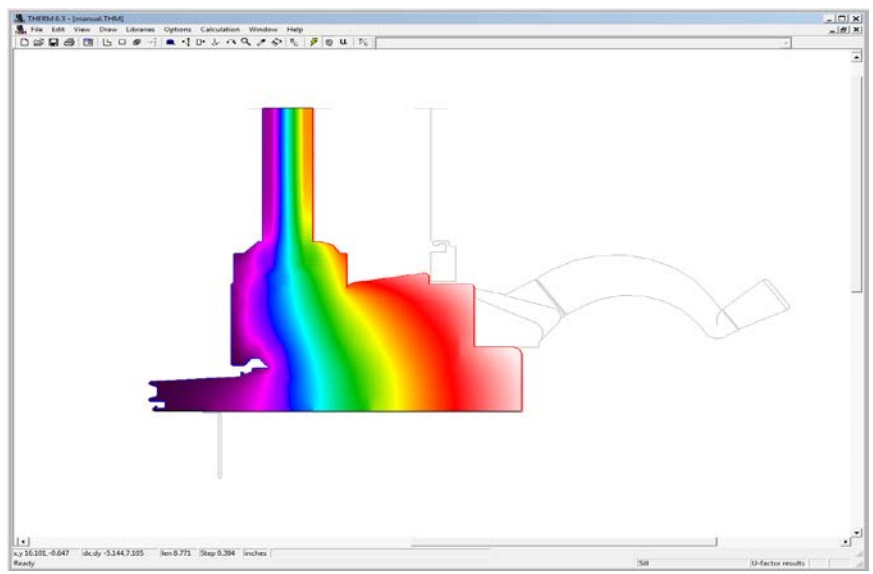
- THERM is used by approximately 25,000 users world-wide. Most widely used building envelope heat transfer modeling tool.
- Used currently primarily to model windows heat transfer and to lesser extent to model building envelopes. This new functionality will expand user base and application

Current THERM Capabilities – Fenestration

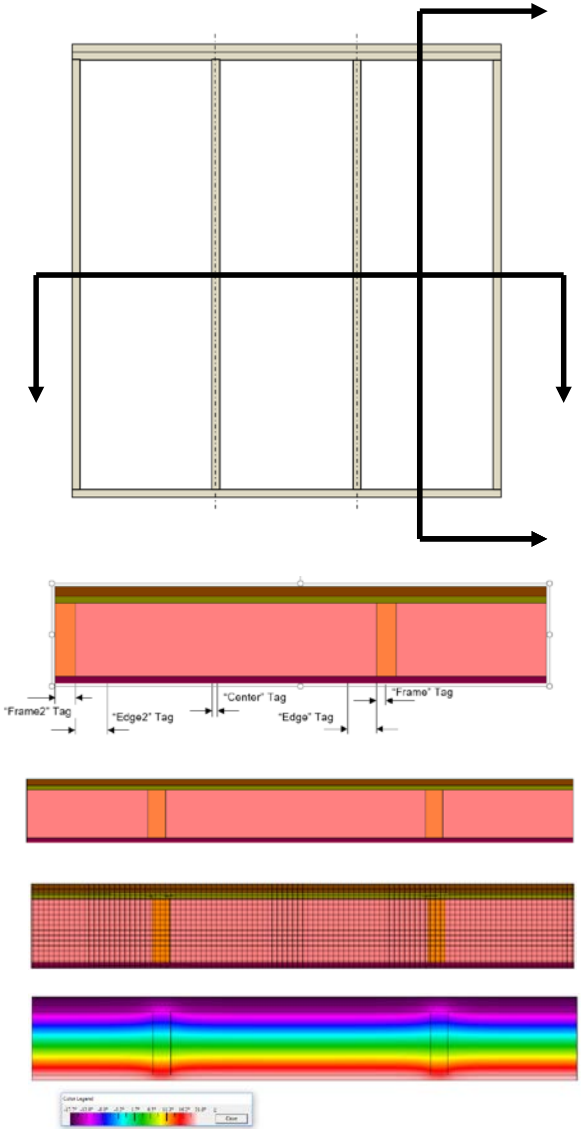


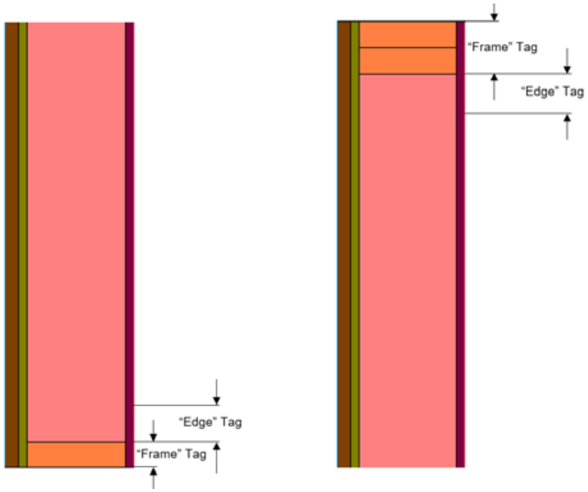


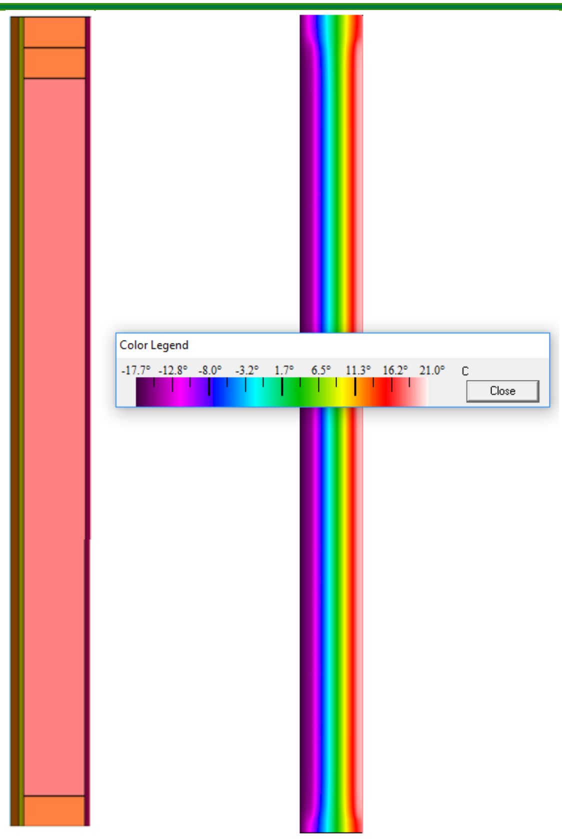




Opaque Envelope Assemblies Modeling in THERMM



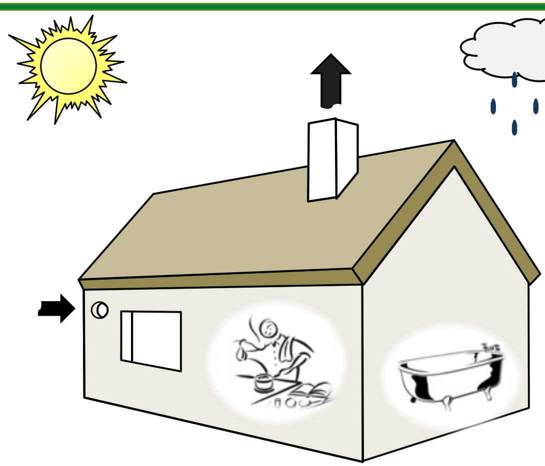


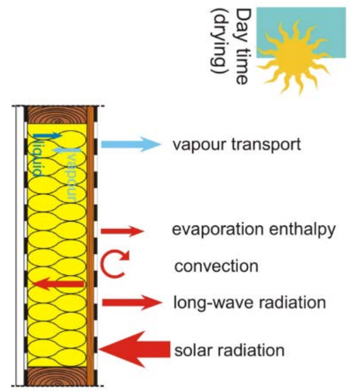


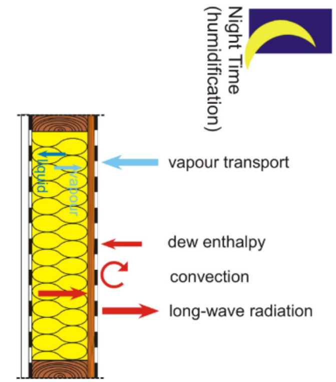
$$U = \frac{7 \cdot 1.5561 \cdot 0.282 + 1.702 \cdot 0.306 + 0.6322 \cdot 0.377}{7 \cdot 1.5561 + 1.702 + 0.6322} = 0.305 \frac{W}{m^2 \cdot K}$$

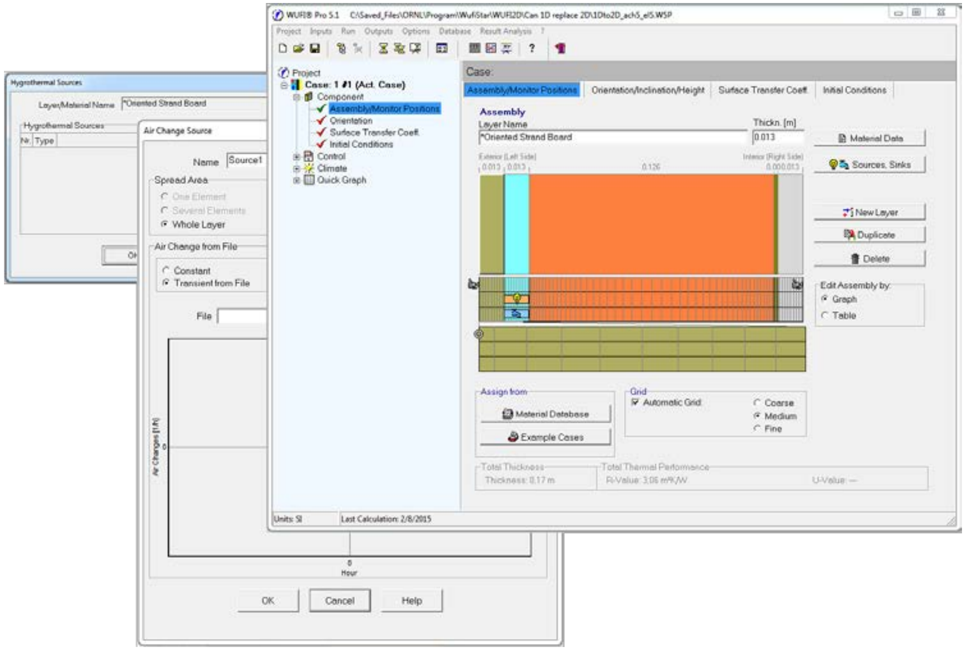
$$U\text{clear wall} = 0.250 \frac{W}{m^2 \cdot K}$$

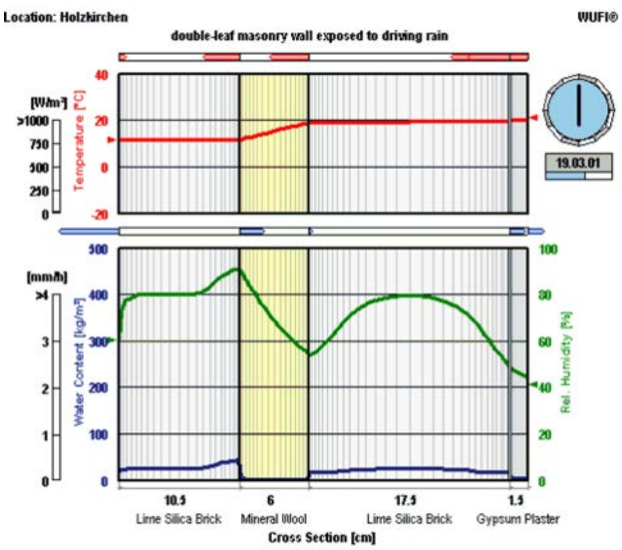
Current Modeling of Moisture Transfer - WUFI



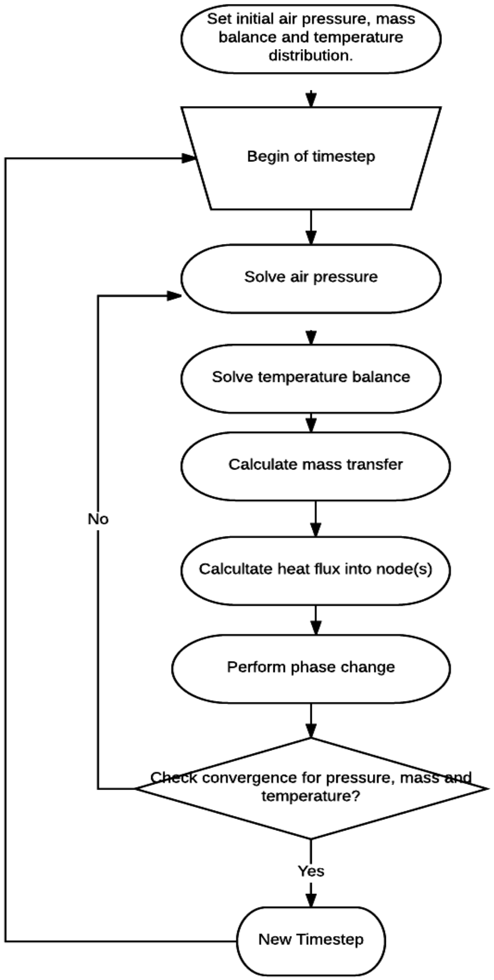








Coupled Heat, Air & Moisture (HAM) Transport Model



Steps in Solving HAM problem

Heat Transfer Model:

$$\rho_{eq} \cdot C_{eq} \frac{\partial T}{\partial t} + S \cdot H_{il} =$$

$$= \frac{\partial \bar{q}_{c,x}}{\partial x} + \frac{\partial \bar{q}_{c,y}}{\partial y} + h_{lg}\left(\frac{\partial \bar{g}_{v,diff,x}}{\partial x} + \frac{\partial \bar{g}_{v,diff,y}}{\partial y} + \frac{\partial \bar{g}_{v,adv,x}}{\partial x} + \frac{\partial \bar{g}_{v,adv,y}}{\partial y} \right) +$$

$$C_l \left(\bar{g}_{l,x} \cdot \frac{\partial T}{\partial x} + \bar{g}_{l,y} \cdot \frac{\partial T}{\partial y} \right) + C_v \left(\bar{g}_{v,x} \cdot \frac{\partial T}{\partial x} + \bar{g}_{v,y} \cdot \frac{\partial T}{\partial y} \right) + C_{air,d} \left(\bar{g}_{air,x} \cdot \frac{\partial T}{\partial x} + \bar{g}_{air,y} \cdot \frac{\partial T}{\partial y} \right) + Q$$

Moisture Transfer Model:

$$\frac{\partial \gamma_w}{\partial \varphi} \frac{\partial \varphi}{\partial t} = \frac{\partial}{\partial x}\left(\frac{E}{\mu_x} \frac{\partial \varphi \gamma_{v_{sat}}}{\partial x} \right) + \frac{\partial}{\partial y}\left(\frac{E}{\mu_y} \frac{\partial \varphi \gamma_{v_{sat}}}{\partial y} \right) +$$

$$\frac{\partial}{\partial x}\left(\frac{k_{air,x} \cdot \varphi \gamma_{v_{sat}}}{\eta_{air}} \cdot \frac{\partial P_{air}}{\partial x} \right) + \frac{\partial}{\partial y}\left(\frac{k_{air,y} \cdot \varphi \gamma_{v_{sat}}}{\eta_{air}} \cdot \frac{\partial P_{air}}{\partial y} \right) +$$

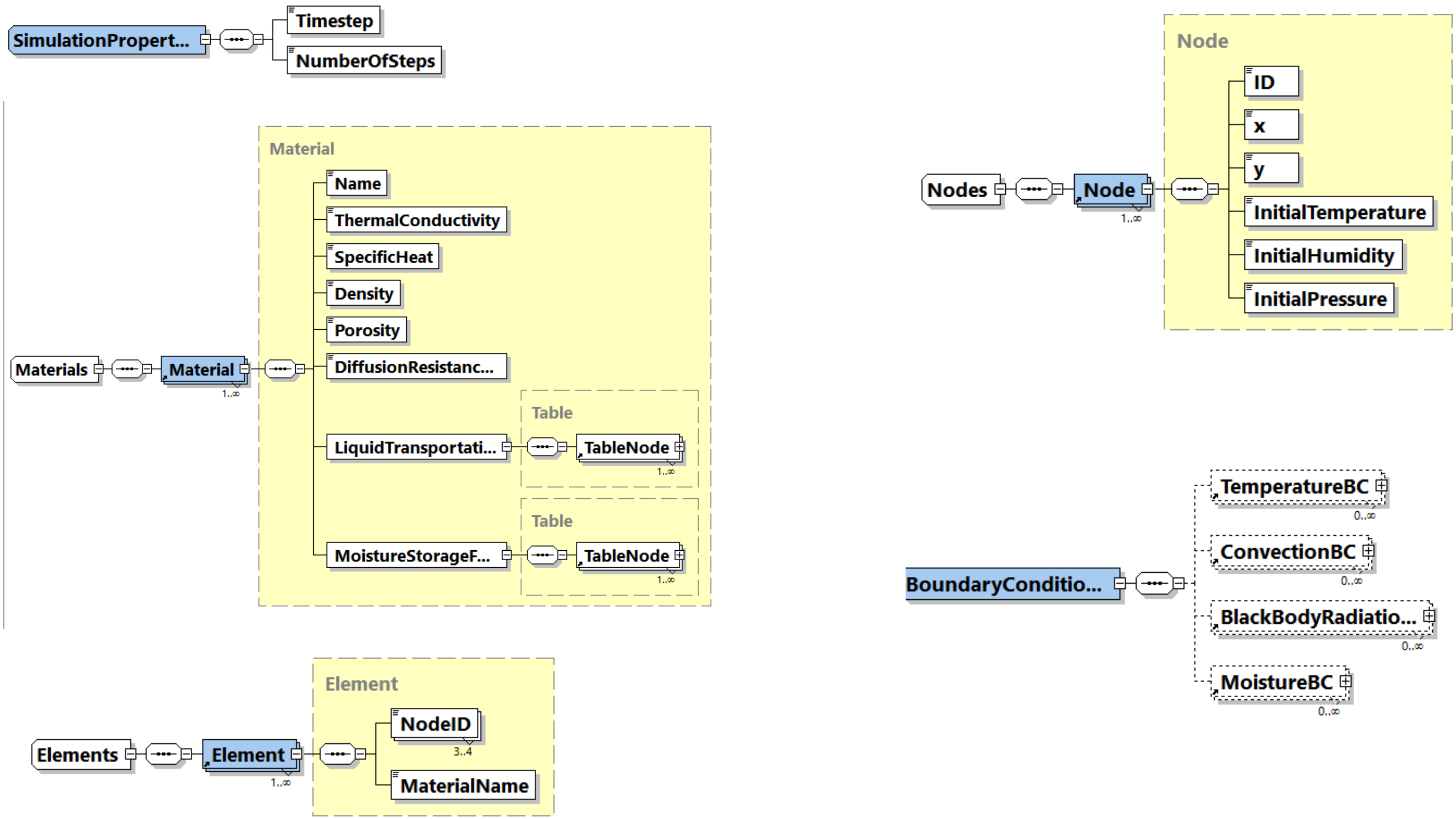
$$\frac{\partial}{\partial x}\left(D_{\varphi,x} \left(\frac{\partial \varphi}{\partial x} \right) \right) + \frac{\partial}{\partial y}\left(D_{\varphi,y} \left(\frac{\partial \varphi}{\partial y} \right) \right) + S_l + S_v$$

Air flow model:

$$\frac{\partial \gamma_{air}}{\partial t} = \frac{\partial}{\partial x}\left(\frac{k_{air} \cdot \rho_{air}}{\eta_{air}} \cdot \frac{\partial P_{air}}{\partial x} \right) + \frac{\partial}{\partial y}\left(\frac{k_{air} \cdot \rho_{air}}{\eta_{air}} \cdot \frac{\partial P_{air}}{\partial y} \right)$$

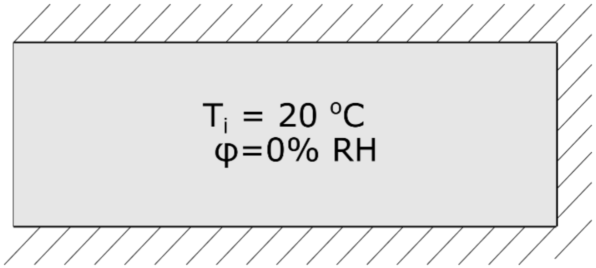
API Development

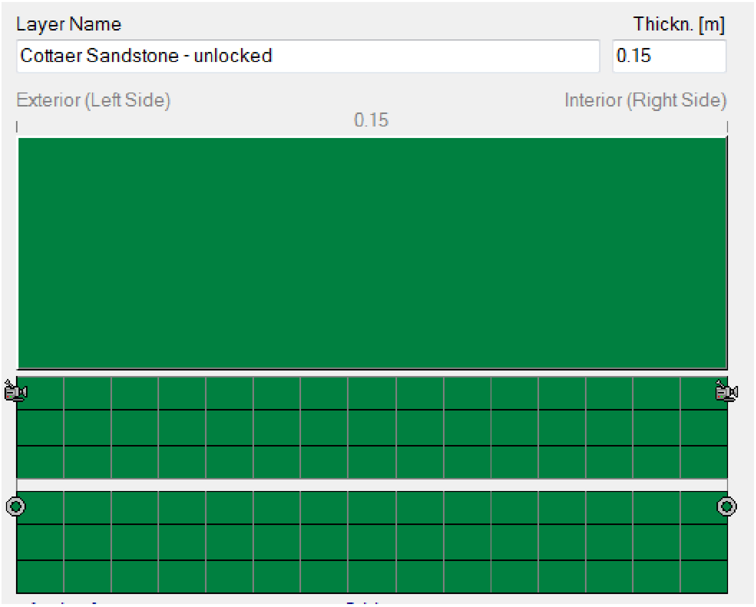
- XML file format to communicate with THERMM engine

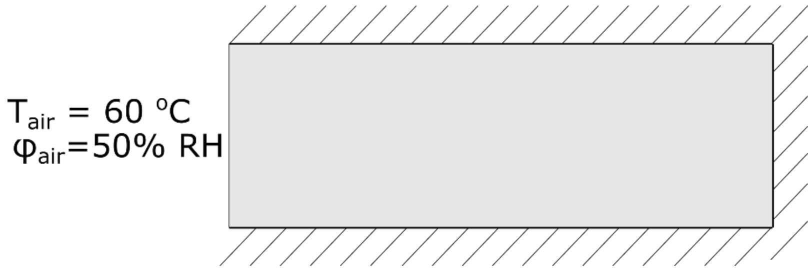


Simple WUFI Comparison Example

- 15 cm Cottaer Sandstone
- Initial conditions: 20 °C and 0 % RH
- Boundary conditions: 20 °C and 50 % RH applied on left side
- Modified material properties
- Liquid and heat transfer disabled

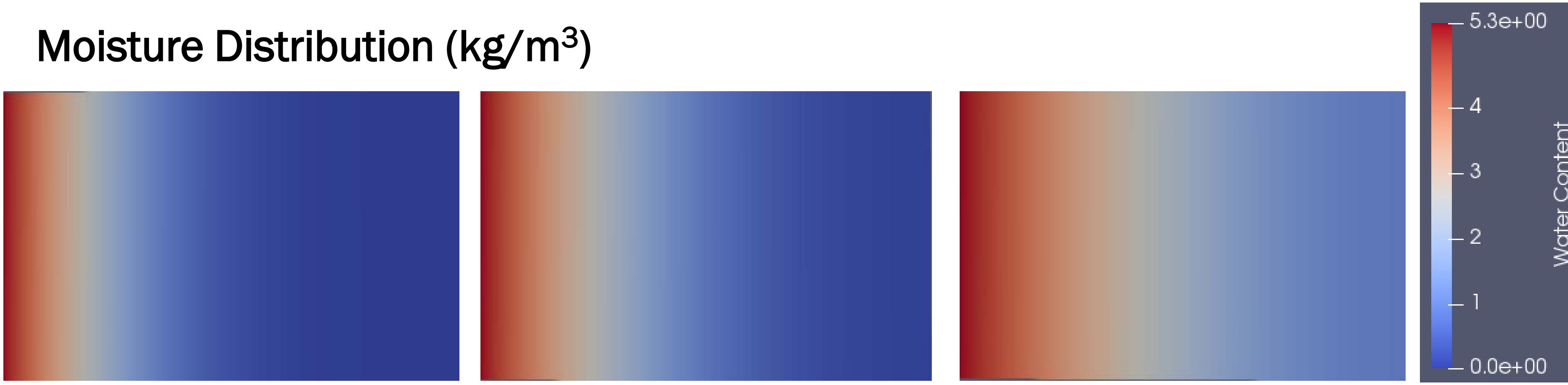






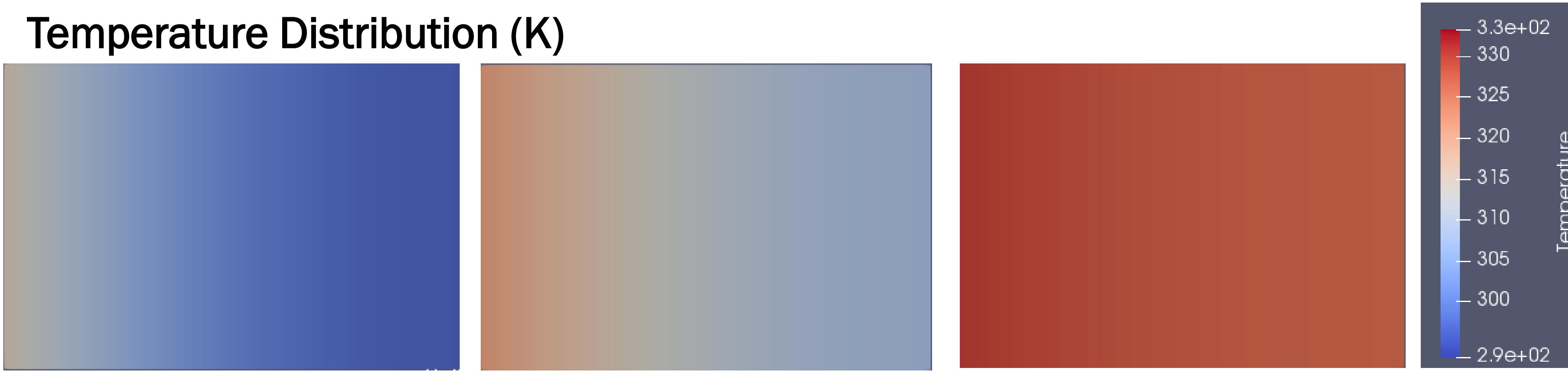
Modeling results from THERMM

Moisture Distribution (kg/m^3)



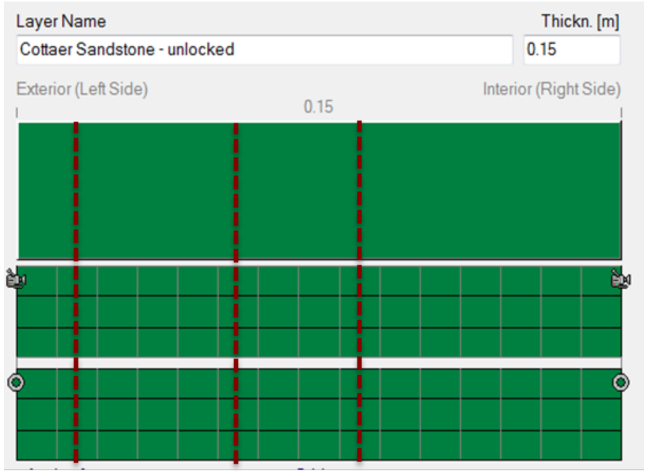
Time at 10 hours | Time at 20 hours | Time at 50 hours

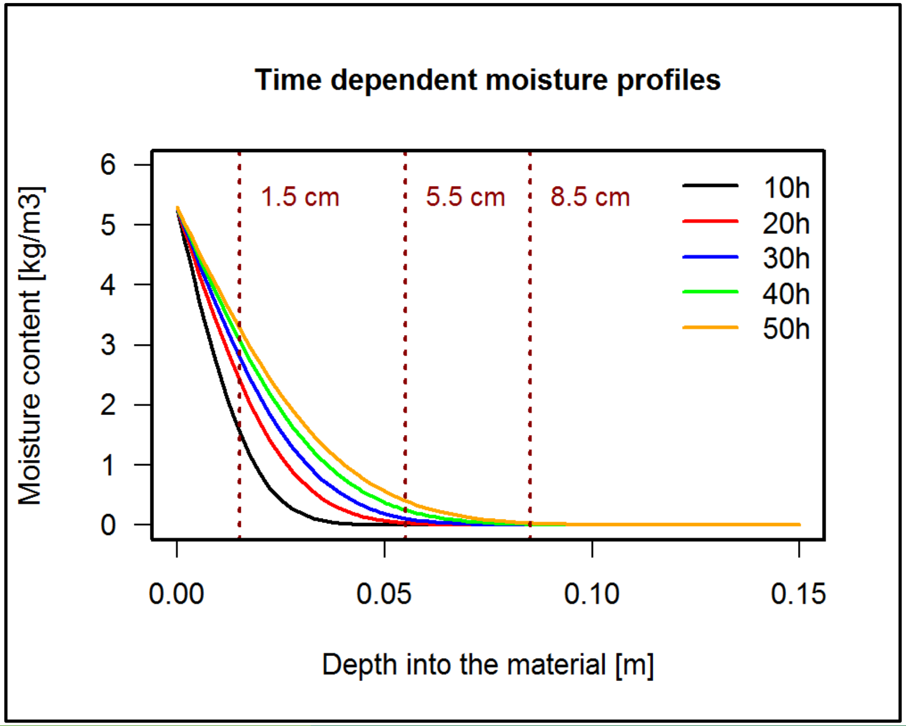
Temperature Distribution (K)

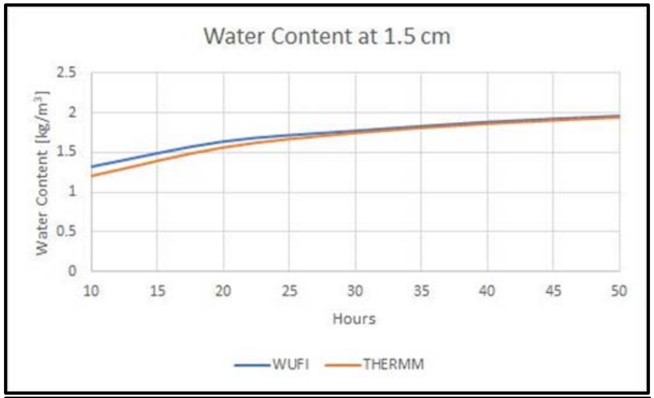


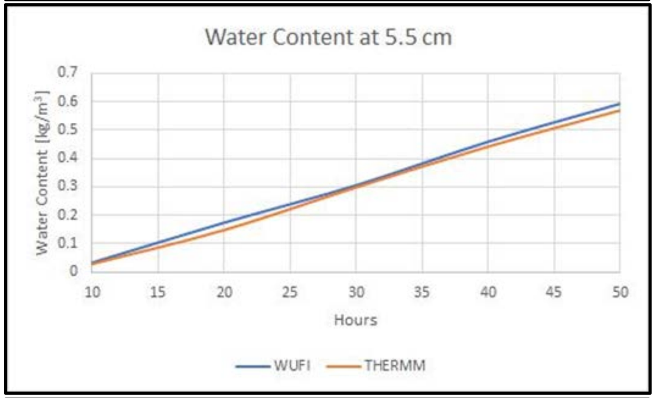
Time at 1 hour | Time at 3 hours | Time at 10 hours

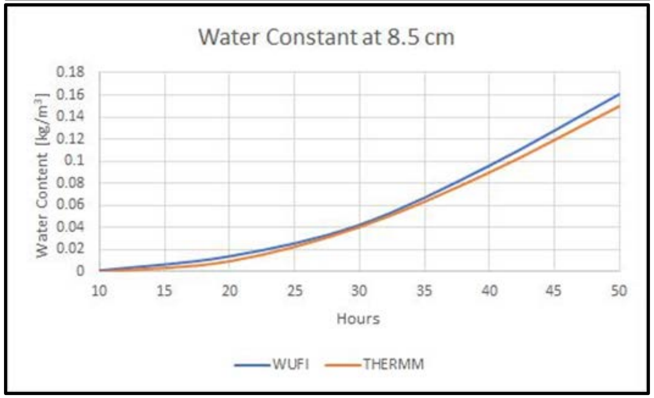
THERMM Results vs. WUFI











Identified validation cases

- Hygric model with EN 15026 with analytical limit value table and graphic

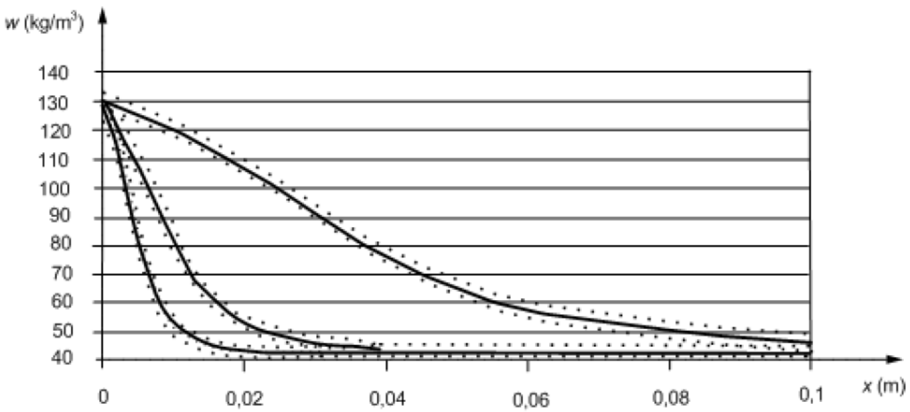
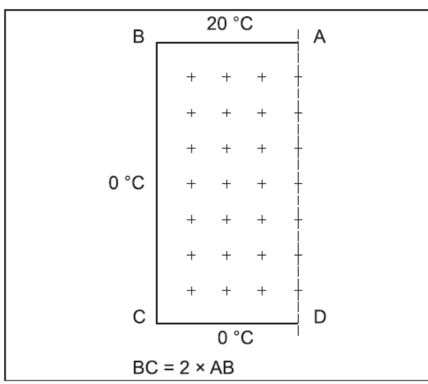


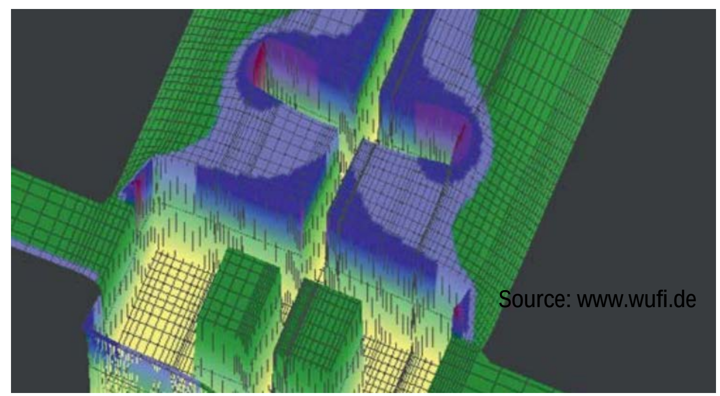
Table A.1 — The limits of validity for results from the humidity calculations

Days	x = 0,01		x = 0,02		x = 0,03		x = 0,04		x = 0,05		x = 0,06		x = 0,08		x = 0,10	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
7	50,2	54,5	41,3	45,6	40,8	45,1	40,8	45,1								
30	81,0	85,3	51,1	55,3	43,6	47,9	41,5	45,7	40,9	45,2	40,8	45,1	40,8	45,1		
365	117,5	121,8	104,4	108,7	88,7	93,0	75,6	77,9	62,8	67,1	55,7	60,0	47,9	52,2	44,1	48,4

- Thermal model with ISO 10211 (static 1D and 2D analytical reference case)



Analytical solution at grid nodes (°C)			
9,7	13,4	14,7	15,1
5,3	8,6	10,3	10,8
3,2	5,6	7,0	7,5
2,0	3,6	4,7	5,0
1,3	2,3	3,0	3,2
0,7	1,4	1,8	1,9
0,3	0,6	0,8	0,9



- Cross-validation with WUFI 1D and 2D

Project Integration and Collaboration

Project Integration:

- Involving NFRC, AERC and PHIUS
- Diverse technical advisory group - TAG
- Reporting at ASHRAE
- Planning to fead future standard implementation

Partners, Subcontractors, and Collaborators:

- Rating organizations
- Government – Forest Products Lab
- Building envelope manufacturers: Owens Corning, window manufacturers
- Associations - ASHRAE
- Universities: University of Waterloo, British Columbia Institute of Technology
- Certified simulators – WESTlab
- Software Companies – Bigg Ladder Software

Communications:

- e-mail/phone user support
- web-based software support forum
- Conferences, Webinars
- TAG meetings

Progress and Accomplishments

Accomplishments

- IP management and data plan completed
- Mathematical model completed
  - Combined heat and moisture model – HAM
  - Identified areas of future development
- Numerical model being finalized
- Early results show good agreement
- Open source plan

Market Impact

- THERM is used by all major fenestration manufacturers, including globally
- Increasing number of users use it for opaque parts of building envelope
- When HAM functionality is completed, we expect further explosion of user base

Recognition

- THERM is most widely used software tool for modeling building envelopes in the world

Lessons Learned

- Decision what to include in software tool vs. what to leave out is very difficult

Next Steps and Future Plans

FY18

- Finalize API
- Complete development of numerical model
- Implement numerical model in FEM engine (current FEM engine name is CONRAD)
- Release Alpha version of software tool to selected group of reviewers (TAG and some selected others)
- Begin verification and validation

Out Years

- Release Beta version to wide public
- Complete verification and validation of THERMM modeling results
- Collect feedback and implement in full release version
- Write final verification and validation reports
- Write user's manual, and technical documentation
- Release final software tool version

REFERENCE SLIDES

Project Budget

Project Budget: 3 year project with DOE budget of $1,250K and cost share of $250K
Variances: Project is on budget with schedule pushed by 1 quarter (end 12/31/2019). Cost share negotiations with CEC were significantly delayed and provided only half of promised funding. Other half was provided by industry.
Cost to Date: DOE: $718K, cost-share: 0K
Additional Funding: Cost shared by CEC and Industry

Budget History					
FY 2017 (past)		FY 2018 (current)		FY 2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$450K	$0K	$268K	$0K	$400K	$175K

Project Plan and Schedule

Project Schedule		
Project Start: 10/1/2016		Completed Work
Projected End: 12/31/2019		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned)
		Milestone/Deliverable (Actual)

	FY2017				FY2018				FY2019			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Establish GitHub, CMAKE, and Gtest												
Develop IP Management Plan												
Develop mathematical model												
Develop numerical model												
Current/Future Work												
Develop API												
Complete simulation engine												
Develop modified GUI design												
Implement new GUI and release alpha version												
Verification testing and bug fixing												
Validation measurements												

Project Budget

Project Budget: **Outline the project budget and history.**
Variances: **Describe any variances from original planned budget and identify if/how the project plan was modified.**
Cost to Date: **Identify what portion of the project budget has been expended to date.**
Additional Funding: **Note, if any, other funding sources.**

Budget History					
Insert Start Date – FY 2017 (past)		FY 2018 (current)		FY 2019 – Insert End Date (planned)	
DOE	Cost-share				

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Project Plan and Schedule

Describe the project plan including:

- Project original initiation date & Project planned completion date
- Schedule and Milestones
- Explanation for slipped milestones and slips in schedule
- Go/no-go decision points
- Current and future work

Project Schedule		
Project Start: Insert Start Date		Completed Work
Projected End: Insert End Date		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned) use for missed
		Milestone/Deliverable (Actual) use when met on time
Task		Q4 (Jul-Sep)
Past Work		
Q1 Milestone: Exa		
Q2 Milestone: Exa		
Q3 Milestone: Exa		
Q4 Milestone: Exa		
Q1 Milestone: Example 5		
Current/Future Work		
Q3 Milestone: Example 6		
Q4 Milestone: Example 7		

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If you have a better visual to put in place for this schedule template, please feel free to do so.