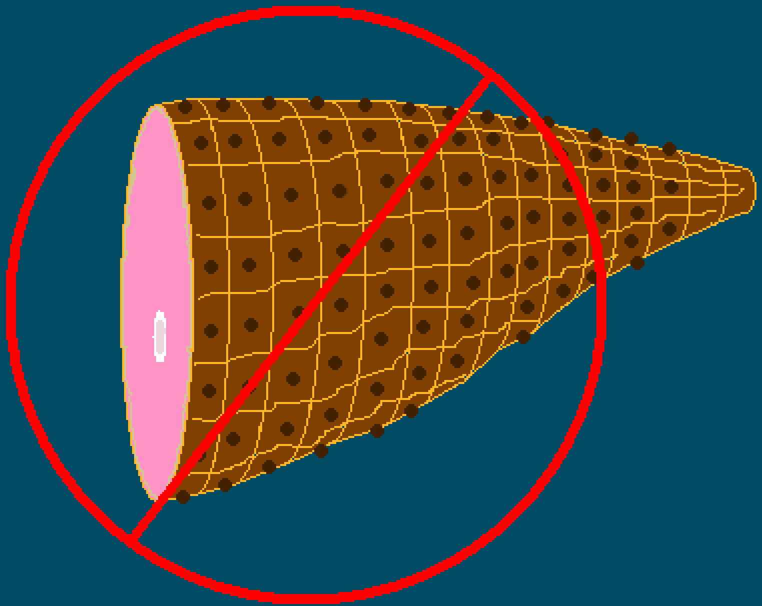
HAM Models --- Where's the meat?



HAM = Heat-Air-Moisture

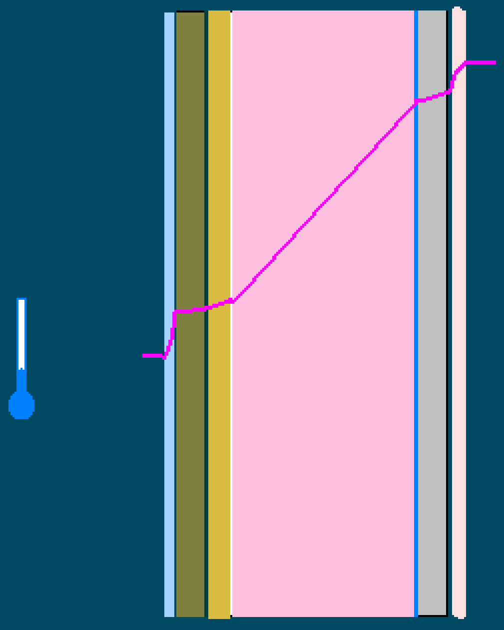
what is a HAM model?

what should you be able to do with one?

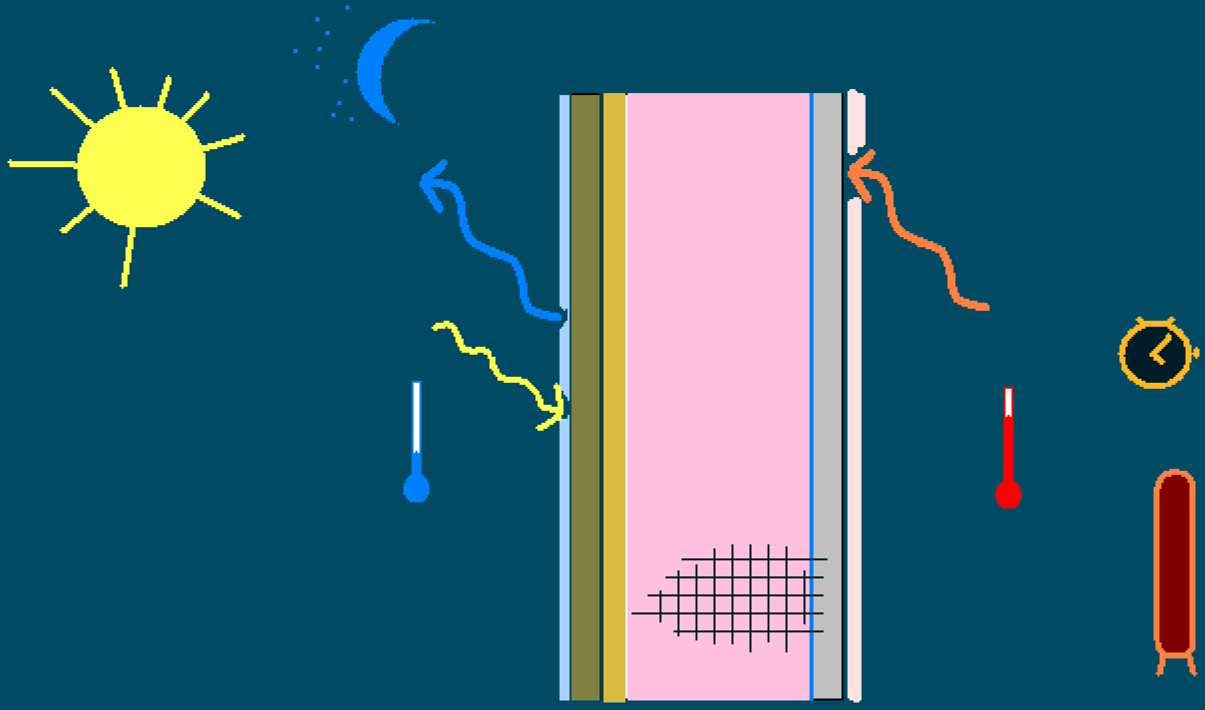
why would you want to?

when will it be ready?

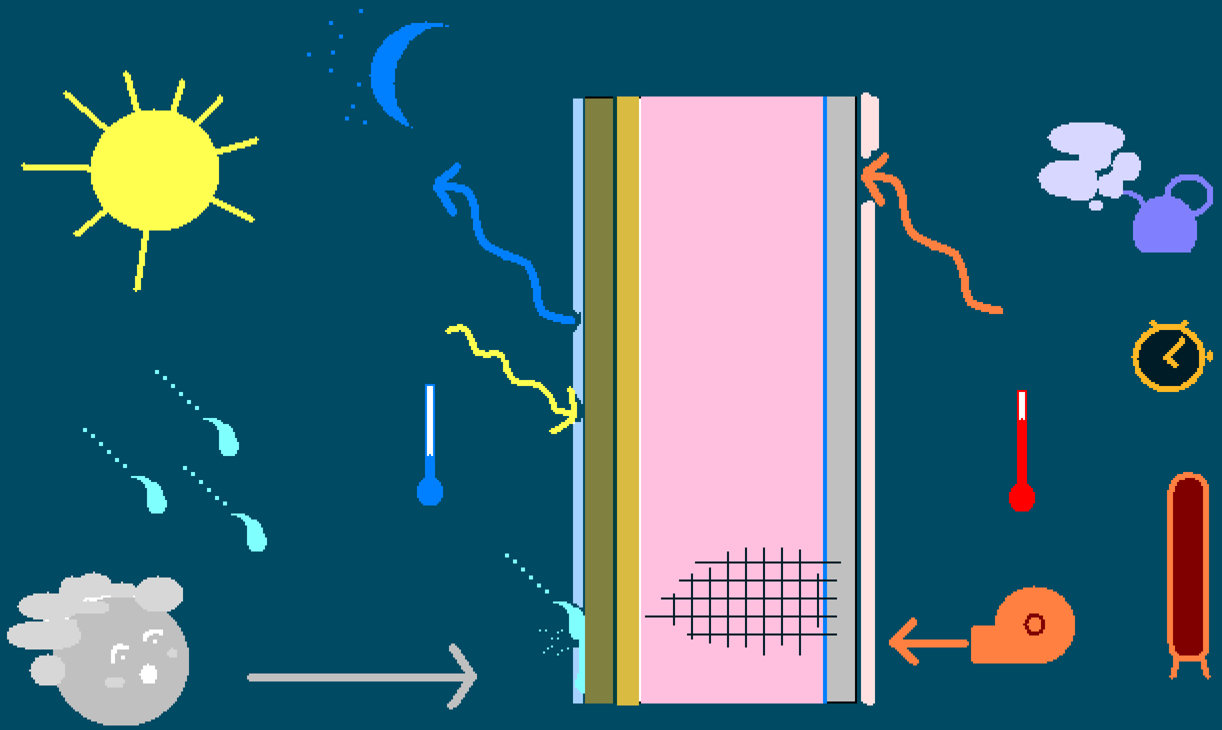
A Simple Heat-flow Model



A Finite-element Heat-flow Model



A HAM Model



What can you do with Models?

thermal models

- thermal bridges & alternative details
- 1st order evaluation of a proven detail in a new environment
- include thermal inertia
- can include radiation, absorption and transmission of radiation by glass, and cavities with radiant heat flow and convection
- simple enough to make 3D models practical

HAM models

- latent heat --- heat of fusion, heat of condensation
- movement of water, water vapour, and solutes
- heat carried by moving water, air, and water vapour
- heating or cooling of incident rainwater
- moisture effects on storage capacity, vapour permeability, and thermal conductivity

What can you do with Models?

with HAM, when we compare designs, or consider the implications of changes in boundary conditions, we can ask

- does moisture alter heat loss or temperature compared to what thermal modeling predicts?
- is one case more likely than another to suffer from damage due to excessive moisture?

we can't learn from HAM ---

- what will be the temperature and moisture content of my north wall, at point A, at 9:00 AM on January 15?
- will moisture damage this wall in this climate?

Moisture in Porous Materials

w_{max} = vacuum saturation

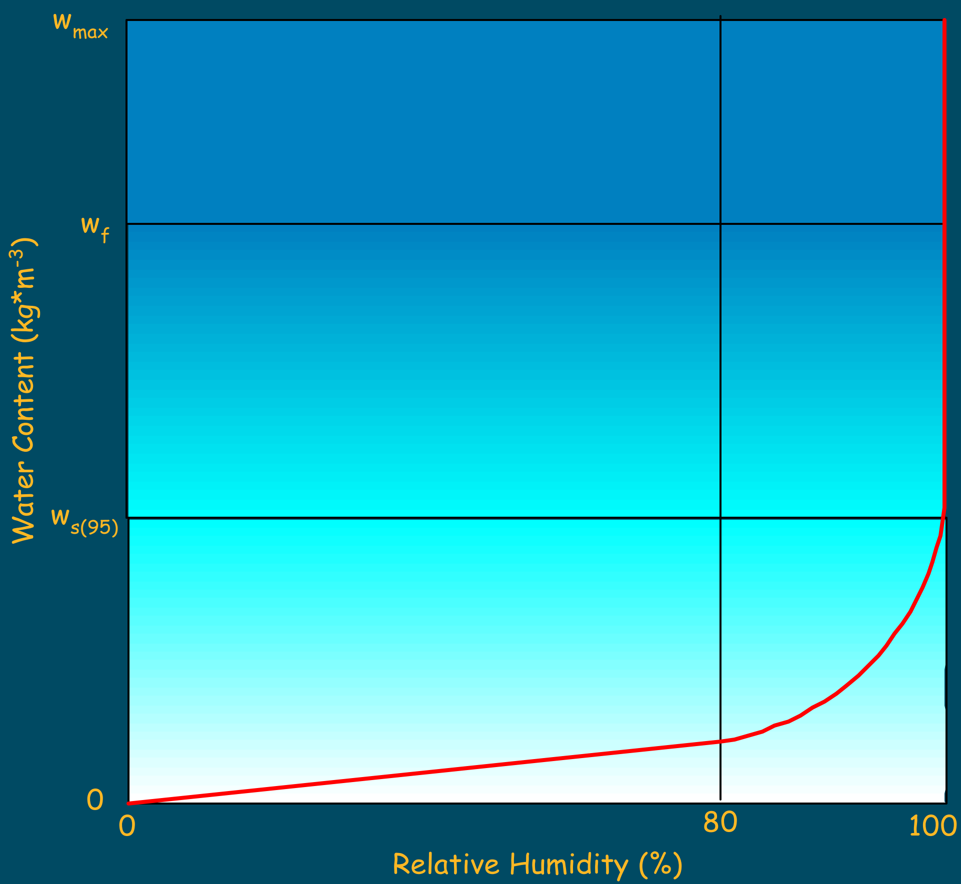
w_f = capillary saturation (equilibrium in contact with water, without pressure)

$w_{s(95)}$ = equilibrium in air at 95% RH

$w_{s(95)} > 0$ for hygroscopic matl.

$w_{s(95)} = 0$ for hydrophobic but capillary-active matl.

$w_f = 0$ for hydrophobic matl.



Evolution of Murus canadensis

Wall	Selection Pressure	Adaptation
mass wall --- little resistance to heat, air, moisture flow, massive storage capacity	cold climate	insulation
	cost	lightweight construction
insulated wall --- reduce heat flow, but outside is colder and wetter	condensation	vapour barrier
	frost damage	non-hygrosopic materials
insulated wall with vapour barrier	condensation and energy cost	air barrier
single stage wall	rain penetration	drained cavities
rain screen wall, of light non-porous materials, with air & vapour barriers	mold, corrosion	??? ....

walls with little storage capacity suffer wild swings of RH with small changes in water content

Walls make good stashes (for moisture)

with apologies to Tim Padfield

Condensation is still with us

Preventing condensation is not possible

Avoiding problems by using lightweight, non-hygroscopic walls does not work

- a mass wall can easily accomodate moisture that would cause mold or corrosion in a lightweight and non-hygroscopic wall
- if there are leaks, water in tightly sealed cavities causes high humidity and can only escape (very slowly) as vapour

Hygroscopic materials can store moisture without harm, and dry out when conditions change. In the process, they can moderate humidity not only in the wall, but inside the building (if not isolated). If interior structures also buffer moisture, that too can mitigate envelope moisture problems.

Moisture Content of Walls at 90% RH

Wall	Adsorbed Moisture	
	kg*m^-2	kg*m^-3
200 mm concrete	15.2	76
20 mm gypsum plaster	1.03	52
300 mm clay brick masonry	2.20	7
TOTAL	3.23	
20 mm gypsum plaster	1.03	52
300 mm aerated concrete	6.90	23
19 mm Stucco	1.14	60
TOTAL	9.07	
12.7 mm gypsum board	0.668	52
0.15 mm poly	0.00	
38 x 89 @ 400 oc w/	0.893	89
fiberglass insulation	0.00671	0.75
12.5 mm plywood sheathing	0.940	75
10 min. sheathing paper	0.080	
19 mm stucco.	1.14	60
TOTAL	3.73	

Wall	Adsorbed Moisture	
	kg*m^-2	kg*m^-3
12.7 mm gypsum	0.668	52
0.15 mm poly	0.00	
92 mm steel studs w/ glass fibre ins.	0.00671	
12.7 mm fiberglass-faced gypsum sheathing	0.668	52
SBP sheathing paper	0.00	
Vinyl siding	0.00	
TOTAL	1.34	

but moisture is harmful, no?

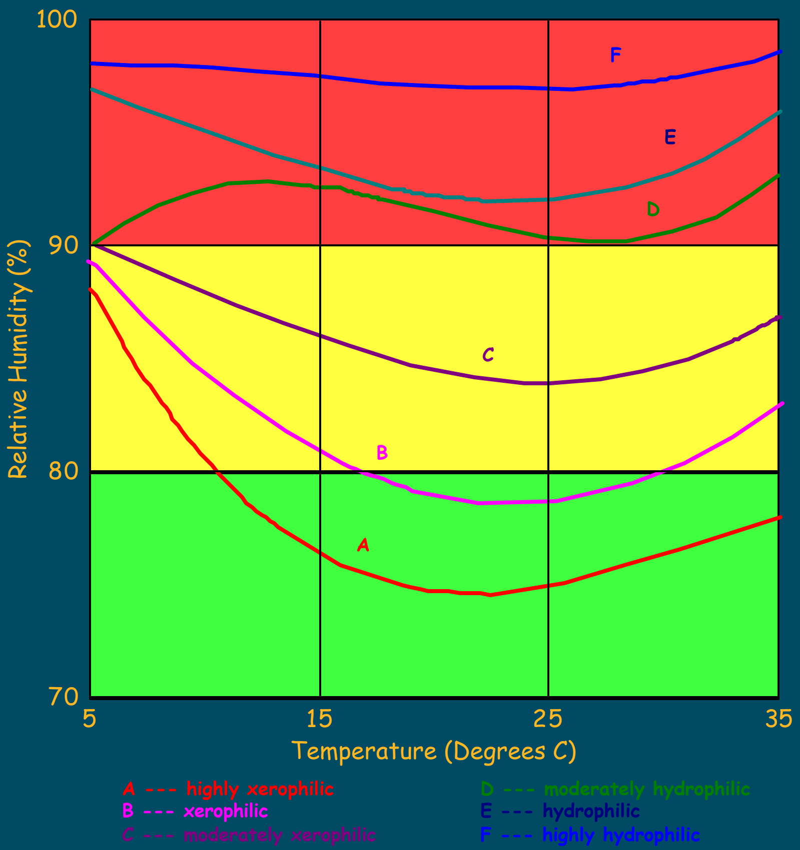
it causes frost damage, mold, efflorescence, corrosion, and cracks in Gym floors ...

yes, exposure to moisture, especially if prolonged, is a primary cause of deterioration, but it all depends ...

How Much is "too much for too long"?

Mold and rust occur when surrounding air is humid and warm for a long time.

- belt and suspenders: stay below 75% RH
- reasonably safe: choose a maximum cumulative time above 80% RH and above 5 deg C (RHT80)
- living dangerously: time above 90% RH and above 5 deg C (RHT90)



How Much is "too much for too long"?

without HAM models, we have no effective way of quantifying

how wet?

how warm?

how long?

additional research on mold & corrosion is needed to know how to translate the answers into risk assessments

"If you can not measure it, you can not improve it" -- Lord Kelvin

Anatomy of a HAM Model

Numerical methods solve systems of partial differential equations describing HAM flows in a matrix of finite elements. Inputs are

- measured properties of materials
- boundary conditions (temperature, humidity, pressure, water, radiation)
- geometric description of the assembly
- geometric description of finite element matrix (automatic in some models, user-specified in others)

At each time-step, the program takes each element in turn, calculates flows to and from adjoining elements and boundaries, and then repeats the process until overall errors reach an acceptable limit. The calculation then moves on to the next time step.

Different Approaches

- general purpose solver (CVODE, MatLab + Femlab, Mathematica?, ...?) with user-selected equations and post-processing visualization
- routines designed for (and linked to) a solver behind the scene, allowing user-selection of effects (Delphin uses CVODE)
- preprocessors to transform available input data, for example:
  - wind velocity, wind direction, hourly rain, building orientation & shape ---> local intensity and pressure
  - horizontal diffuse radiation, direct solar radiation, local time, and latitude ---> hourly total radiation on envelope surface
  - interpolation of material properties between measured data points
- dedicated black box (all complications behind the scene) with limited user-selected parameters, enclosing input data menus and preprocessors (WUFI, HygIRC?)

Movement of Heat & Moisture

	Transport Mechanism	Potential
heat	heat conduction	temperature difference
heat	heat radiation	T^4 at boundary and surroundings
heat	air flow	total pressure difference
heat	enthalpy flows due to moisture movement and phase change	vapour diffusion, phase change, liquid transport in temperature field
water vapour	gas diffusion (Fick's Law)	Mass fraction of vapour, $T^{-0.81}$, total atm. pressure --- dominant in pores > 10^{-6} m
water vapour	effusion (Knudsen Effect) diffusion in heavy traffic	Mass fraction, some f(T), not proportional to Fick's, but so approx. in diffusion resistance factor --- dominant in pores < $5*10^{-9}$ m
water vapour	solution diffusion	partial pressure gradient, or differential concentration, solubility (in polymers), T^x
water vapour	convection of air	total pressure gradient

	Transport Mechanism	Potential
liquid water	capillary conduction	suction stress
	surface diffusion	relative humidity, occurs at > 30% RH
	hydraulic flow	total pressure differences, gravity
	electrokinesis	electrical fields (neglected)
	osmosis	ion concentration (neglected)
salts	solution diffusion	ion concentration gradient, solubility (neglected)

Inputs

exterior conditions, hour by hour

- dry bulb temperature
- wet bulb temperature
- wind speed
- wind direction
- solar (and environmental) radiation
- rainfall
- cloud cover

interior conditions, hour by hour:

- dry bulb temperature
- wet bulb temperature
- radiation
- specified inputs of moisture at selected points and times (to simulate the effect of gravity leakage)

Inputs

material properties:

- dry density
- dry thermal conductivity
- thermal conductivity vs. moisture content
- dry heat capacity
- vapour diffusion resistance
- vapour diffusion resistance vs. moisture content
- moisture storage function (RH &/or pore pressure vs. water content)
- water absorption coefficient
- moisture diffusivity
- diffuse air permeance or permeability
- soluble salt content

Inputs

description of the assembly and boundaries

- geometry of different materials
- geometry of boundaries, and assignment of conditions (exterior, interior, or not subject to flow
- orientation of exterior surface (if model adjusts wind and rain, and solar radiation accordingly)
- latitude and longitude (for preprocessing solar radiation and adjusting to standard time)
- exposure of exterior surface (some models adjust wind and rain inputs to approximate local intensity factors on a facade)
- initial moisture content
- emissivity of exterior surface
- emissivity of interior surface

Outputs

typical output is a matrix of the following values

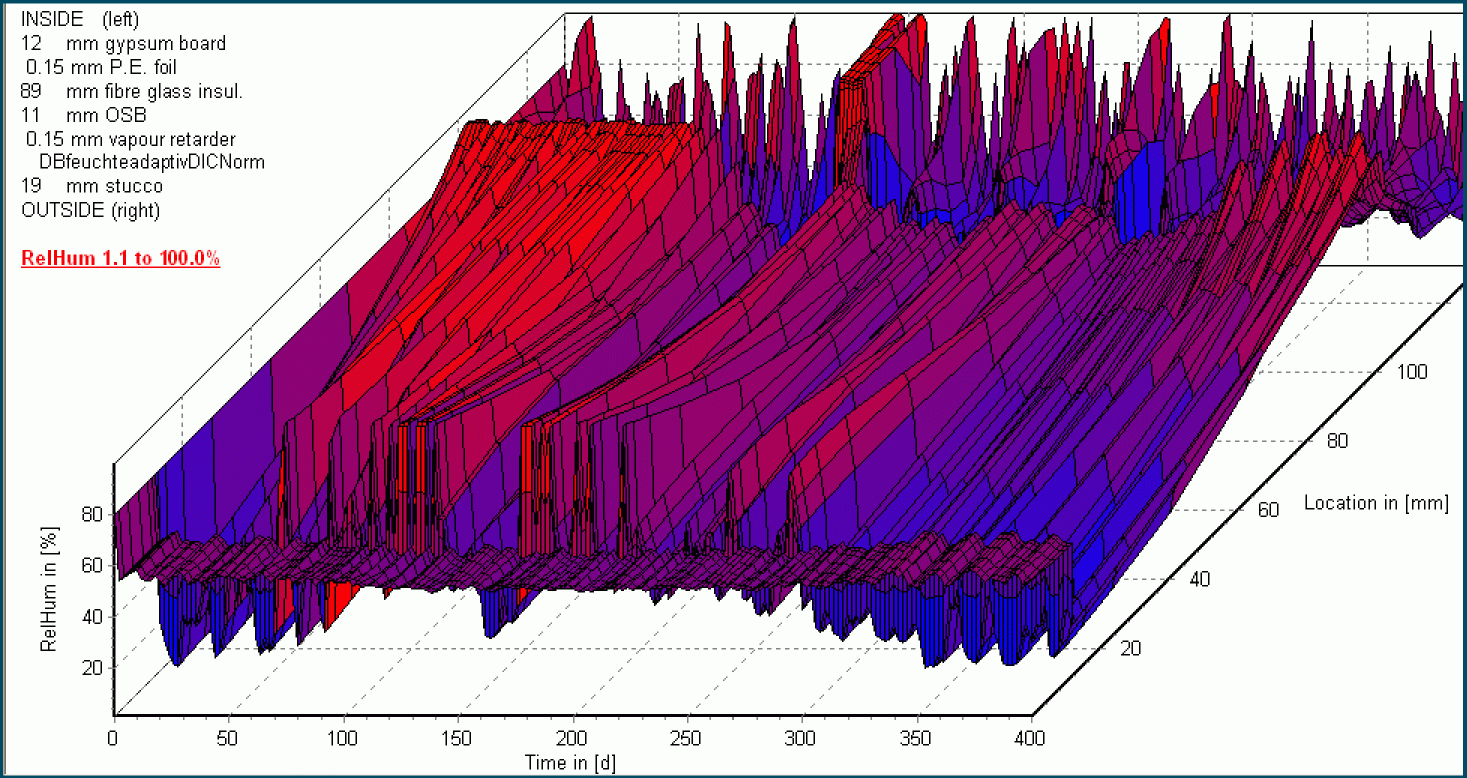
- time
- temperature
- moisture content
- relative humidity
- fluxes

visualization tools, external, or built into the model allow various presentations of these (or input) data, for example

- total moisture content of assembly as a function of time
- same (or relative humidity) for a layer or specified region
- movies of cross sections displaying moisture content, temperature, or relative humidity in fast time

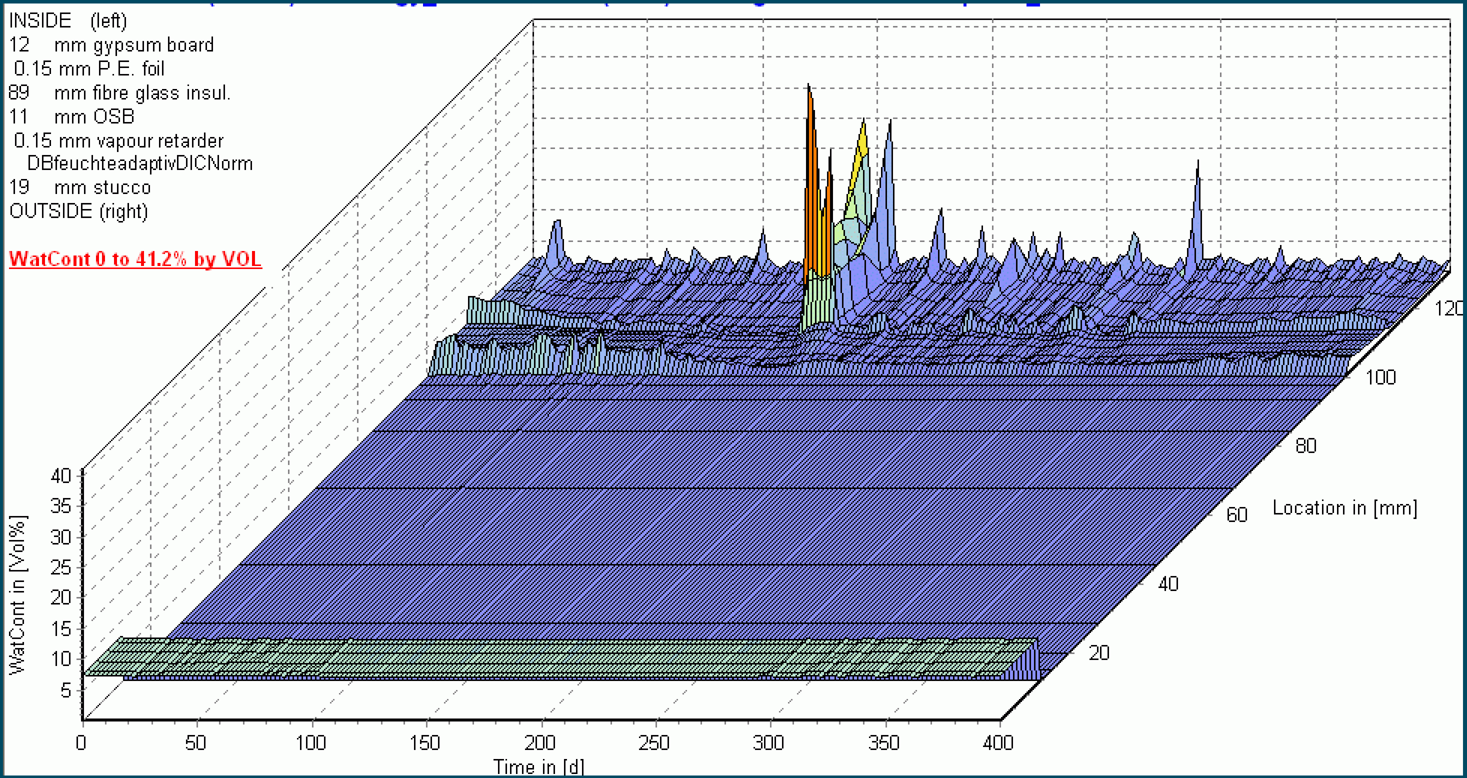
Delphin 1D

Calgary, 1980, RH in a frame stucco wall



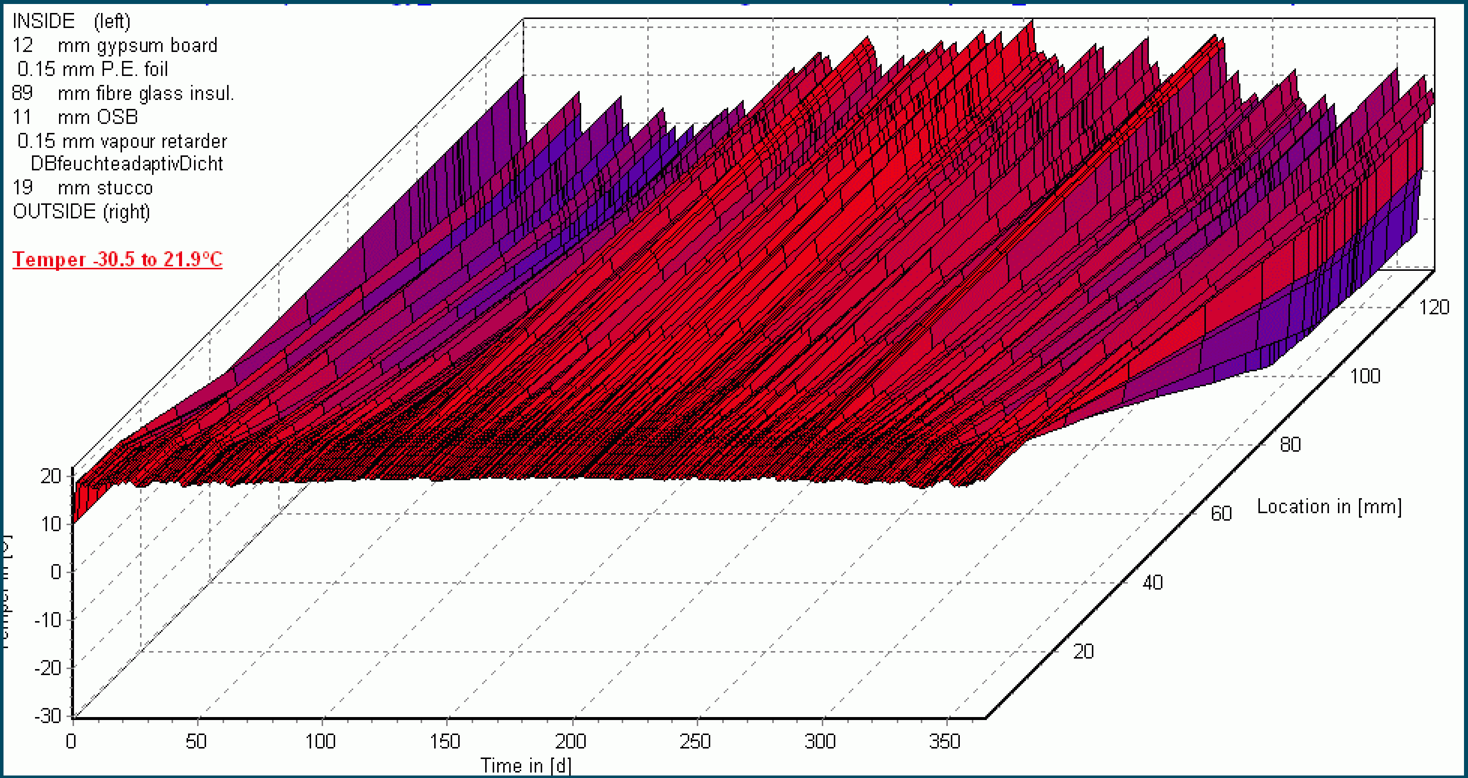
Delphin 1D

Calgary, 1980, water in a frame stucco wall



Delphin 1D

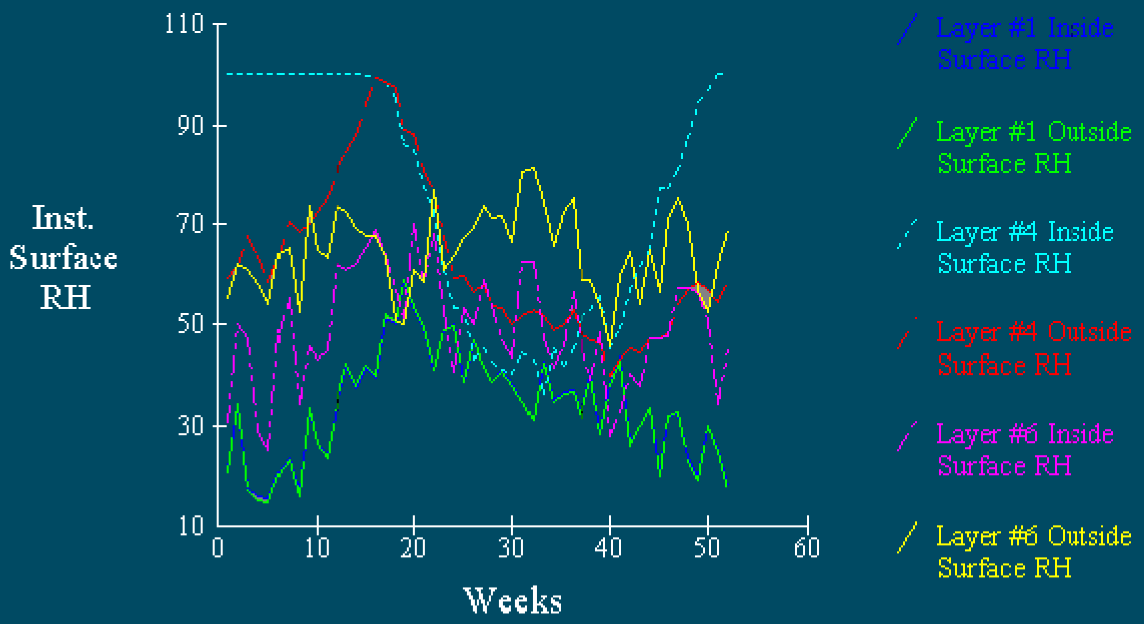
Calgary, 1980, temperature in a frame stucco wall



Moist 3.0

Edmonton, ASHRAE WYdata, Stucco Wall, 10th year

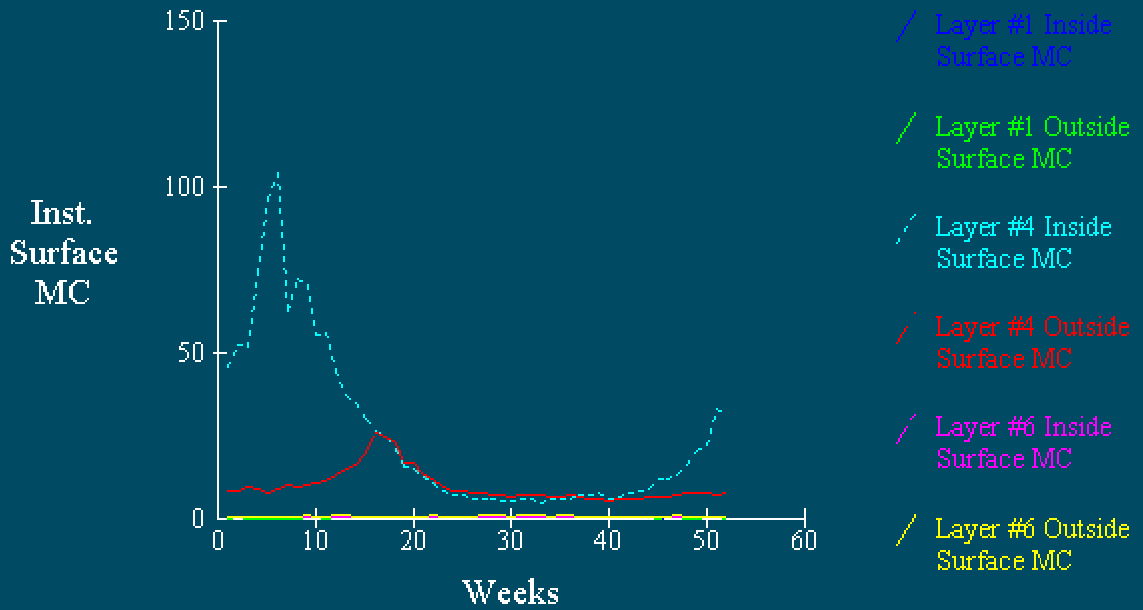
Layers: 1 = drywall 4 = OSB 6 = Stucco



Moist 3.0

Edmonton, same wall, MC computed with **coarse mesh**

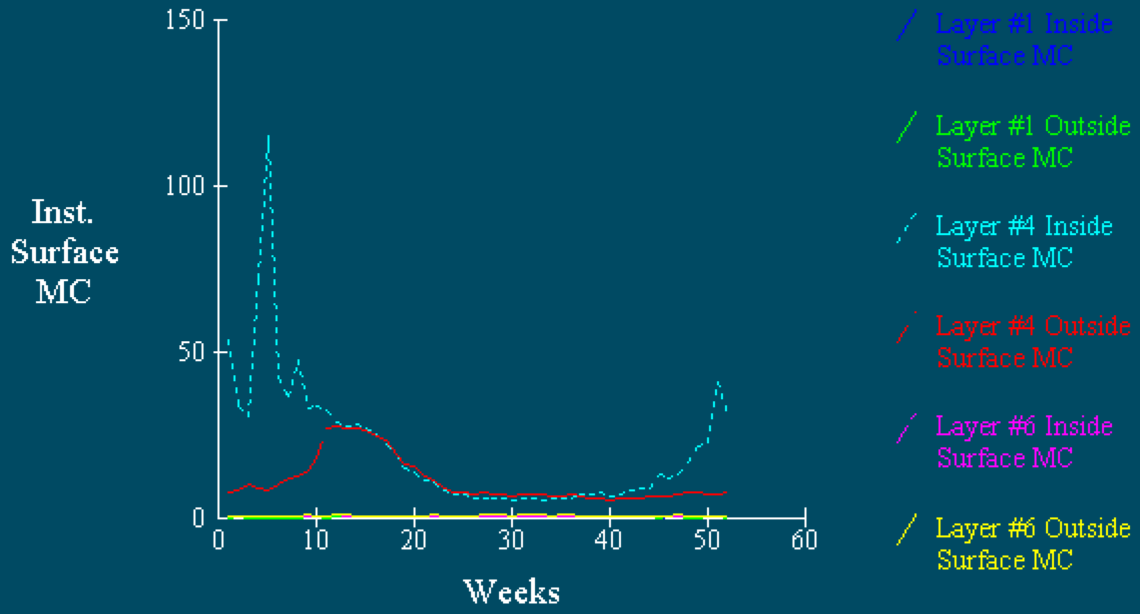
Layers: 1 = drywall 4 = OSB 6 = Stucco



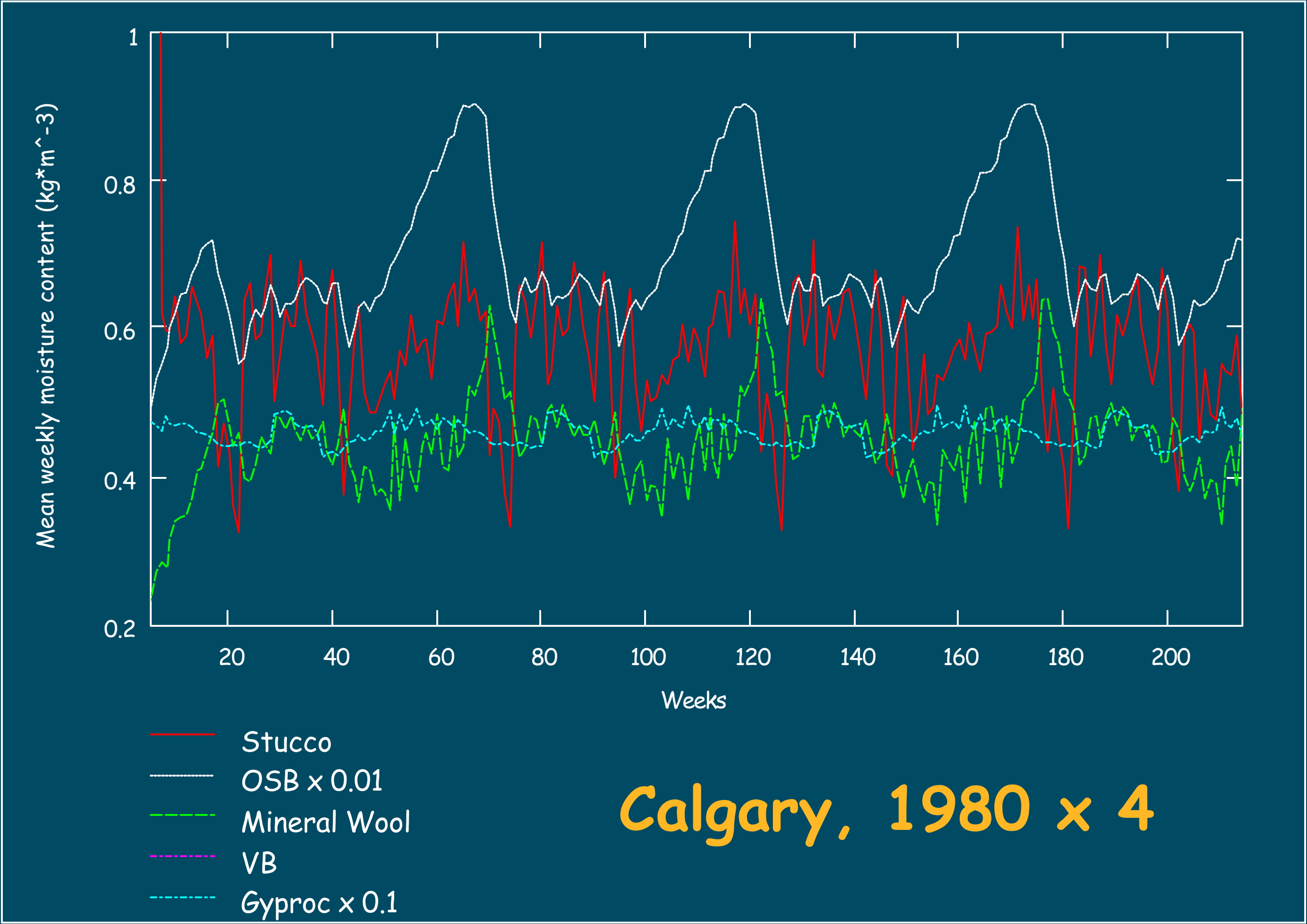
Moist 3.0

Edmonton, same wall, MC computed with **finer mesh**

Layers: 1 = drywall 4 = OSB 6 = Stucco

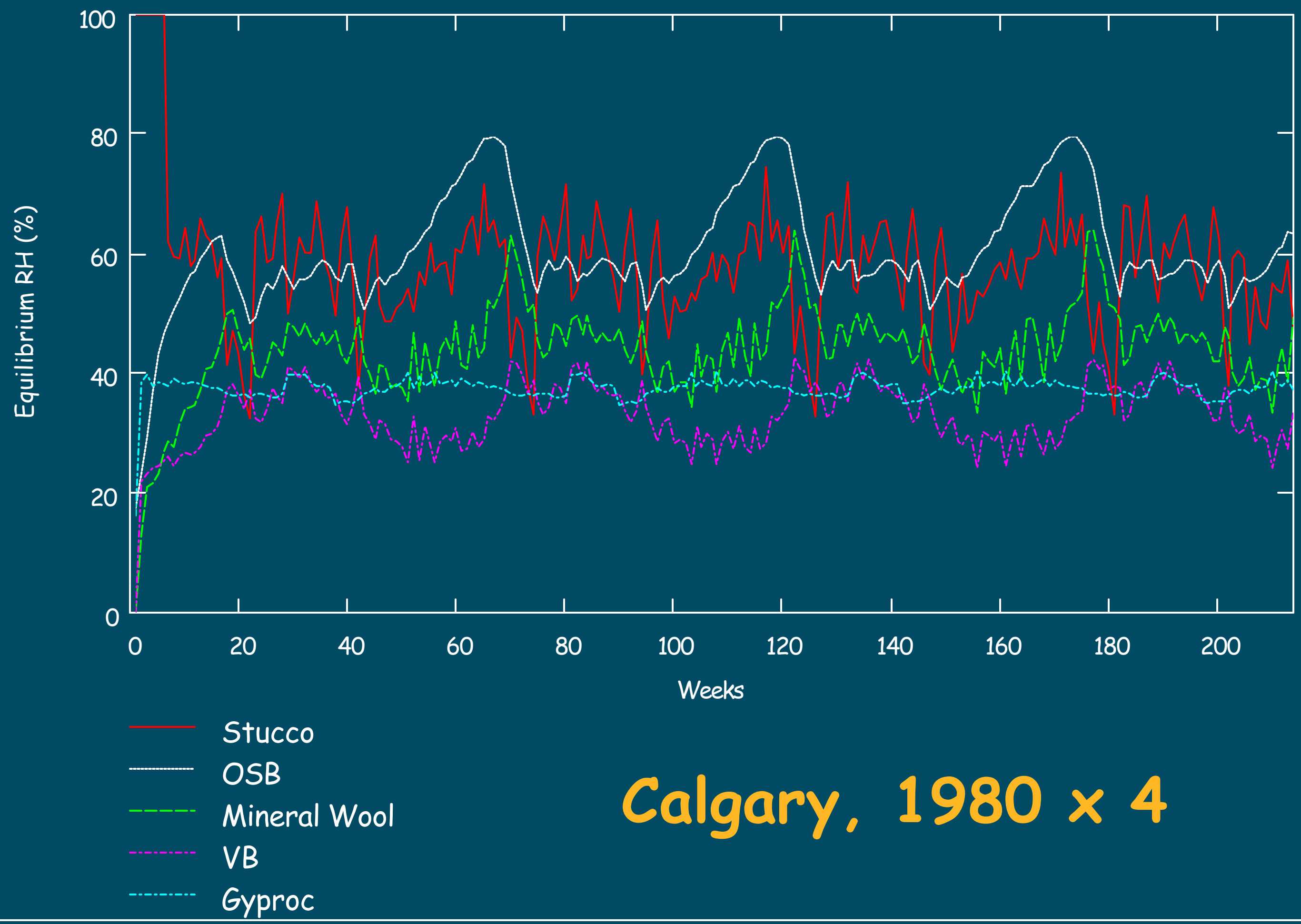


1dHAM



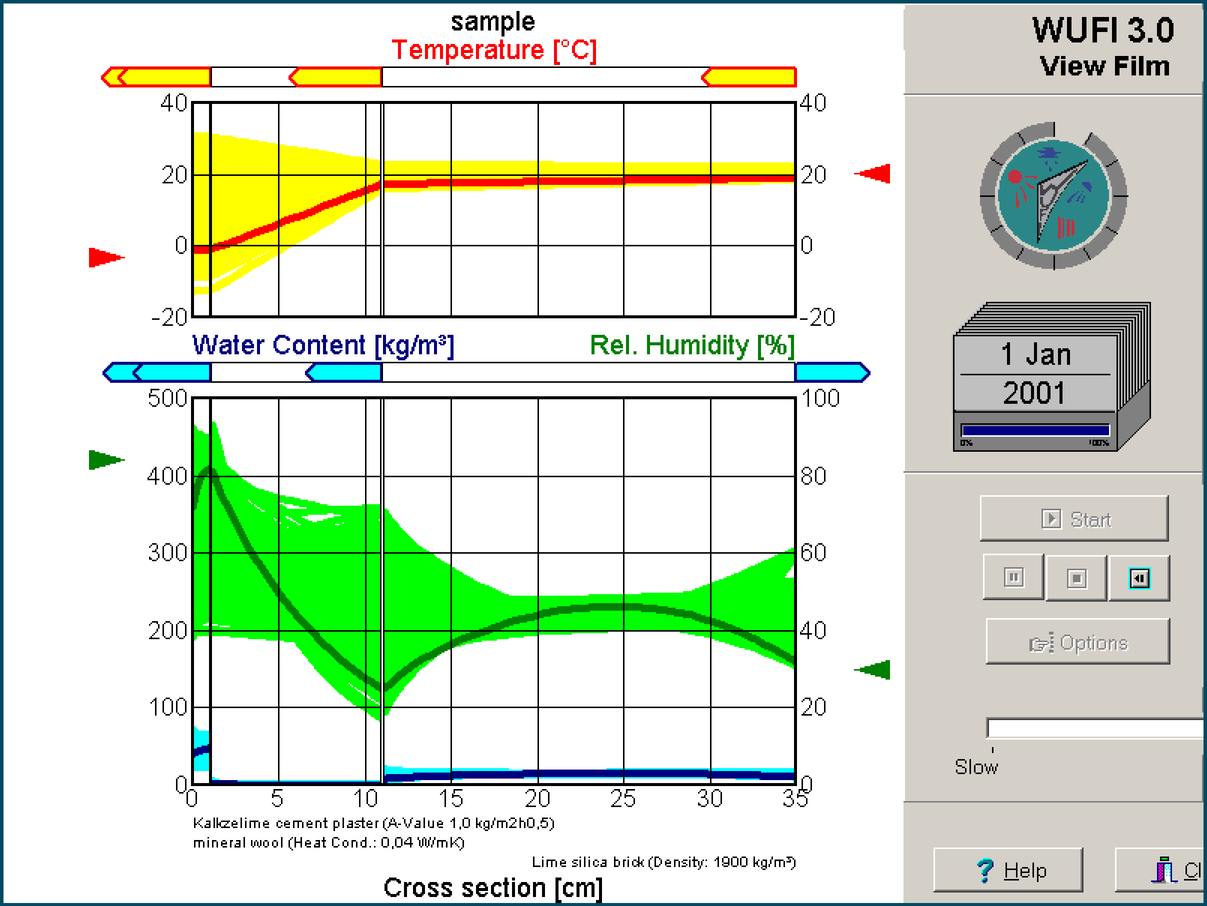
Calgary, 1980 x 4

1dHAM



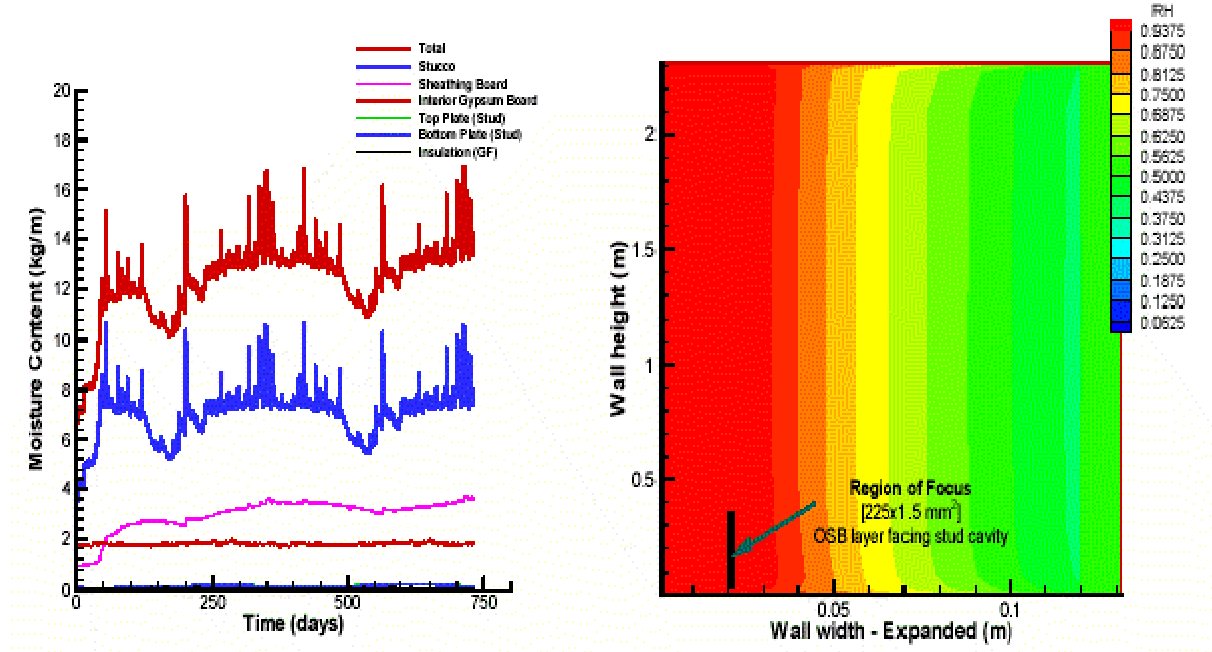
Calgary, 1980 x 4

WUFI 1D



Cement-lime plaster, mineral wool, lime-silica brick

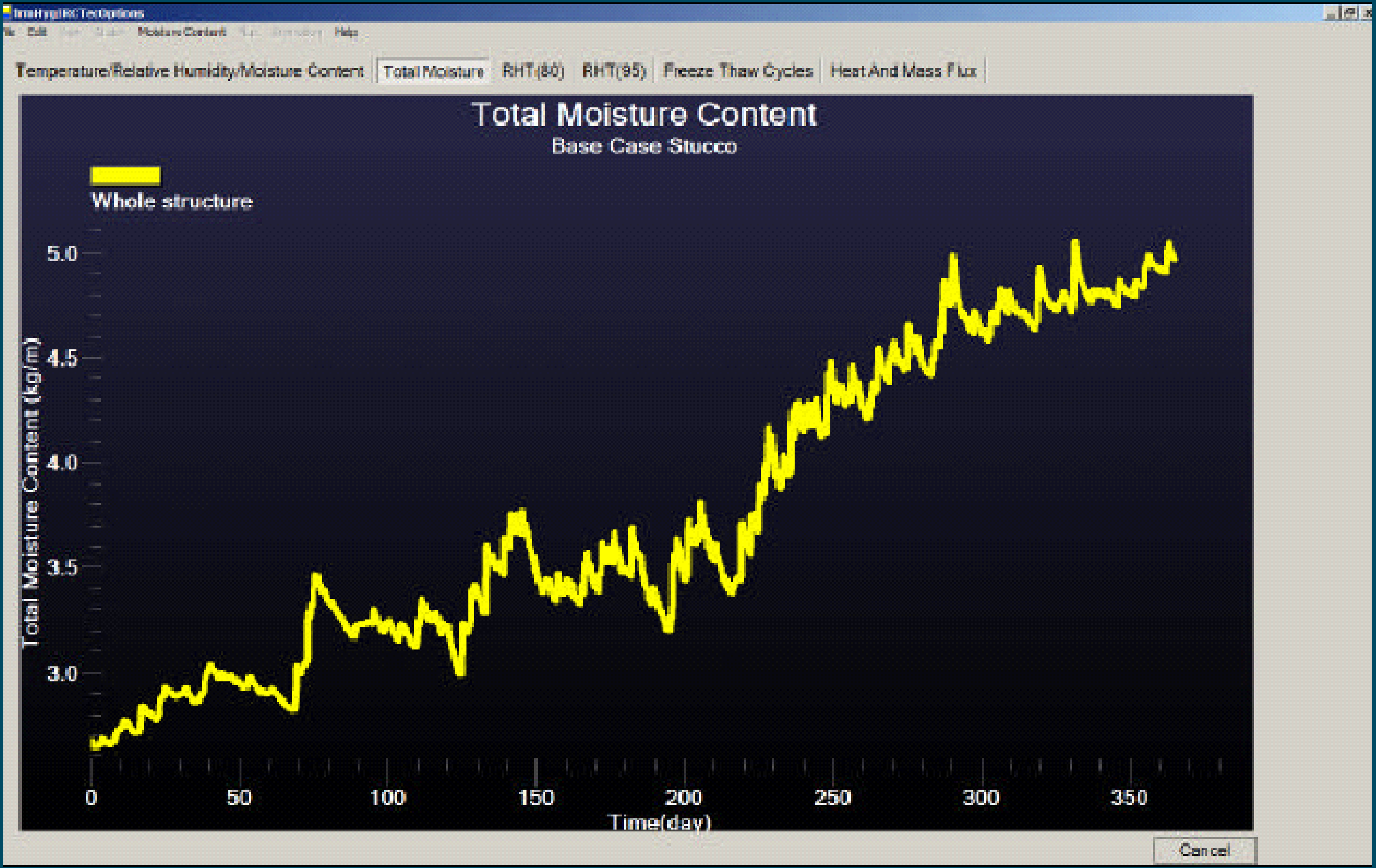
HygIRC 2D



(a) Drying curve (b) RH contour plot

Output for a wood frame stucco wall, from HygIRC 2D.

HygIRC 1d



Temperature/Relative Humidity/Moisture Content
Total Moisture
RHT(80)
RHT(95)
Freeze Thaw Cycles
Heat And Mass Flux
Total Moisture Content
Base Case Stucco
Whole structure
Total Moisture Content (kg/m)
5.0
4.5
4.0
3.5
3.0
0
50
100
150
200
250
300
350
Time(day)
Cancel

Caveats

HAM models that correctly represent all of the mechanisms, potentials, and relations in play are "research models". They are kept manageable by leaving out variables that are held constant in the corresponding experiment.

HAM models for building design manage by simplification using

- approximation
  - use of a linear relation to represent an exponential or geometric relation over a limited range
  - discarding small terms
  - empirical relationships to represent combined effects of more than one mechanism
- omission of some mechanisms or inputs (e.g. gravity, air flow, capillary redistribution, rain)
- assumption of perfect contact between materials
- allowing only porous materials

Limitations

- sensitivity to errors or variation in inputs is unknown
- different models use different mathematical formulations, with obscure but possibly significant implications
- obtaining reliable input for material properties and boundary conditions is non-trivial
- materials that seem similar have different reported properties because of
  - real differences in products that meet the same commodity standard
  - differences in measurement procedures or reporting
- to be sure that a solution is correct, one needs to increase the mesh density or decrease the time step and run again --- but for some programs even a coarse representation may take too much memory or run-time, or the mesh may be inaccessible
- models often crash, or run slower than real time

So, is it ready?

Not quite yet. We need, at least

- accurate information about hygrothermal properties of the specific materials we want to use
- uniform (and relevant) standards for measuring and specifying hygrothermal properties of materials
- models that let us pick and choose simplifications
- models that have plug-ins for data from other sources
- more extensive validation --- especially for situations where many variables are active simultaneously